AGROCHIMICA

**International Journal of Plant Chemistry,
Soil Science and Plant Nutrition
of the University of Pisa**

SPECIAL ISSUE

UNIVERSITÀ DI PISA
Centro Interdipartimentale per lo Studio degli Effetti dei Cambiamenti Climatici
Centre for Climate Change Impact

THE RESEARCHES OF THE UNIVERSITY OF PISA IN THE FIELD OF THE EFFECTS OF CLIMATE CHANGE

Proceedings of a Conference Held in Pisa on December 6, 2019

Edited by GIACOMO LORENZINI

PISA UNIVERSITY PRESS

CONTENTS

SESSION 3: EFFECTS ON AGROECOSYSTEMS

SESSION 4: EFFECTS ON NATURAL BIOSYSTEMS

Preface

PAOLO MARIA MANCARELLA
Rector, The University of Pisa

Climate change is real. The evidences come from direct measurements of the increase in surface air temperature and the temperature of the subterranean oceans, as well as phenomena such as the increase in the average global sea level, the withdrawal of glaciers and changes in many physical and biological systems. It is an epochal and planetary problem that we can no longer neglect.

Recently – in view of the disengagement of the United States on these issues – the French premier Emmanuel Macron has caught, with a truly wonderful synthesis, the heart of the matter: “Gentlemen – he reminded us – there is no planet B”. A concept that then became the slogan of increasingly larger audiences.

Our generation has historical responsibilities, as President Mattarella reminded us a few months ago complaining about the limitations of the various international conferences and expressing the refusal to use the failed solutions of the past: “We are – he said – on the verge of a global climate crisis, to avoid which we need measures agreed at a global level and [...] we must definitely reject temptations aimed at re-proposing solutions already widely tested in the past with a negative outcome, sometimes a prerequisite for future disasters”.

Words that bring to mind the appeal of the UN Secretary General, Antonio Guterres, who asked all world leaders to implement by 2020 concrete and realistic plans that allow the reduction of greenhouse gas emissions by 45% over the next decade and net emissions by 2050. This will mean, for example, changing energy strategies, moving towards renewable sources and climate-friendly practices. The fight against climate changes will require an unprecedented exploitation by all sectors of the society.

In this perspective it is time for Universities (both for their social role and as large communities) to understand that they can play a fundamental role in the affirmation of a true sustainability culture that can deeply permeate the society, both at the level of education of the individual citizen and of corporate culture.

Our University has included this commitment in its Statute and, more recently, in its Strategic Plan, making the culture of sustainability a central element of its activity in its aspects of social sustainability, economic sustainability and environmental sustainability.

Today there are three university interdepartmental centres that have an evident reference to the sustainable development objectives set by the UN: the Interdepartmental Research Centre “Nutraceuticals and Food for Health” (Nutrafood); the Interdepartmental Research Centre for Energy for Sustainable Development (CIRESS) and the Interdepartmental Research Centre for Climate Change Impact (CIRSEC).

The latter was founded in 2018 with the aim, among others, of “promoting, coordinating and developing studies as well as promoting the technological transfer of research results on issues related to the effects of climate changes on the entire biota and their environments of life”. The CIRSEC commitment resulted on December 6, 2019 into a training day dedicated to the “Activities of the University of Pisa on the theme of the effects of climate change”, which offered a first comparison opportunity to a number of researchers from our University who are working on these issues. Over a hundred researchers were involved, who addressed topical issues involving many disciplinary sectors, from medicine to environmental biology, from veterinary sciences to economics, from geology to agricultural sciences. But the December event was also a laboratory in which it was shown that it is possible to reduce the environmental footprint of major events: to do so our University has, among other things, planted trees in its green areas to offset the carbon dioxide emissions produced for the organization of the meeting.

It is not the first time that our University has implemented such actions. I like to recall that almost three years ago the University Green Data Centre was inaugurated; it was realised following precise criteria to obtain a reduction in consumptions and emissions, and was designed following sustainability criteria. This year we have given all the freshmen a metal bottle to limit the use of plastic ones. And this is because we are convinced that the great battles of civilization are won when we manage to move from saying to doing.

It is also in this way that our University intends to take up the challenges that derive from a complex society in increasing transformation, assuming an increasingly proactive role. This vision cannot disregard a responsible approach to sustainability, considered in its three aspects: social, economic and environmental.

The book in your hand tells all the scientific contributions shared during the first event organized by CIRSEC and photographs the state of the art of research at the University of Pisa in the field of climate change effects on all aspects of human and animal life and their environments. The hope is that it can represent a first opportunity to exchange ideas for the creation of connections and the sharing of opinions, which are fundamental to contrast the current situation, with an interdisciplinary approach that involves the whole scientific community and allows the development, at every level of our society, of a new way of thinking that allows us to do things in a better way.

Editorial

MIKE FRANK QUARTACCI
Editor in Chief, Agrochimica

Agrochimica (International Journal of Plant Chemistry, Soil Science and Plant Nutrition) was founded in 1956 by the Pisan agricultural chemist Prof. Orfeo T. Rotini. The journal is published by Pisa University Press (which has as single shareholder company the University of Pisa) and is indexed in the main scientific database such as Scopus, Web of Science, and SCImago Journal and Country Rank.

The journal focuses on plant and soil (bio)chemistry as well as on chemical aspects of plant nutrition. Also covered are several new, rapidly-expanding fields such as agricultural and environmental pollution, agro-industrial biotechnology, and agricultural waste treatment and disposal. At his foundation the journal dealt mainly with agricultural sciences primary production topics in a sectoral and independent manner as if they were compartments separated and not connected from each other. In the following years, with the progress of knowledge and the understanding that agriculture and environment are closely interconnected, the demarcation lines among the disciplines were no longer considered so clear and marked. There was, in fact, a necessary, natural and inevitable tendency to contamination among disciplines and a mutual exchange of information and methodologies. This process quickly brought to expand the range of topics and subjects covered by the journal. In summary, the journal began to treat the several scientific aspects directly related to sustainable agriculture and environment protection.

Climate change have been one of the topics the journal has dealt with, hosting both reviews and various scientific works aimed at clarifying the single aspects of the phenomenon. In 2014 a special issue of *Agrochimica* was dedicated to the proceedings of a congress held in Pisa entitled ‘The hot summer of 2012: some effects on agriculture, forestry and related issues’. After five years the journal is pleased to host again the proceedings of a meeting organized following the growing interest on climate change and its implications for the future generations. This special issue of *Agrochimica*, for the first time published in an open access form, represents an attempt to give space and voice to topics that probably would have been difficult to arrange in a specialized or monothematic journal. In the new role that the journal is hiring, we believe that the assembling of contributions covering so different aspects of climate change in a single issue can make an important contribution to the discussion and provide an overall picture not always readily available. The impact of making research papers freely accessible can be enormous, particularly for topics in which there is a strong public interest. Hopefully, this new opportunity offered by the *Agrochimica* journal will disseminate new information to a multitude of researchers and readers and, in a small way, contribute to pay due attention to an increasingly serious and worrying problem.

Editorial

GIACOMO LORENZINI
Director, CIRSEC, Centre for Climate Change Impact of the University of Pisa

In spite of the presence of forms of "climate change scepticism and denial", evidence for the warming of our planet over the past decades is now overwhelming. Scientists are also increasingly confident that many of the patterns associated with global warming are linked to an anthropogenic influence on climate. It is clear that climate can change not only due to long-term natural variations but also due to human intervention. Mankind's activities such as the burning of fossil fuels and changing land surface processes are having a discernible effect on the global climate, and these processes will impact upon the functioning of many of the planet's natural systems. A build-up in the atmosphere of carbon dioxide (and other minor climate-altering anthropogenic pollutants gases) is widely recognized as the major culprit of these phenomena. So, global climate change is having and will have profound implications for the quality of life of hundreds of millions of people. New climate will modify our geography, history and everyday way of living. There are people (and scientists) who believe that the world is in the early stages of a truly catastrophic era (the so called "alarmists" who exaggerate the degree and threat of global warming likely to enhance their status, funding, and influence with policy makers); surely the rate of climate change may be unprecedented in the history of our planet. No doubt that climate change is a threat to our future, but also to our natural and cultural heritage as well as overall welfare and sustainability.

Climate affects humans through a variety of channels. Weather and climate influence societal (*e.g.,* civilization, culture, migration), psychological (*e.g.,* aggression, cognition, mental illness), physiological (*e.g*., health, diet, nutrition), economic (*e.g*., energy production, tourism, agriculture, fishery) and ecological conditions (*e.g.,* fauna and flora). Climate change would affect all of these. Actually, climate change has direct and indirect effects on all biota and is now affecting every country on every continent. It is disrupting national economies and affecting lives, costing people, communities and countries dearly today and even more tomorrow. Climate change creates stress on land, exacerbating existing risks to livelihoods, biodiversity, human and ecosystem health, infrastructure, and food systems. The prospect of human-induced climate change illustrates for the first time in history that humankind is in a position to exercise a significant influence on the global environment. This is a testimony to our inventiveness and power on the planet but also a warning about its possible harmful consequences.

Almost all the Sustainable Development Goals[1] (SDGs) of the United Nations Development Programme are involved in climate change. Apart from SDG 13, which is fully devoted to climate action (its mission is: "take urgent action to combat climate change and its impacts"), this is the case, for instance, of SDG 1 (End poverty in all its forms everywhere), SDG 2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture), SDG 3 (Ensure healthy lives and promote well-being for all at all ages), SDG 6 (Ensure availability and sustainable management of water and sanitation for all), SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable), SDG 14 (Conserve and sustainably use the oceans, seas and marine resources for sustainable development), SDG 15 (Life on land: protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss).

In Italy, as well as in many European countries, we have witnessed exceptional heath waves, droughts, floods, increased incidence of storms and forest fires, and several other environmental perturbations over recent years, which may be directly related to climate change: they may represent the first irrevocable sign of environmental global change and the consensus view is that they represent the direction(s) in which our climate is likely to move. Although some of the individual aspects of predicted climate change are relatively easy to identify, it is the interactions among these single factors that makes the prediction of overall impacts of global change on biosphere an all but impossible task. These potential interactions are evident, for instance, in the case of the overall effect of climate change on plant productivity. Over the coming decades, the climate will become milder and wetter in the winter and significantly

[1] According to the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015 (*https://www.un.org/sustainabledevelopment/sustainable-development-goals/*), the Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice. The Agenda also identifies, climate change as "one of the greatest challenges of our time" and worries about "its adverse impacts undermine the ability of all countries to achieve sustainable development".

hotter and drier during the summer months. Changing temperature not only impacts directly on the form and function of the plant itself, but also interferes on pests, pathogens, competitor weeds and the surrounding environment overall through its effects on water balance, litter turnovers, volatile organic compounds cocktails and nutrient availability. So, for instance, due to climate change, the wine world will have to tackle significant challenges all over. Furthermore, changes to the timing and abundance of food sources such as foliage and seeds will have consequences for insect, bird and mammal species. Changing temperature and precipitation regimes will influence the spatial distribution of plants and their resilience ability to stress factors, and so on.

Changes in temperature and precipitation as well as weather and climate extremes are already influencing crop yields and livestock productivity in Europe. Weather and climate conditions also affect the availability of water needed for irrigation, livestock watering practices, processing of agricultural products, and transport and storage conditions. Plants exposed to excess heat and intense water deficit exhibit a characteristic set of cellular, metabolic and physiological responses, which may be summarized in terms of a combination of "thirsty roots and hungry leaves". The C balance of an individual plant is the difference between photosynthesis (C input) and respiration (C output): these functions are strictly temperature-dependent. Under favourable conditions a plant takes up more C than it consumes on a daily basis (C surplus) and the excess C is used for growth and synthesis of defence compounds, or is stored in the form of non-structural carbohydrates for future use, resulting in biomass increase. But under severe drought and heat stress things go in a different way as both photosynthesis and respiration rates may be deeply altered. Under the biological point of view, the characterization of plants living in stressful environments (such as urban areas) and of their response to constraints related to climate results of great interest. Higher temperatures and the increasing risk of drought are expected to reduce livestock production through negative impacts on grassland productivity and animal health and welfare.

Global warming, interacting with social, biological and other environmental determinants, constitutes a profound health risk threat to the human race. This concerns malnutrition from crop failures to drinking water availability as well as epidemiological issues. All prevalent human and animal diseases are linked to climate fluctuations, from cardiovascular mortality and chronic respiratory illnesses due to heat waves and record-breaking temperatures (with older people and children among the most exposed) to altered transmission of infectious diseases. Indeed, new warming scenarios will enable the expansion of the geographical distributions of vectors such as insects, and their population dynamics will change in response to extended seasons suitable for development and generation time reductions. Depressive and psychological disorders may be affected as well. Earlier and longer pollen season, not to mention higher pollen production, is another collateral phenomenon of climate change, exposing adults and children affected by respiratory allergic disease, such as asthma and allergic rhinitis, to the risk of exacerbations. Furthermore, impacts on labour productivity could be one of the several economic consequences of climate change.

Marine life faces challenges from warming waters and ocean acidification. Overall, marine species are responding to warmer temperatures by moving northward or deeper when possible in search of cooler waters. Species affected by climate change include plankton, which forms the basis of marine food chains, and temperature variations affect top-down and bottom-up circulation. The result is a widespread disruption of interconnected food webs. Climate change could be the knock-out punch for many species which are already under stress from overfishing and habitat loss. Current anthropogenic changes to the Earth system, particularly changes in the carbon cycle, are unavoidably geologically significant. Their effects may include substantially reduced polar ice cover, sea level rise and modified precipitation.

The effects of climate change on the physical environment are inextricably linked, and also have devastating socio-economic impacts: it is not surprising that there is a concern about its social and security implications, including poverty and economic crises, migrations and exacerbation of human conflicts due to competition over scarce resources (*e.g.,* land degradation, food insecurity and drinking water availability). Climate change and increasing inequality are at the top of the international political agenda as they represent a severe threat to contemporary standards of living, peace, and democracy. Poor and developing countries, particularly least developed ones, will be among those most adversely affected and least able to cope with the anticipated shocks to their social, economic and natural systems. In recent years there have been numerous calls to reinforce the presence of social sciences in this field. Social sciences are providing invaluable insights into how human societies can limit climate change, and live in a changed environment.

This perspective is often expected to provide a deeper understanding on both the anthropocentric factors causing climate change, the social and economic determinants of climate impacts and vulnerabilities, and the possibilities for coordinated response to climate threats. In brief, descriptions of the disciplines' contributions to the understanding of mitigation and adaptation include equity/equality, wealth/resource distribution, policy, political systems/governance, political economy, economic systems, economic costs and incentives, and globalization, not to mention social and cultural transitions. Social scientists are asked to develop culturally relevant policy recommendations on the social dimensions of societal response and adaption to climate change. This may have to do with the obvious expertise of economists in delivering cost benefit analyses for all kind of policy proposals and a preference for models and numeric indicators, much like climate scientists.

* * *

No doubt that climate change is already affecting human health and welfare, and future projections are alarming. Climate change often acts as a threat multiplier, in addition to a direct cause, of stress for biota and environment. Reducing the future risks of extreme climate warming is a complex affair and involves, for instance, adoption of alternative energy production strategies that emit fewer greenhouse gases in the atmosphere as well as changes to eating habits and consumption patterns. Our climate change management strategies include both slowing the pace of change (emission reduction) and adapting our systems to cope with changing climate. Resilience to environmental stress is achieved through a number of actions, building upon each other over time. Adaptation is widely recognized as a fundamental response to climate change. Options throughout the food system, from production to consumption, including food loss and waste (up to influence on dietary choices), can be deployed. For instance, adaptation measures at farm level with positive effects on mitigation of the effect of climate change include adapted crops, modifying crop calendars (timing of sowing and harvesting), precision farming, no- or minimum tillage, improved irrigation efficiency, field margins management, improved livestock rearing conditions and using improved livestock genetics.

Where the world is going to arrive is not clear: 1.5-2 or 3°C of warming are all still potential futures. Which one eventuates depends on how fast we act and how hard we work to change. In the meantime adaptation and mitigation strategies to climate change challenge must be adopted and there is a strong need to build the knowledge base needed to support the transformation required. To do that, we must fully realize the actual impact ('effects') of present and estimated climate change scenarios. There is much we do not know about adaptation and indeed there is some reluctance to study it. The literature is growing, but further interdisciplinary research is needed for a comprehensive view of how specific climate actions intersect with, or otherwise hinder, the pursuit of the broader sustainable development agenda as well as to understand best practices for strengthening synergies. We must fully realize the actual impact of present and estimated climate change scenarios.

Climate change involves many aspects of the Earth system as well as a wide range of human activities, and both climate change and actions taken to respond to climate change interact in complex ways with other global and regional environmental changes. Climate change research is crucial in this context and needs to be integrative and interdisciplinary. Understanding climate change, its impacts, and potential responses thus inherently requires integration of knowledge bases from many different scientific disciplines, including the physical, social, biological, health, and engineering sciences, and across different spatial scales of analysis, from local to global. The climate-impact research community is asked therefore to contribute to identifying the challenges associated with and required actions for meeting these goals. The University of Pisa is internationally renowned for its high quality teaching, research, and innovation. Several research groups are actively involved in climate research – from fundamental climate science and its effects on our biophysical environment, to sanitary, societal, economic, political, legal and technological impacts and responses. Recently, CIRSEC, the Centre for Climate Change Impact (*www.cirsec.unipi.it*), was founded at the University of Pisa. About 100 scientists actively participate to CIRSEC interdisciplinary activities, and a first opportunity for them to gather together, interact with networking opportunities and focus on a variety of advanced research topics was represented by an *ad hoc* meeting organized in Pisa on December 6, 2019. Thirty six lectures were offered, covering literally topics from A (*allergy, Anthropocene*) to Z (*zoonosis*). All the speakers were scientists of the University of Pisa, belonging to 12 departments. Taken together more than 150 authors (many of them young) were involved. Several contributes are the outcome of national or international collaborative projects. Attempts have been made to realize a “climate friendly, sustainable, green and carbon neutral” event: steps to reduce emissions included the selection of locally-based speakers as well as of food and beverage, with preference to local and seasonal products; a “zero plastic” waste approach was also applied together with a solid waste proper management, within a “paper smart” approach. Since planting trees is a unique, effective and long-term approach for managing the unavoidable environmental impact of our business activities, emissions that it has not been possible to avoid or reduce in advance are going to be offset by planting six hundred trees to compensate the overall estimate carbon footprint of the conference. The tree species have been selected to fit in with our local biodiversity.

Coming back to the conference, all the oral communications have been collected in the present volume, which represents the state of the art of the activity of the research community of the Pisa University in the field of the effects of climate change. The structure of this book reflects the programme of the meeting. Following a couple of introductory reports, session 1 (5 papers) deals with effects on human health; session 2 (3 papers) covers effects on animal health; session 3 (7 papers) is devoted to effects on agroecosystems; session 4 is constituted by 6 papers on natural biosystems; session 5 (geological issues) contains 5 papers; session 6 (2 papers) deals with effects on marine environment; finally, 6 papers on economic, social and political issues form session 7. The text is reinforced by several illustrations and tables. Taken together, the contributions to this issue highlight both the progress and the still existing bottlenecks for the full knowledge of the interactions between climate change and the several aspects of human life. The hope is that this collective work could help to stimulate in the coming years more studies and a multiple perspective debate on the responses to climate change of all the related aspects and targets to address the pressing challenges humankind is currently faced with.

Many questions remain to be clarified or further emphasized and the road ahead is still long and winding. This first-hand collection of papers will be useful as a reference volume for research scientists, students and policy makers in all the fields of human activities connected to climate change, and hopefully will stimulate more thinking, research and action in environmental protection. *The time for emotions is over, it is time for more notions!*

I would like to express appreciation to all the authors for preparing high-quality manuscripts under a tight time schedule. Pisa University Press staff actively helped in the editorial work. Gratitude is due to the Executive Board (‘Giunta’) of CIRSEC, which acted as organizing/scientific committee of the event. The financial support of the University of Pisa is gratefully acknowledged. Special thanks are due to UniCoopFirenze (for the sustainable coffee break) and Vannucci Piante (Pistoia) for the generous gift of 600 autochthonous trees planted to compensate greenhouse gas emissions connected to the conference. It is a symbolic action but the company has immediately appreciated the idea and as usually has unconditionally given its total availability. Finally, OLT-LNG Toscana offered a light eco-friendly lunch to participants and contributed to supply the conference eco-kit. Thanks are also due to IKEA-Pisa for its generous support. This project could not have been possible without the precious contribution of Professor Mike Frank Quartacci, Editor in Chief of *Agrochimica*.

OPENING REPORTS

The humanities yard of the Anthropocene

CARLA BENEDETTI[*]
Department of Philology, Literature and Linguistics, University of Pisa, Italy

You cannot solve a problem by using the same kind of thinking you used when you created it (Albert Einstein)

What is most painfully striking in our time – and with which we have to deal with the urgency that requires us the awareness of the risk we are running, is that being aware of both the climate change and the habitat crisis is not enough. There is by now an enormous quantity of studies, reports, articles and books treating on a scientific basis about climate changes and related phenomena. Yet they have difficulty motivating an action proportional to the announced tragedy.

One of the central questions that animate the "humanistic yard of the Anthropocene" is: why does the knowledge we have acquired by now fail to create a positive sense of emergency and a consequent action? This question recurs today in the minds of many, often with broken accents, sometimes arising even as a cry, especially in the youngest who in various parts of the world ask that politicians listen to scientists, that we get out of the irresponsible immobility and do something against the real crisis, the climate one. The question finds an expression also in the voices of writers and thinkers of our time: "Something enormous is happening: ours are the first human generations to live in the presence of a species extinction […] Yet everything goes on as before as if nothing had happened, the endless human multitudes do not seem able to change the direction of their race by a single millimetre" writes Antonio Moresco in his latest book entitled *Il grido* (The scream, 2018). The thing that is happening is enormous, but so is what is *not* happening.

What to do then when knowledge is not enough, when scientists inform us but men are idle? And how to counteract the painful sense of powerlessness that today prostrates so many conscious men and women and that, among all the factors of paralysis, is perhaps the most insidious one?

Certainly it will be necessary "to rethink the grammar of our understanding of the world" as the French philosopher Bruno Latour wrote. But even stronger and more fitting is Einstein's aphorism reported in

[*]carla.benedetti@unipi.it

epigraph: *you cannot solve a problem by using the same kind of thinking you used when you created it*. Besides inciting to correct, the epigraph also has the merit of indicating the coincidence between what must be corrected and what caused the damage. If we have reached this point it is also merit of the contribution of that grammar, of deleterious ways of reasoning and of limited visions of the complexity of the world. We cannot find a solution to the anthropogenic climate change unless we get out of those paradigms of thought that caused it.

Before now no man had ever faced such an emergency, I do not say in the last few centuries, but in the millennia of human history. We are absolutely the first to run the risk of a mass extinction caused by ourselves, which would also involve many living species. Many apocalyptic elaborations of the 20th century, cinematographic, literary, philosophical, imagined an end of humanity. But no one before us had faced it as a concrete and imminent risk. It is this dramatic emergency, which we could call *experience of man's limits as a species*, to give us the absolute measure of the end of a historical cycle, of the conclusion of that thing called "modernity" and the beginning of an uncertain time that we do not yet know what it will lead to: whether a total catastrophe or a determined metamorphosis.

To work on this second hypothesis, the contribution of the humanities disciplines, including philosophy, literature and the arts, is fundamental.

We need a great work of "intellect amendment" (I use Spinoza's formula in homage to his great dream of mind reform) in order that inactive forces – that were frozen by the complex thought system of the western modernity – can awaken in us, and so that the totality of the human civilization possibilities can reopen, even the dormant ones considered "overcome" by History, fossilized by those same structures of thought that have favoured the type of development and society that is now leading us to catastrophe. Perhaps it will also be necessary to turn on the imagination since, as another Einstein's aphorism says, "*knowledge is limited, imagination embraces the world*". And it will also be necessary to work on emotion, which is the most neglected – when instead we know, from experience and from the teaching of many writers and philosophers, how the sense of justice itself rests on it even before reason.

A humanities yard of the Anthropocene already exists, even if less visible than that of the earth and environmental sciences: workers, philosophers, anthropologists, artists who have inserted this high emergency in their field of activity and who work to reopen the horizon, to correct the blocked conceptual tools and to elaborate new ones. One of the aims of the work I am doing over the years at the Department of Philology, Literature and Linguistics of the University of Pisa, both in teaching and in research, is to contribute to make the humanities yard more visible, taking up important ideas, connecting threads and meeting the challenges as far as possible.

In the next year I intend to strengthen this type of work with the collaboration of researchers from within the University and from outside groups working on these issues. An example of this is the international meeting we are organizing in Naples from November 14th to 17th, entitled "Earthlings" (the detailed program can be read at this link: *https://www.ilprimoamore.com/blog/spip.php?article4297*), with the participation of people working in different fields: from the Indian writer Amitav Gosh, author of *The Great Derangement. Climate Change and the Unthinkable* (2017), to the French philosopher and anthropologist Bruno Latour author of *Où atterrir? Comment s'orienter en politique (Tracing the Route: How to Orientate in Politics*, 2017); from the meteorologists and researchers of climate change Stefano Caserini and Davide Faranda to the volcanologist Laura Sandri; from the historian Federico Paolini to some members of *Friday for future*; from the Italian writers Antonio Moresco, Bruno Arpaia and Flaminia Cruciani, to the anthropologists Giuseppe Gaeta, Giovanni Gugg and Vito Teti.

In 2020 a similar meeting will also take place at the University of Pisa, aimed at creating links and convergences among different disciplines, both scientific and humanistic, on the problems raised by the climatic and environmental emergency.

AN EXAMPLE OF ISSUES TO BE ADDRESSED. – In recent years in the history of science and sociology a research field called *agnotology* has been developed, which studies the fabrication of areas of ignorance or blind points of knowledge thanks to which the failures caused by the so-called modernization have been made invisible. Processes of this type have prevented or largely delayed the awareness of the environmental holocaust. The "climate denial" that has been conspicuous in the past years, fomented by economic potentates and unscrupulous politicians, should be also considered. But these devices of ignorance cannot completely explain the dreadful removal of the climatic emergency that has occurred and continues to exist in these years. Today it is no longer possible to deny the anthropic origin of the global warming, except at the price of a blatant and grotesque denial. It is equally difficult to conceal the limited resources of the planet that are dangerously diminishing while the world population is growing vertiginously.

Following *agnotology*, the term *agnotocene* was coined to indicate the making of those blind spots of knowledge that have allowed, during modernity, to hide the damage caused to the environment. For Christophe Bonneiuil and Jean-Baptiste Fressoz, authors of *L'événement Anthropocène*. *La Terre, l'histoire et nous* (2016), for example, the history of the Anthropocene does not coincide – as many tend to depict it – with that of a frenetic modernism that transforms the environment ignoring the damage it causes. It is rather the history of a scientific and political development of a "modernizing unconsciousness". The two authors identify some cultural devices that produce ignorance or great "put in shape of the world" that accompanied the commodification of man and nature. The most important is the one which conceals the finiteness of the Earth, creating the illusion of an unlimited supply of energy and raw materials, guaranteeing a progress without limits.

But today even this type of unconsciousness has been greatly weakened in the common perception. The very fact that in the Western world the most exploited collective emotion fuelled by unscrupulous politicians is the fear of migrants is proof of this. If the belief in the possibility of an unlimited growth really continues in the current opinion, some political program could draw arguments in its favour. Instead, no leader or political party feeds it, knowing that few voters would believe it.

An investigation into the causes of the climate emergency repression cannot therefore be limited to the *areas of ignorance* artfully constructed. And it will not only have to turn to the processes of world politics and the economy, but it will also be directed towards cultural forms and thought mechanisms that structure the mind of man in this era. These factors are less evident than the climate denial or the idea of a nature with unlimited resources, but also much more powerful in the negative effects they create because they have acted longer and deeper.

If certain habits of thought and behaviour, certain models of reading the world that hide parts of the reality, blind the vision, numb the feeling preventing a different action will not change in man, it will be difficult to combat climate change. This is one of the strong themes about which we intend to deal with, identifying also within culture and its forms what continues to hinder a vision and an action proportional to the emergency in which we live, and the way to counter it.

GHG emissions in industrial activities: the role of technologies for their management and reduction

FEDERICA BARONTINI, CHIARA GALLETTI, CRISTIANO NICOLELLA, LEONARDO TOGNOTTI*

Dipartimento di Ingegneria Civile e Industriale, Università di Pisa

Keywords: Green House Gases, industrial emissions, energy production, carbon capture, renewables, CO_2 reutilization

ABSTRACT – To deal with the problem of the Climate System Change and the Global Warming, countries as well industries require to decrease the amount of CO_2 emissions released globally by developing greener technologies and improving the use of renewable energies. The role of the research, in particular process engineering, is to develop and demonstrate technologies in order to protect the world from the current deterioration situation, which could potentially develop more frequent natural disasters, raising in the sea level and cause harm to the human health and ecosystems. The Chemical Engineering group at Department of Civil and Industrial Engineering of Pisa University has been involved in several projects concerning carbon reduction and emission from energy production in different Sectors, in collaboration with public and private organizations and international networks. The research topics have been briefly reviewed and objectives for further studies have been identified.

INTRODUCTION. – The Climate system change and the global warming, associating the upsurge of global average temperature to the observed increase of the anthropogenic greenhouse gases (GHG) concentrations in the atmosphere. Carbon dioxide (CO_2) is considered the most important GHG, due to the dependence of industrial sectors on fossil fuels, where combustion processes are the most important sources. To deal with the problem of the Climate System Change and the Global Warming, countries as well industries require to decrease the amount of CO_2 emissions released globally by developing greener technologies and improving the use of renewable energies.

Energy is essential for societal development. All energy sources will be needed to meet growing demand, including renewables and oil

*Corresponding author: leonardo.tognotti@unipi.it

and gas. Access to affordable, reliable energy is essential to the growth of strong economies, sustained improvements in the quality of life and the eradication of poverty. To ensure these benefits for today's and future generations alike, GHG reduction and climate change adaptation objectives must balance the need for development, economic growth, environmental protection and energy security. Oil and gas have a continuing role to play in a future of increasingly diverse energy sources, steadily improving energy efficiency and new technologies to minimize emissions.

The International Energy Agency has recently published the Global Energy and CO_2 Status – Report 2018, from which the main conclusions can be drawn:

- **Global energy consumption** in 2018 increased at nearly twice the average rate of growth since 2010, driven by a robust global economy and higher heating and cooling needs in some parts of the world. Demand for all fuels increased, led by natural gas, even as solar and wind posted double-digit growth. Higher electricity demand was responsible for over half of the growth in energy needs. Energy efficiency saw lackluster improvement.
- **Energy-related CO_2 emissions** rose 1.7% to a historic high of 33.1 Gt CO_2. While emissions from all fossil fuels increased, the power sector accounted for nearly two-thirds of emissions growth. Coal use in power alone surpassed 10 Gt CO_2, mostly in Asia. China, India, and the United States accounted for 85% of the net increase in emissions, while emissions declined for Germany, Japan, Mexico, France and the United Kingdom.

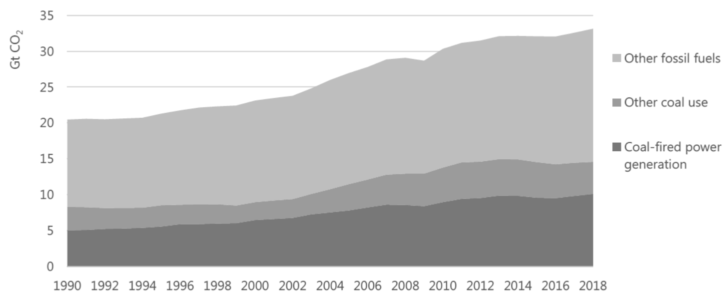


FIG. 1. Global energy related carbon dioxide emissions by source, 1990-2018 (Source: Global CCS Status Report: 2018. International Energy Agency, 2019).

Figure 2 shows the changes in global carbon dioxide emissions and avoided emissions from 2017 to 2018. It is evident that the measures for avoiding the emissions – energy efficiency, renewables, natural gas and other – are still not sufficient to balance the increase of generation due to increasing energy demand. This issues are also related to the capability of new technologies to become reliable and sustainable in terms of costs and acceptability from different stakeholders, including local communities.

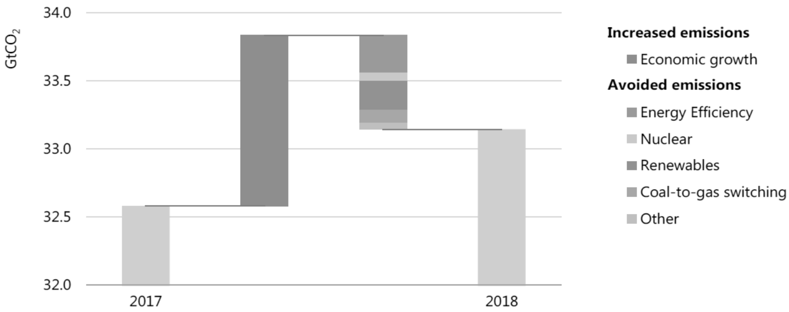


FIG. 2. Changes in global carbon dioxide emissions and avoided emissions 2017-2018 (Source: Global CCS Status Report: 2018. International Energy Agency, 2019).

THE LONG TERM CLIMATE ACTIONS AND POLICIES. – September 2015, United Nations general assembly issued 17 Sustainability Development Goals (SDG) and 169 targets underpinning the new universal Agenda. The SDG's will stimulate action for the next 15 years in critical areas of importance for humanity and the planet. Among these SDG's, the 13th SDG lays the climate action goal which shows that climate change is one of the issues that requires the international cooperation, commitment from governments and corporations.

The United Nations Framework Convention on Climate Change (UNFCCC, *https://unfccc.int/*) is the main international agreement on climate actions and is ratified by 195 countries. Since then there has been two issues related to the UNFCCC:

Ratification of the Doha amendment to the **Kyoto Protocol**, which concerns commitments under the second period, running from 2013-2020.

Paris Agreement – or **COP21** is a new global climate change agreement covering all UNFCCC countries, its ratification, implementation and enter into force in 2020. The Paris agreement sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C. According to *Intergovernmental Panel on Climate Change* (*https://www.ipcc.ch/*) cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the probability of limiting warming to 1.5°C (see Figure 3).

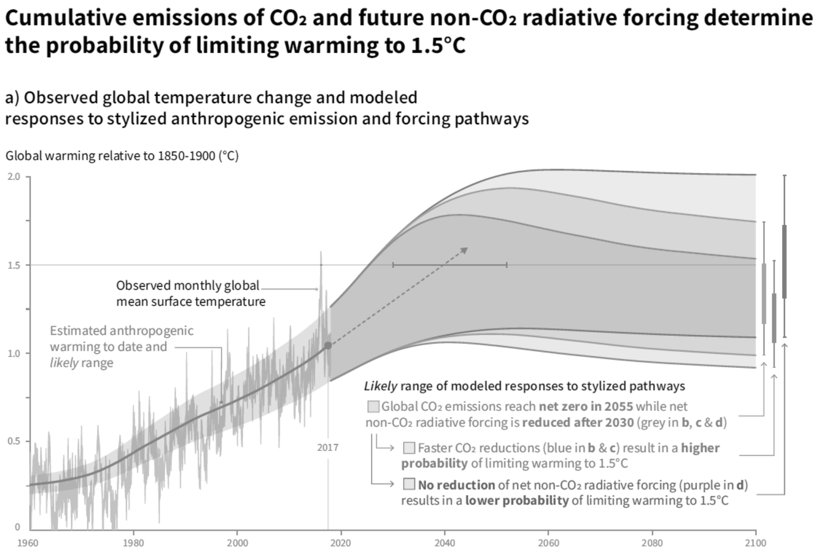


FIG. 3. Observed global temperature changes and modeled responses to stylized anthropogenic emission and forcing pathways *(Source: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty; Intergovernmental Panel on Climate Change 2018).*

One of the most effective measure to limit carbon emission has been set up by EU. The EU emissions trading system (EU ETS) is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively. It is the world's first major carbon market and remains the biggest one.

The EU ETS works on the "cap and trade" principle. A cap is set on the total amount of certain greenhouse gases that can be emitted by installations covered by the system. The cap is reduced over time so that total emissions fall. Within the cap, companies receive or buy emission allowances which they can trade with one another as needed. They can also buy limited amounts of international credits from emission-saving projects around the world. The limit on the total number of allowances available ensures that they have a value. If a company reduces its emissions, it can keep the spare allowances to cover its future needs or else sell them to another company that is short of allowances. A robust carbon price also promotes investment in clean, low-carbon technologies.

THE TECHNOLOGIES AND THE ROLE OF RESEARCH. – The Department of Civil and Industrial Engineering (DICI) of Pisa University is involved in several projects concerning carbon reduction, the Climate Change and access to energy, in collaboration with public and private organizations, and international networks. The research topics at DICI can be summarized as: 1. Managing emissions from industrial production; 2. Reducing emissions from power generation: natural gas and renewables; 3. Carbon capture.

MANAGING EMISSIONS: ENERGY CONSERVATION AND BEYOND. – The relevant GHGs for industrial activities are CO_2, CH_4, N_2O. The main sources in a typical industrial facility are: *Combustion:* fuel consumption (gas, diesel, kerosene, …) for power generation, transportation; *Flaring:* routine flaring, emergency flaring (including start up and commissioning phases, blow downs) and flaring during drilling and well workovers; *Venting:* process and emergency venting, venting from gas processing units, storage tanks; *Fugitives:* unintentional leakages from valves, flanges, etc. within the plant.

DICI has a long term collaboration with ENI through a University Master – *Management of Health, Safety, Environment and Quality Systems.* The Master trains experts in the development and Management of HSE&Q Systems. Ongoing projects, including flaring reduction, control of methane emissions and other efforts are reviewed and analyzed as project works within Master activities. In parallel, DICI has collaborations with industrial sectors (iron & steel, pulp & paper, refineries, glass, cement) to improve energy efficiency in production: conserving energy goes beyond traditional energy efficiency measures, including recovery and recycle of secondary raw materials in a circular economy frame (Tognotti 2019).

REDUCING EMISSIONS FROM POWER GENERATION: NATURAL GAS. – The power sector accounts for about half of global energy-related GHG emissions. Multiple approaches and technologies can be used to reduce the GHG intensity of this sector. In the near term, one of the most cost-effective and impactful steps that society can take is to switch from coal to natural gas. This step could cut emissions in half for every unit of electricity generated. Reducing the GHG intensity of the power sector could enable the electrification of parts of the transport, residential, commercial and industrial sectors to decrease their GHG intensity. Natural gas is the cleanest-burning fossil fuel and is increasingly accessible, affordable, abundant and flexible. With ongoing management of emissions, natural gas will continue to play a pivotal role as a dependable lower carbon fuel in the transition to a low-carbon energy future. DICI has developed original modeling approaches in the study of clean and efficient natural gas combustion, including hydrogen enrichment (Aminian *et al.* 2011, 2016), energy recovery from flue gases and recuperative burners (Galletti *et al.* 2007; Parente *et al.* 2008), gas turbine diagnostics and optimization (Bellagoni *et al.* 2019; see Figure 4).

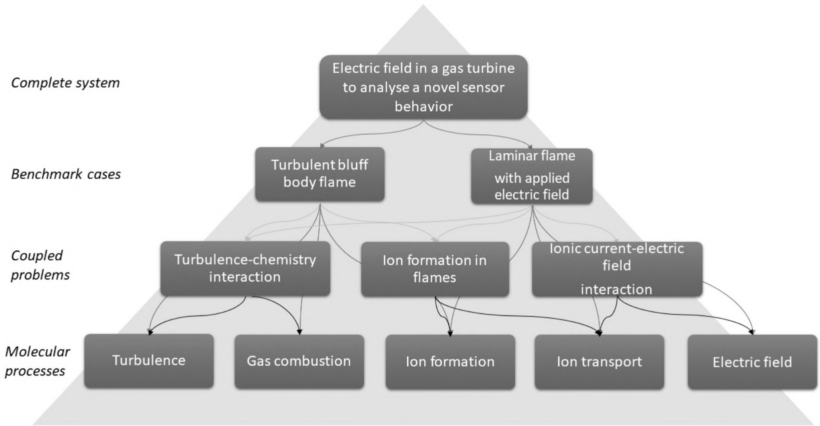


FIG. 4. Hierarchical scheme for CFD study validation: application to gas turbine diagnostics.

REDUCING EMISSIONS FROM POWER GENERATION: RENEWABLES. – Near-zero emissions options for energy generation at local and medium scale are represented by renewables. While these technologies continue to be developed, additional technical breakthroughs will be needed to achieve cost-effective deployment at the scale needed to transform the energy system.

Biomass combustion, in collaboration with DESTEC -Department of Energy, Systems, Territory and Construction – (Barontini *et al.* 2018; Capusciutti *et al.* 2018), and biomass gasification (Biagini *et al.* 2014, 2015, 2016; Simone *et al.* 2012, 2013a,b, see also Figure 5) have been the main topics of research of DICI in the last decade, including biofuel production such as biomethane, biodiesel and torrefied biomass (Bacci di Capaci *et al.* 2019; Tasca *et al.* 2019; Li *et al.* 2013).

The main objective, among others, was to demonstrate the feasibility and availability of technologies for local, small scale, distributed generation (Galletti *et al.* 2016; Patronelli *et al.* 2018, see Figure 6). Biomass combustion at the Cornia 2 hybrid geothermal/biomass power plant of Enel Green Power – an innovative technology integrating renewable and geothermal energy – has also been investigated (Galletti *et al.* 2017).

Carbon Capture and Storage (CCS). – Carbon Capture and Storage is a technology which is used to capture large emissions of CO_2 released into the atmosphere from stationary point sources such as power plants and energy intensive industrial processes (pulp and paper, steel and oil refineries, etc.). The technology can be integrated into the combustion of fossil fuels during energy generation, where CO_2 is captured and transported to the "storage bank" in order to isolate it from the atmosphere.

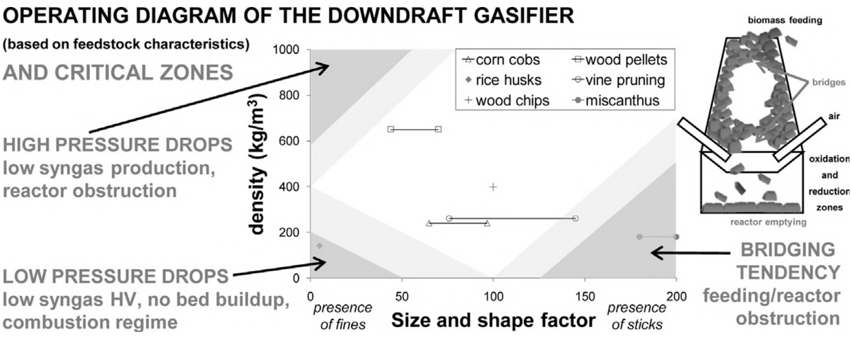


Fig. 5. Operating diagram of the downdraft gasifier (Biagini *et al.* 2015).

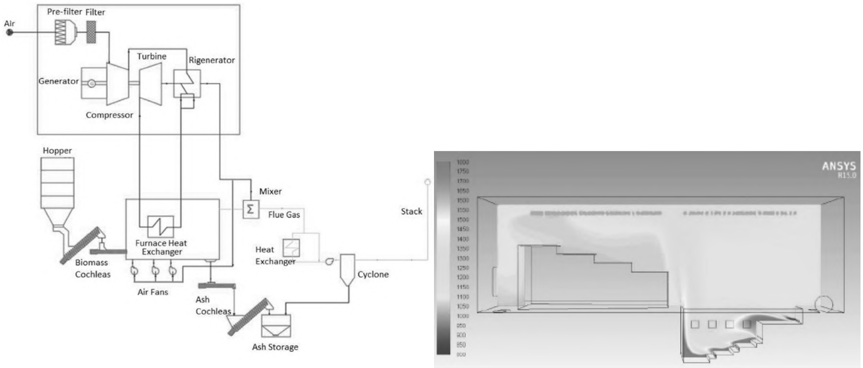


Fig. 6. Biomass furnace for externally fired gas turbine: development and validation of the numerical model (Galletti *et al.* 2016).

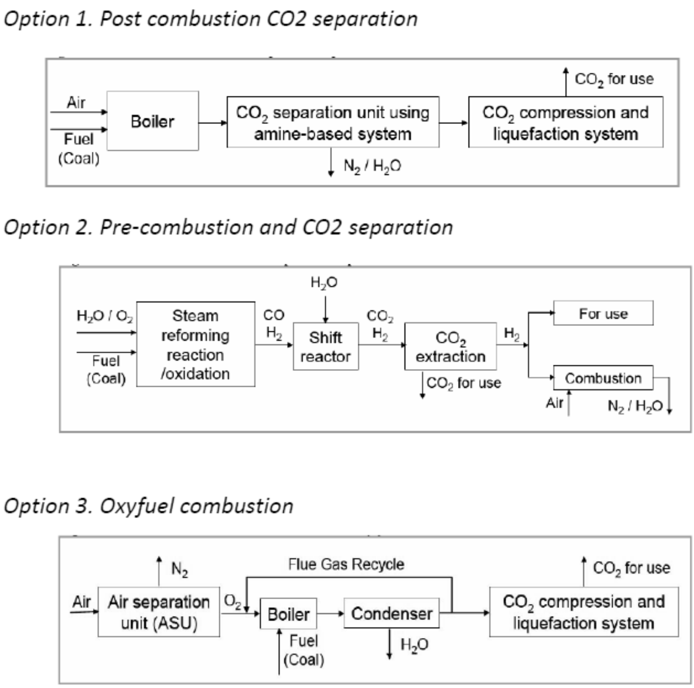


Fig. 7. Carbon Capture options.

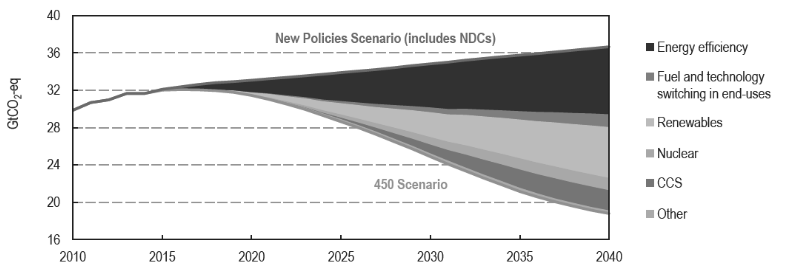
CCS involves three major steps; capturing CO_2 at the source, compressing it for transportation and then injecting it deep into a rock formation at a carefully selected and safe site, where it is permanently stored. DICI research on CCS has been devoted on the Capture phase, *i.e.,* the separation of CO_2 from other gases produced at large industrial process facilities such as coal and natural-gas-fired power plants, steel mills, cement plants and refineries. The Capture options are represented in Figure 7.

Research at DICI has been conducted on all the options, with particular focus on oxyfuel combustion, in which the combustion of fuel takes place with a mixture of oxygen and recycled flue gas (RFG) (Coraggio *et al.* 2011; Galletti *et al.* 2013a,b). The applications for gas combustion in a O_2–RFG mixture are both the retrofit of existing fired utility boilers and the building of new ones expressly designed for this technology.

Deployment of CCS on a scale that makes a material contribution to reducing CO_2 emissions requires addressing current barriers, which include: cost, complexity along the value chain, regulatory/policy uncertainty, public acceptance, large-scale storage sites and long-term liability issues.

More recently efforts have been focused on CO_2 recycle market. Two categories, direct utilization of CO_2 and conversion of CO_2 to chemicals and energy products, can be used to classify different forms of CO_2 utilization. Regarding the direct utilization of CO_2, in addition to its use in soft drinks, welding, foaming, and propellants, as well as the use of supercritical CO_2 as a solvent, are being considered with different levels of technology readiness. The conversion of CO_2 to chemicals and energy products can be achieved mainly through: i) photosynthesis to directly fix carbon into microalgae, which can then be digested to produce biogas/biomethane (Barontini *et al.* 2016); ii) co-electrolysis with water using renewable/surplus energy to produce syngas and then methanol; iii) direct catalytic hydrogenation of CO_2 to methanol.

Conclusions. – Meeting the aims of the Paris Agreement implies a transformation of the energy and industrial system over the course of this century. Throughout this transition, fossil fuels will continue to be an important part of the broad energy mix needed to deliver affordable, reliable and modern energy products and services. There are many possible pathways to reach a low-emissions future, most of which share three common elements: improving **efficiency** and saving energy; reducing **emissions** from power generation; and deploying alternative **low-emission options** in end-use sectors. Carbon capture and storage (CCS) is a key technology to support this transition. As an example, Figure 10 reports the predictions of CO_2 eq emissions from the implementation different policy scenarios at global level: the measures needed to surpass current Nationally Determined Contributions (NDCs) to reach the 2°C trajectory through 2040 are indicated.



Note: The New Policies Scenario (NPS) is the central scenario of the World Energy Outlook *and includes the energy-related components of NDCs submitted by 1 October 2015.*

Fig. 8. CO_2 emissions for different policy scenarios (Source: Energy, Climate Change & Environment: 2016 Insights).

The role of the research, in particular industrial process engineering, is to develop and demonstrate technologies in order to protect the world from the current deterioration situation, which could potentially develop more frequent natural disasters, raising in the sea level and cause harm to the human health and ecosystems. Research at different steps of development, from fundamental to demonstration phases, is still needed: to reducing CO_2 emissions requires addressing current barriers, which include cost, complexity along the value chain, regulatory/policy uncertainty, public acceptance.

The Chemical Engineering group at Department of Civil and Industrial Engineering of Pisa University has been involved in several projects concerning carbon reduction and emission from energy production in different Sectors, in collaboration with public and private organizations and international networks. The research topics have been briefly reviewed and objectives for further studies have been identified.

REFERENCES

Aminian J., Galletti C., Shahhosseini S. *et al.* (2012), Numerical investigation of a MILD combustion burner: analysis of mixing field, chemical kinetics and turbulence-chemistry interaction, in Flow, Turbulence and Combustion 88: 597-623.

Bacci di Capaci R.; Tasca A.L., Pannocchia G. *et al.* (2019). Biomethane production: Mass and Energy Balances of Alternative Supply Chains. Industrial & Engineering Chemistry Research 58: doi: 10.1021/acs.iecr.9b01149.

Barontini F., Biagini E., Dragoni F. *et al.* (2016). Anaerobic digestion and co-digestion of oleaginous microalgae residues for biogas production, Chemical Engineering Transactions 50: 91-96.

Barontini F., Galletti C., Di Mitri D. *et al.* (2018). Biomass Combustion in a 140 kW Fixed Bed Boiler: a Joint Experimental and Modeling Study. Chemical Engineering Transactions 65: 55-60.

Bellegoni M., Paccati S., Palanti L. *et al.* (2019). Modelling of ion chemistry in turbulent flames for the analysis of novel sensors for gas turbine combustors. 42nd Meeting of the Italian Section of the Combustion Institute.

Biagini E., Barontini F., Tognotti L. (2014). Gasification of agricultural residues in a demonstrative plant: Corn cobs. Bioresource Technology 173: 110-116.

Caposciutti G., Barontini F., Antonelli M. *et al.* (2018). Experimental investigation on the air excess and air displacement influence on early stage and complete combustion gaseous emissions of a small scale fixed bed biomass boiler. Applied Energy 216: 576-587.

Coraggio G., Tognotti L., Cumbo D. *et al.* (2011). Retrofitting oxy-fuel technology in a semi-industrial plant: Flame characteristics and NOx production from a low NOx burner fed with natural gas. Proceedings of the Combustion Institute 33: 3423-3430.

Galletti C., Parente A., Tognotti L. (2007). Numerical and experimental investigation of a mild combustion burner. Combustion and Flame 151: 649-664.

Galletti C., Coraggio G., Tognotti L. (2013). Numerical investigation of oxy-natural-gas combustion in a semi-industrial furnace: validation of CFD sub-models. Fuel 109: 445-460.

Galletti C., Giomo V., Giorgetti S. *et al.* (2016). Biomass furnace for externally fired gas turbine: Development and validation of the numerical model Applied Thermal Engineering 96: 372-384.

Galletti C., Bitossi N., Serena S. *et al.* (2017). CFD-DEM modeling of biomass combustion on a reciprocating grate. 10th World Congress of Chemical Engineering.

Li J., Bonvicini G. Tognotti L. *et al.* (2014). High-temperature rapid devolatilization of biomasses with varying degrees of torrefaction. Fuel 122: 261-269.

Parente A., Galletti C., Tognotti L. (2008). Effect of the combustion model and kinetic mechanism on the MILD combustion in an industrial burner fed with hydrogen enriched fuels. International Journal of Hydrogen Energy 33: 7553-7564.

Patronelli S., Antonelli M., Tognotti L. *et al.* (2018). Combustion of wood-chips in a small-scale fixed-bed boiler: Validation of the numerical model through in-flame measurements. Fuel 221: 128-137.

Simone M., Barontini F., Nicolella C. *et al*. (2012). Gasification of pelletized biomass in a pilot scale downdraft gasifier. Bioresource Technology 116: 403-412.

Simone M., Barontini F., Nicolella C. *et al.* (2013). Assessment of syngas composition variability in a pilot-scale downdraft biomass gasifier by an extended equilibrium model. Bioresource Technology 140: 43-52.

Tasca A.L., Bacci di Capaci R., Tognotti L. *et al.* (2019). Biomethane from short rotation forestry and microalgal open ponds: system modeling and life cycle assessment. Bioresource Technology 273: 468-477.

Tognotti L. (2019). Strengthening the knowledge-base on sustainability aspects of raw material supply chains: the role of a research institution, Third RMIS workshop, Joint Research Center, Ispra, June 2019.

SESSION 1
EFFECTS ON HUMAN HEALTH

Psychological mechanisms for gaining awareness of (and reacting to) climate change challenges: emotional levers for cognitive remodeling

SERGIO FRUMENTO[1], ANGELO GEMIGNANI[1], DANILO MENICUCCI[1*]
[1]Department of Surgical, Medical, Molecular and Critical Area Pathology
University of Pisa, Via Savi, 10 - 56126 Pisa

Keywords: psychological obstacles, cognitive bias, conditioning, effective communication

ABSTRACT. – Environmental issues linked to climate change are more visible and dangerous than ever, causing a growing concern in public opinion: still, lot of persons seems to not really understand the situation, trying to ignore it or not changing their behaviors consequently. Here we describe some core concepts of Psychology that can help understanding this phenomenon and counterbalancing it with a proper communication. Four basic cognitive mechanisms are described, that could account for the lack of awareness, concern and put-to-practice: 1) the limits in understanding number-based communication, 2) the instinctive reject for news perceived as too negative, 3) the learning and memory mechanisms underlying the difficult cause-effect association concerning climate change, and, 4) finally, the reasons to not embrace ecological behaviors even being aware of their relevance. Our suggestion can promote awareness of environmental issues and the adherence to the consequent ecological behaviors. Specifically, we propose a wise use of cognitive mechanisms and of emotional leverage; a smart timing of communication; and a socially desirable, step-by-step twist to ecological behaviors in order to make them more acceptable (and, thus, widely adopted).

INTRODUCTION. – Climate change and environmental issues are probably the most dangerous menaces that humanity will face in this first century of the third millennium, according to both institutional and scientific reports (Solomon *et al.* 2007; Costello *et al.* 2009). Forecasts agree that the planet Earth will warm up to many degrees in few decades, this causing devastating effects (Hansen *et al.* 2006), from increase of sea level and desertification to frequent extreme events such as tsunami,

*Corresponding author: danilo.menicucci@unipi.it

hurricanes, heat waves. Climate changes already happened in the past, and humanity successfully faced periods of colder and warmer weather (Birks & Ammann 2000) but now the climate change we are facing is unique in history for spread and entity (Neukom *et al.* 2019): without strong and immediate human reaction, even larger regions will become hardly for humans to live, due to warming and reduction of resources, water and food, that will cause mass migration and increased probability of conflicts. Even if the worst is yet to come, some aftermaths of climate change are already under everyone's eyes, with effects on ordinary life such as the damages to persons and properties caused by the strengthening of natural phenomena. There is no reasonable doubt that climate change is a relevant problem: are we enough aware of it and thus concerned by its effects? Surprisingly, the answer is probably 'no'.

It's hard to empirically state the relevance of such topic in World population, but combining scientific literature with political polls a probable pattern can be figured out. Scientific literature concerning climate change is rapidly increasing, to the point that dedicated journals are born. In 2015, a wide survey explored the perception of climate change in 119 countries, stating that levels of awareness and perceived threat vary around the world (Lee *et al.* 2015): according to the authors, most aware populations are those from first-world countries such as North America, Europe and Japan. Interestingly, these countries are also evaluated as the more responsible for climate change, while being the less affected by its aftermaths (Oxfam Media Briefing 2015; Althor *et al.* 2016; Hubacek *et al.* 2017). In Europe, these topics are rapidly rising in political debate and public opinion, as demonstrated by the growing support for "green" parties: still, the perception of such menaces is not proportioned to their gravity (Knight 2016; Archibald & Butt 2018). Younger population groups are more sensitive to climate change: in 2019, a poll filled by EU citizens reported that environmental issues are the most important topic for Europeans aged between 16 and 26 (Tui Stiftung poll, May 2019). On the other hand, a survey administered the same year to U.S. citizens shows that environmental issues and climate change are reported as the main problem by the 4% of respondents, whereas immigration is considered the most important issue by 27% (Gallup poll, July 2019). Apparently, popular opinion is still far from recognizing the problem: even who consider it the main world's issue, probably underestimate its importance. Why aren't we all focusing every effort – both personally and collectively – on reversing the devastating effects of climate change and all the linked environmental issues?

Most of us is able to remember where he/she was when the Berlin Wall fell, or when the terrible attacks on the New York Twin Towers occurred, but hardly anyone can even vaguely identify what period of his life he was experiencing when the concentration of carbon dioxide in the atmosphere has exceeded 400 ppm.

In this paper, we propose a psychological model explaining the lack of awareness and relevance assigned in the public debate to climate change and environmental issues, and we give some hints for facilitating an ecological consciousness in populations.

COMMUNICATION AND (MIS)PERCEPTION. – It seems difficult for us to appreciate the impact of climate change on our life: Media show that climate change hit hardest elsewhere, not everywhere. Numbers labeling climate change do not help to emotionally understand the problem: two degrees of the average temperature seems a small change, trillions tons of carbon in the permafrost that are going to be released in the atmosphere is too large and too abstract to be really understood.

A proper and effective communication of environmental issues and consequent risks for human civilization is fundamental for evoking reactions in the public opinion: herein some biases that could affect it have been highlighted, and possible countermeasures have been proposed.

A. LIMITS OF NUMBER-BASED COMMUNICATION. – A way to communicate environmental issues is using numbers: "Humans have been messing up the planet for more than 4,000 years, study claims" (Mirror, 30 August 2019) or "the concentration of carbon dioxide in the atmosphere has exceeded 400 ppm" are examples of such communication.

Even if the information is correct, the take-home message can be misled by some limits in the interpretation of – apparently – simple information, such as numbers. Seminal researches of Nobel prize Kahneman show **that humans are way more irrational than we could expect, when dealing with quantitative information** (Gilovich *et al.* 2002). The average person hardly manages large numbers (Alonso-Diaz & Cantlon 2018), being more impressed by simple arithmetic multiples (*e.g.,* "emissions have doubled") than by geometric multiples (*e.g.,* "emissions went from a billion to a trillion ppm").

In order to be more effective, communication of quantitative data via not-specialized media should take in account the biases occurring in the processing of numbers and real-life consequences related to such numbers should always be explicitly stated.

B. EMOTIONAL AFFECT ASSOCIATED TO COMMUNICATION. – Emotionality is a fundamental component of an effective communication.

In the communication of environmental issues, emotional affect can represent an important agent of sensitization (Leiserowitz 2006), being able to overwhelm the rational, numbers based, knowledge of the problem and automatically guiding information processing and decision making (Zajonc 1980). A stronger education is predictive of a higher sensitization to climate change issue (Stevenson *et al.* 2014), but for a wider awareness adding some emotional affect to the communication could make messages more and more effective.

It is not to be taken for granted that the stronger is the message, the stronger is the understanding and the reaction, in particular when the message can hardly be positive. Messages too hard (even if more realistic) could bring the receiver to react with a **defensive rejection** (Leiserowitz 2006) or **to develop a lack of empowerment** (intended as the perceived power to effectively change a situation) or **learned helplessness** (the perceived absence of control over the outcome of a situation) (Krosnick *et al.* 2006).

C. DIFFICULTY IN CAUSE-EFFECT ASSOCIATION. –Basic principles of human learning can be raised for discussing some of the present difficulties in communicating the criticality of environmental issues on planet hearth and human civilizations.

Two most fundamental forms of learning – classical (Pavlovian) and instrumental (operant) **conditioning** – are always influencing human behavior. Through them, we respectively learn to associate 1) stimuli in the environment, or 2) our own behaviors, with salient events, such as rewards and punishments that would happen following a specific stimuli or own appropriate behavior; namely we learn to predict. The acquired ability to predict induces changes in specific neuronal networks leading to behavioral modifications that occur automatically, *i.e.,* without any explicit reasoning.

From classical psychological studies (reviewed in Gerrig & Zimbardo 2002), some parameters affecting effectiveness, speed and strength of the acquisition of conditioning have been identified. **Contiguity** in the space and time between stimulus/behavior and salient event favor the acquisition. Also, **contingency**, *i.e.*, the predictability of occurrence of the salient event from the occurrence of a stimulus/behavior, favor the acquisition; however, some degree of uncertainty further increases its strength.

On the one hand, the lack of contiguity (long-term effect of our actions) and contingency (no one-to-one correspondence between individual actions and environmental consequences) make hard to learn the link actually existing between events: for example, it is hard to make links between one's single polluting actions (*e.g.*, driving a car) and the collective aftermaths (*e.g.,* flood given by the increase of sea level caused by the ice melting induced by the emissions of CO_2 by cars).

On the other hand, the unpredictability of some natural disasters – such as hurricanes, floods, heat/cold waves – can increase the perceived relevance of such events (a phenomenon described as **intermittent conditioning**, also used to explain gambling addiction); and this could indicate a way of intervention.

D. DIFFICULTIES IN ADHERING TO ECOLOGICAL BEHAVIORS. – Awareness and sensitization are the base for embracing ecological behaviors, still could be insufficient: other variables can affect this process, both cultural and individual. **Cognitive flexibility plays a key role**, being the necessary condition to change our own habits and to accept the gravity of environmental issues: as every important change, the adherence to ecological behaviors is also hardly maintained for a long time. Furtherly, ecological behaviors are still **not enough recognized at social level**: economic incentives aren't always able to counterbalance the higher cost of such behaviors, and their social desirability still does not represent a determinant factor, but in few promising examples (Carattini *et al.* 2019). Finally, embracing ecological behaviors today apparently lead to visible advantages only in the long time, mainly in terms of avoided menaces: few immediate rewards are perceived.

PSYCHOLOGICAL SOLUTIONS. – We have discussed some reasons addressing for the discrepancy between the relevance of climate change issues and perception of (and reaction to) such issues in the public opinion: now, based on the cognitive mechanisms previously described, we propose possible approaches for enhancing awareness and sensitivity to the topic, providing some specific guidelines for making communication more effective and pushing behavior to ecological changes.

A. WHAT TO COMMUNICATE: ARE RAW DATA COMMUNICATING THE WHOLE INFORMATION? – Scientific data have to be reported without emotional transport to preserve their objectivity, however there is no reason to do the same in a general media context: in that case, the emotion that should be linked to the news is a useful further information, that complete the raw data increasing its comprehension. Concerns about climate change are often expressed as raw data indicating the exceptionality of some measured variables: this way could be ineffective in communicating the gravity of a situation.

The general receiver could be not enough competent to evaluate or not enough engaged to pay attention to information describing how climate data are moving. The raw data should be associated to information that increase the relevance, such as telling the possible consequences for himself, his children or his community.

When talking about climate change, focusing on negative data could be counterproductive (defensive rejection, lack of empowerment and learned helplessness). **Sharing also good news and promoting handy examples could increase the sensitization** while also making people more likely to embrace ecological behaviors. The success of the trashtag challenge (the trend of cleaning places from trash and posting a before vs after comparison on some social networks) demonstrated that the affordability of such behavior lead to an increased sense of self-efficacy, that represent a strong predictor of concern for environmental issues (Kellstedt *et al.* 2008). Studying the diffusion of solar panels, emerged that their visibility enhances and makes viral their adoption in the neighborhood, up to raise the action of an individual to a social norm (Carattini *et al.* 2019).

B. HOW TO COMMUNICATE IT: PUSHING ON THE EMOTIONAL LEVERAGE TO BRIDGE INDIVIDUAL HABITS TO GLOBAL EFFECTS. – Unfortunately, some environmental issues linked to climate change are not easy to detect in everyday life, being the aftermaths of human's ecological footprint deferred from the original cause. For reducing the difficulty of cause-effect linking in climate changes issues related to contiguity lack, the **higher-order conditioning learning could be used** (Baetu & Baker 2009). Higher-order conditioning consist in firstly making a stimulus meaningful through an initial step of classical conditioning, and then in using the previously conditioned stimulus as a basis for a new association. For example, the Pavlov's dog might first learn to associate the bell with food (first-order conditioning), and then learn to associate a light with the bell (second-order conditioning) and the result would be dog salivation just following lights on. In this way, association chains can be set up and individual ecological habits could be linked to some immediate positive consequences that in turn could be linked to other ones at a larger scale and so on up to the global environmental impact.

C. WHEN TO COMMUNICATE IT: A SMART USE OF TIMING. – Sometimes unexpected catastrophic events hit suddenly and violently, shocking for a while those experiencing it. If we consider the sensitization to environmental issues and the put in practice of ecological behaviors something that have to be learnt and remembered, it's possible to use conditioning learning (both classical and instrumental) to our advantage. For example, **catastrophic events can be easily suited to intermittent conditioning stimuli, if linked by media in a unique narration**: in such a way, they will not be perceived as single exceptional events, but as repetitive – even if unpredictable – menaces. The hope of avoiding such disasters could represent a further reason to embrace ecological behaviors: if properly (and frequently) communicated, a catastrophic event happening in a specific Earth's region could lead persons from all over the world to reject unsustainable habits. The combination of strategies involving both classical and instrumental conditioning could lead to a higher knowledge and increased sensitization towards climate change and environmental issues, this also promoting the adherence to ecological behaviors.

D. FROM WORDS TO DEEDS: PROMOTING THE PUT-IN-PRACTICE OF ECOLOGICAL BEHAVIORS. – Many factors complexly interact to increase or decrease the decisional threshold that must be overcome in order to adhere to ecological behaviors. In order to make ecological behaviors the more acceptable as possible, they could be promoted as a step-by-step process able to lead an affordable solution of the problem, not twisting the habits of the persons and exposing them to a positive social visibility. When dealing with environmental issues, public opinion should **feel less guilty and more responsible**: the message has to be realistic in his gravity, still giving to the receiver the perception of his possibility to avoid the tragedy if he acts quickly. Moreover, solid evidences indicate that being involved in restorative positive experiences in natural environments makes people more prone to behave ecologically (Hartig *et al.* 2001). This emotional leverage could induce a long-lasting cognitive remodeling able to balance the decisional threshold in the direction of ecological behaviors.

CONCLUSIONS. – The emotional leverage can be integrated both in popular and scientific communications in order to add to the raw data the relevance of the subject matter: taking in account main psychological mechanisms and biases described in this paper will hopefully help scientists and journalists to improve the efficacy of their communication, and, thus, its positive consequences in spreading ecological behaviors. The cognitive remodeling induced by this emotional leverage should represent a long-term factor of sensitization towards environmental issues and flexibility to adapt own behaviors to a greener approach.

REFERENCES

Alonso-Diaz S., Cantlon J.F. (2018). Confidence judgments during ratio comparisons reveal a Bayesian bias. Cognition 177: 98-106.

Althor G., Watson J.E.M., Fuller R.A. (2016). Global mismatch between greenhouse gas emissions and the burden of climate change. Scientific Reports, 6, 20281.

Archibald C.L., Butt N. (2018). Using Google search data to inform global climate change adaptation policy. Climatic Change 150: 447-456.

Baetu I., Baker A.G. (2009). Human judgments of positive and negative causal chains. Journal of Experimental Psychology: Animal Behavior Processes 35: 153-168.

Birks H.H., Ammann B. (2000). Two terrestrial records of rapid climate change during the glacial-Holocene transition (14,000-9,000 calendar years B.P.) from Europe. Proceedings of the National Academy of Sciences 97: 1390-1394.

Carattini S., Levin S., Tavoni A. (2019). Cooperation in the Climate Commons. Review of Environmental Economics and Policy 13: 227-247.

Costello A., Abbas M., Allen A., *et al.* (2009). Managing the health effects of climate change. Lancet 373: 1693-733.

Gallup (2019). Most important problem, July 2019. Gallup Inc. Retrieved from *https://news.gallup.com/poll/1675/most-important-problem.aspx*.

Gerrig R.J., Zimbardo P.G. (2002). Psychology and Life. Allyn and Bacon.

Gilovich T., Griffin D., Kahneman D. (Eds) (2002). Heuristics and biases: The psychology of intuitive judgment. New York, Cambridge University Press.

Hansen A.J., Sato M., Ruedy R. *et al.* (2006). Global temperature change. Proceedings of the National Academy of Sciences 103: 14288-14293.

Hartig T., Kaiser F.G., Bowler P.A. (2001). Psychological restoration in nature as a positive motivation for ecological behavior. Environment and Behavior 33: 590-607.

Hubacek K., Baiocchi G., Feng K. *et al.* (2017). Global carbon inequality. Energy, Ecology and Environment 2: 361-369.

Kellstedt P.M., Zahran S., Vedlitz A. (2008). Personal Efficacy, the Information Environment, and Attitudes Toward Global Warming and Climate Change in the United States. Risk Analysis 28: 113-126.

Knight K.W. (2016). Public awareness and perception of climate change: a quantitative cross-national study, Environmental Sociology 2: 101-113.

Krosnick J.A., Holbrook A.L., Lowe L. *et al.* (2006). The origins and consequences of democratic citizens' policy agendas: A study of popular concern about global warming. Climatic Change 77: 7-43.

Lee T.M., Markowitz E.M., Howe P.D. *et al.* (2015). Predictors of public climate change awareness and risk

perception around the world. Nature Climate Change 5: 1014-1020.
Leiserowitz A. (2006). Climate change risk perception and policy preferences: the role of affect, imagery, and values. Climatic Change 77: 45-72.
Neukom R., Steiger N., Gómez-Navarro J.J. *et al.* (2019). No evidence for globally coherent warm and cold periods over the preindustrial Common Era. Nature: 571(7766): 550-554.
Oxfam Media Briefing (2015). Extreme carbon inequality, report Oxfam of 2 December 2015.
Solomon S., Qin D., Manning M. *et al.* (2007). Technical summary. In: Solomon S., Qin D., Manning M. (eds) (2007). Climate change 2007: the physical science basis. Contribution of WG I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
Stevenson K.T., Peterson M.N., Bondell H.D. *et al.* (2014). Overcoming Skepticism with Education: Interacting Influences of Worldview and Climate Change Knowledge on Perceived Climate Change Risk Among Adolescents. Climatic Change 126: 293-304.
TUI Foundation (2019). Tui Stiftung poll, May 2019. TUI Group. Retrieved from *https://www.tuigroup.com/en-en/media/press-releases/2019/2019-05-03-tui-foundation-youth-study*.
Zajonc R.B. (1980). Feeling and thinking: Preferences need no inferences. American Psychologist 35: 151-175.

Impact of climate change on pollen allergy and respiratory health in children

MARIA ELISA DI CICCO[1*], MARIA GIOVANNA MARCHI[2], SOFIA D'ELIOS[1], PASQUALE COMBERIATI[1], DIEGO PERONI[1]
[1]Sezione di Allergologia Pediatrica, U.O. di Pediatria, Azienda Ospedaliero-Universitaria Pisana, Via Roma, 67 - 56126 Pisa
[2]Agenzia Regionale per la Protezione Ambientale della Toscana (ARPAT), Via N. Porpora, 22 - 50144 Firenze

Keywords: asthma, allergic rhinitis, children, risk for exacerbations

ABSTRACT. – Global warming and climate change are unequivocal events caused mainly by the increasing atmospheric concentrations of air pollutants and greenhouse gases, such as carbon dioxide, related to human industrial growth. Their effects have been described as the biggest global health threat of the 21st century: as far as pollen allergy, global warming has a big impact on plants life-cycle with earlier and longer pollen season as well as higher pollen production, putting adults and children affected by respiratory allergic disease, such as asthma and allergic rhinitis, at risk for exacerbations. Extreme weather events may play a role too, with thunderstorms causing a higher respirable allergen loads in the air and floods favoring indoor and outdoor growth of moulds. In collaboration with ARPAT we are going to collect data on pollen seasons since 2013 in Lido di Camaiore, near Pisa, and correlate them with clinical data from pollen allergic children in follow up at our Pediatric Department, especially in terms of exacerbations and symptoms control. Our pilot study on airborne pollen trends will shed light on ongoing pollen changes in our area as well as their possible correlations with clinical outcomes in children with asthma and/or allergic rhinitis.

CLIMATE CHANGE: IMPACT ON POLLEN. – The 1st August 2019 U.N. Secretary-General António Guterres announced that July 2019 was the hottest month ever recorded on Earth (United Nations Press encounters Archives, 2019): it is well known that global earth temperature is rising since the start of the industrial era due to the continuously increasing atmospheric concentrations of air pollutants and greenhouse gases, such as carbon dioxide. This phenomenon occurred more significantly

*Corresponding author: maria.dicicco@unipi.it

in the last 50 years, as a consequence of the exponential human industrial growth. Global warming is already causing enormous effects on precipitation and weather, with more and more prolonged heat waves, floods, droughts, thunderstorms and other weather extreme events, which, in the future, will put food and water supplies at risk. Therefore, climate change put human health at great risk, to the point that it has been described as "the biggest global health threat of the 21st century" (Costello *et al.* 2009) and *The New England Journal of Medicine* has recently launched a new page focused on the effects of climate change on physical and psychological health and on the function of health care systems, entitled *Climate Crisis and Health*. Climate change has also a great impact on plants life-cycle, which can be studied analyzing pollen production, since flowering is greatly influenced by temperature. As a matter of fact, higher temperatures favor a rapid growth of many plants, increase pollen production and the amount of allergenic proteins contained in pollen (Table 1) (Katelaris & Beggs 2018). In particular, plants that flower in spring and early summer are highly dependent on temperature, while plants that flower in late summer and fall are more dependent to light: consequently, plants flowering in spring and early summer will have earlier flowering in occasion of warmer winters and springs, with longer pollination period (Levetin & Van de Water 2008). Moreover, CO_2 is the sole supplier of carbon for photosynthesis and act as fuel to plants, which respond to higher concentrations with increased growth and pollen production (Wayne *et al.* 2002; Ziska 2008).

It has already been described that changes in phenology (*i.e.,* seasonal plant and animal activity driven by environmental factors) are already occurring in Europe, with spring events such as leaf unfolding advanced by 6 days, whereas autumn events, such as leaf colouring, have been delayed by 4.8 days, with the highest rate of phenological changes being observed in Western Europe and Baltic regions (Menzel & Fabian 1999). There are also evidences related to change in flowering, for example a recent study demonstrated an anticipated flowering of grasses in Perugia (Central Italy), which seems to be linked with the increase of the air temperature in March and April recorded in recent decades (Sofia *et al.* 2017). Due to the earlier onset, the pollen seasons are also more often interrupted by adverse weather conditions in late winter/early spring (D'Amato *et al.* 2015). Finally, the increased temperatures will lead to the spread of many plant species to areas where they were previously rare (D'Amato *et al.* 2007a).

Effects of pollen changes on respiratory health. – There are still limited data on the effects of climate change on respiratory allergy, especially in children. However, in 2009 the ERS released a position statement on climate-related health impacts, warning on the upcoming risks for people affected by respiratory diseases. Extreme temperature events (both hot and cold), higher concentrations of pollutants and ozone, floodings, change in allergen distribution and concentrations of allergens and spread of infectious disease vectors, will worsen the respiratory conditions of this patients, and are likely to increase the incidence and prevalence of respiratory diseases (Ayres *et al.* 2009; D'Amato *et al.* 2013). In particular, it has been described that heat waves can increase mortality among respiratory patients: for each degree Celsius rise in temperature, the risk of premature death among respiratory patients is up to 6 time higher than in the rest of the population (Kovats, Hajat 2008). As far as pollen allergy, in Europe, its prevalence in the general population is estimated at 40% (D'Amato *et al.* 2007): accordingly, a huge number of people affected by asthma and/or allergic rhinitis will potentially be hit by the effects of climate change (D'Amato *et al.* 2016). Asthma is one of the most common chronic disease worldwide, affecting more than 300 million people with a continuously increasing prevalence (GINA, 2019). Asthma is also the main chronic disease of childhood, affecting 10% of children in the Western countries, and 5-20% of children in school age in Europe (Anderson *et al.* 2008). Moreover, World Health Organization (WHO) estimates that 400 million people in the world suffer from allergic rhinitis (Bousquet & Khaltaev 2007).

Many studies have shown the role of pollen exposure in causation of allergic respiratory exacerbation, analyzing the correlation between patterns of sensitization to various pollen allergens, local pollen counts and asthma exacerbations, as registered by hospital attendances or admissions (Erbas *et al.* 2012), also in children (Schmier & Ebi 2009). Any future increase in allergen loads, due to earlier and longer pollen seasons and higher pollen production, is expected to cause more exacerbations both for asthma and allergic rhinitis (Cecchi *et al.* 2010). Not only the increase of pollen counts will be important, but also the interactions of pollen with pollutants (D'Amato *et al.* 2007a, 2015): air pollution can by itself cause airway inflammation and be a trigger for respiratory exacerbations, but it can also interact with pollen grains, leading to an increased release of antigens characterized by modified allergenicity (D'Amato *et al.* 2007a).

Climate change is causing an increase in thunderstorms, which are known to be dangerous events for asthmatics allergic to pollen and fungi, as demonstrated by the November 2016 Melbourne thunderstorm asthma event (Rangamuwa *et al.* 2017). In fact, when a thunderstorm breaks out in the pollen season, during the first 20-30 minutes there is evidence of high respirable allergen loadings in the air because after hydration and rupture by osmotic shock during the beginning of a thunderstorm, pollen grains may release in atmosphere part of their cytoplasmic content, including inhalable, allergen-carrying paucimicronic particles (D'Amato *et al.* 2007b). Moreover, extreme weather events and recurrent floods lead also to indoor and outdoor proliferation of moulds, which can worsen respiratory diseases even in those who are not allergic (Katelaris & Beggs 2018).

ONGOING RESEARCH ON CLIMATE CHANGE AND RESPIRATORY HEALTH IN CHILDHOOD. – Knowing the effects of climate change in pollen allergy is of extreme importance to correctly manage allergic patients. First of all, every allergologist and pediatric allergologist should evaluate the sensitization to pollens which were previously uncommon in their area. Secondly, the pharmacological treatment as well as the allergen immunotherapy in asthma and allergic rhinitis patients should be based also on the analysis of the local exposure to pollens and their higher peak. Finally, physicians should warn their patients and their parents on the risk related to extreme weather events.

However, in order to study the real impact of climate change on pollen allergy and to look for prevention strategies and prediction of peak exposures, longitudinal studies are needed (Katelaris & Beggs 2018). Some evidences are already available on health effects of changes in trends in airborne pollen and fungal spore counts: for example, data from three decades in Wester Liguria, Italy, demonstrate that there has been an increase in the duration of the pollen season for parietaria, olive and cypress with an increase in the percentages of patients sensitized to those allergens over these years, whereas sensitization rates to the house dust mite remained stable (Ariano *et al.* 2010).

In Tuscany pollen counts are collected daily by the Regional Agency for the Protection of the Environment (ARPAT), which is a public agency established in 1996 by a national law (*http://www.arpat.toscana.it*). ARPAT aerobiology department is aimed at collecting data from four pollen monitoring stations in Tuscany, respectively in Florence, Arezzo, Grosseto and Lido di Camaiore: each station is equipped with a seven-day Lanzoni VPPS 2000 spore trap (a Hirst volumetric sampler). Lido di Camaiore station (34 m a.s.l.; 43° 54’ 00’’ N; 10° 13’ 00’’ E) is the closest pollen monitoring station to Pisa and that’s why we choose it as the source of data for our research: we are collecting data from ARPAT database from 2011 to today to analyze if changes in pollen counts and duration of pollen seasons are already detectable in our district. In particular, we are collecting data to describe the pollination period for the more common pollen of our area, in terms of start, end, duration, peak day and annual pollen index (API, which is the total amount of one pollen type in one year and it is given by the sum of the daily mean concentration). This information will be analyzed with regional temperature monitoring as well as clinical data. In fact, during the next pollen season (starting from January 2020) we will collect data on asthma and allergic rhinitis control on pediatric patients currently on follow up in our Section of Pediatric Allergology (Pediatrics Department, University Hospital of Pisa). Our patients will undergo a deep clinical evaluation, skin prick testing and lung function testing; specific disease control questionnaires will also be provided.

CONCLUSIONS. – Climate change is an unequivocal event that has been described as the biggest global health threat of the 21st century. Its impact on plants life-cycle will result in earlier and longer pollen season as well as higher pollen production (Table 1), putting patients affected by respiratory allergic disease at risk for exacerbations and children will be the more exposed and susceptible population. Our pilot study on airborne pollen trends in Tuscany will shed light on ongoing pollen changes as well as their possible correlations with clinical outcomes in children with asthma and / or allergic rhinitis.

ACKNOWLEDGEMENTS. – The Authors want to thank ARPAT staff for their support in collecting pollen counts data.

REFERENCES

Anderson H.R., Gupta R., Kapetanakis V. *et al.* (2008). *International correlations between indicators of prevalence, hospital admissions and mortality for asthma in children*. International Journal of Epidemiology 37: 573-582.

Ariano R., Canonica G.W., Passalacqua G. (2010). *Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years.* Annals of Allergy, Asthma & Immunology 104: 215-222.

ARPAT (Agenzia Regionale per la Protezione Ambientale della Toscana) website: *http://www.arpat.toscana.it*.

Ayres J.G., Forsberg B., Annesi-Maesano I. *et al.* (2009). *Climate change and respiratory disease: European Respiratory Society position statement.* European Respiratory Journal. 34: 295-302.

Bousquet J., Khaltaev N. (2007). *Global Surveillance, Prevention and Control of Chronic Respiratory Diseases: A Comprehensive Approach*. World Health Organization, Geneva, Switzerland, pp. 155.

Cecchi L., D'Amato G., Ayres J.G. *et al.* (2010). *Projections of the effects of climate change on allergic asthma the contribution of aerobiology*. Allergy 65: 1073-1081.

Costello A., Abbas M., Allen A. *et al.* (2009). *Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission*. Lancet 373: 1693-1733.

D'Amato G., Cecchi L., Bonini S. *et al.* (2007). *Allergenic pollen and pollen allergy in Europe*. Allergy 62: 976-990.

D'Amato G., Liccardi G., Frenguelli G. (2007). *Thunderstorm-asthma and pollen allergy.* Allergy 62: 11-16.

D'Amato G., Baena-Cagnani C.E., Cecchi L. *et al.* (2013). *Climate change, air pollution and extreme events leading to increasing prevalence of allergic respiratory diseases*. Multidisciplinary Respiratory Medicine 8: 12.

D'Amato G., Vitale C., De Martino A. *et al.* (2015). *Effects on asthma and respiratory allergy of climate change and air pollution*. Multidisciplinary Respiratory Medicine 10: 39.

D'Amato G., Pawankar R., Vitale C. *et al.* (2016). *Climate Change and Air Pollution: Effects on Respiratory Allergy*. Allergy, Asthma & Immunology Research 8: 391-395.

Erbas B., Akram M., Dharmage S.C. *et al.* (2012). *The role of seasonal grass pollen on childhood asthma emergency department presentations*. Clinical & Experimental Allergy 42: 799-805.

Global Initiative for Asthma (2019). *Global Strategy for Asthma Management and Prevention*, 2019. Available at: *www.ginasthma.org*.

Katelaris C.H., Beggs P.J. (2018). *Climate change: allergens and allergic diseases*. Internal Medicine Journal 48: 129-134.

Kovats R.S., Hajat S. (2008). *Heat stress and public health: a critical review*. Annual Review of Public Health 29: 41-55.

Levetin E., Van de Water P. (2008). *Changing pollen types/concentrations/distribution in the United States: fact or fiction?* Current Allergy and Asthma Reports 8: 418-424.

Menzel A., Fabian P. (1999). *Growing season extended in Europe*. Nature 397: 659.

Rangamuwa K.B., Young A.C., Thien F. (2017). *An epidemic of thunderstorm asthma in Melbourne 2016: asthma, rhinitis, and other previous allergies*. Asia Pacific Allergy 7: 193-198.

Schmier J.K., Ebi K.L. (2009). *The impact of climate change and aeroallergens on children's health*. Allergy & Asthma Proceedings 30: 229-237.

Sofia G., Emma T., Veronica T., Giuseppe F. (2017). *Climate change: consequences on the pollination of grasses in Perugia (Central Italy). A 33-year-long study*. International Journal of Biometeorology 61: 149-158.

United Nations Press encounters Archives, 1st August 2019, available at: *https://www.un.org/sg/en/content/sg/press-encounter/2019-08-01/full-transcript-of-secretary-generals-press-encounter*.

Wayne P., Foster S., Connolly J. *et al.* (2002). *Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia *L.) is increased in CO_2-enriched atmospheres*. Annals of Allergy, Asthma & Immunology 88: 279-282.

Ziska L.H. (2008). *Rising atmospheric carbon dioxide and plant biology: the overlooked paradigm*. DNA and Cell Biology 27: 165-172.

TABLE 1. – *Effects of climate change on plants and pollen.*
Increased plant growth
Diffusion of plants species in different areas
Increase in the pollen production for each plant
Increased allergenicity of the pollen (higher allergenic protein load)
Earlier pollen season start; possible interruption of the season due to extreme weather events
Longer pollen seasons

Water heating and new bacteria: emerging infections in health-care facilities

MICHELE TOTARO, BEATRICE CASINI, COSTANZA BISORDI, TOMMASO MARIOTTI, LORENZO FRENDO, PAOLA VALENTINI, GAETANO PRIVITERA, ANGELO BAGGIANI*
Department of Translational Research and New Technologies in Medicine and Surgery, University of Pisa. Via San Zeno 37 - 56123 Pisa, Italy

Keywords: Legionella, Nontuberculous Mycobacteria, hot water

ABSTRACT. – Literature data assert that climatic conditions are changing, and physical-chemical factor may influence the proliferation of waterborne pathogens in drinking waters. Aim of study is the evaluation of water temperature influencing the opportunistic pathogens growth in hospital water networks. Between 2010 and 2018 in an Italian hospital hot water networks treated with monochlorammine, *Legionella* spp. and Nontuberculous Mycobateria (NTM) were researched and temperature values were measured during the sampling procedure. Temperature lowering has been observed during Legionella colonization in hot water networks, while NTM were detected after the temperature increase. We observed moderate correlations between the presence of waterborne pathogens (*Legionella* spp. and NTM) and the water increase/decrease. In conclusion, temperature changing is a risk factor for the occurrences of waterborne pathogens proliferation in water networks, and we highlight the need of microbiological tests aimed to ensure the water safety for patients.

INTRODUCTION. – Several studies assert that climatic conditions are changing, and this appears to be altering drinking water quality with potential public health implications (Delpla *et al.* 2016; Valdivia-Garcia *et al.* 2019). In fact, some factors, as the water treatment processes, geographical location, pipeline material, water type, operational conditions, and water physical-chemical quality shape the microbial communities in drinking water distribution systems (Dai *et al.* 2018; Inkinen *et al.* 2019).

Hot water plumbings are critical nexus of energy, water, and public health. Water heating represents a large energy demand in worldwide buildings (Keinath and Garimella, 2017) and a prominent health concern due to the proliferation of opportunistic pathogens, such as *Legionella*

*Corresponding author: angelo.baggiani@med.unipi.it

pneumophila and *Nontuberculous Mycobateria*, *Pseudomonas aeruginosa*, etc. These bacteria tend to be detected at greater frequencies in hot water systems than in cold water (Edberg and Allen 2004; Dai *et al.* 2017).

Only few studies has been performed to understand how operational conditions, such as water heater temperature setting may influence tap water microbes. An improved understanding of factors shaping hot water microbiomes could lead to improved management strategies for water and energy sustainability, water quality, and public health.

Temperature setting is an overarching factor driving changes in microbial community composition (Bedard *et al.* 2015; Rhoads *et al.* 2015; Ji *et al.* 2017). Higher temperature (>55°C) are effective for microorganism control (Bedard *et al.* 2015), but warm temperatures (32– 41°C) can stimulate growth of some waterborne pathogens (Proctor *et al.* 2017).

Considering these literature data, aim of study is the evaluation of water temperature influencing the opportunistic pathogens growth in a hospital water network.

MATERIAL AND METHODS. – Between 2010 and 2018, in the building housing the Emergency Department (ED) of the Azienda Ospedaliero-Universitaria Pisana (AOUP), a 1077-bed teaching hospital, six points for tap water sampling were selected as distal and proximal sites from the continuous producing and dispensing monochloramine device. Hot water samplings were performed with a total of 228 one-liter water samples collected within the water networks to detect the presence of *Legionella* spp. and Nontuberculous Mycobacteria (NTM).

Before the opening of the ED, a hyper-chloramination shock with 4 mgl/L of monochloramine for 4 hours and a super-flushing were performed to disinfect all the water system. Subsequently the dosage was regulated to obtain a continuous chloramination of about 2 mg/L. Over the course of the investigation, the average distal site monochloramine concentration was 1.93 (±1.04) mg/L.

Hot water temperature values were detected during the sampling procedures.

The isolation of *Legionella* spp. in hot water samples was performed as suggested by the international standards procedure ISO11731:1998 (updated to 2017), and described elsewhere (Casini *et al.* 2017).

The isolation of NTM in hot water samples was performed as suggested by scientific protocols (Telenti *et al.* 1993; Falkinham *et al.* 2001), and applied elsewhere (Totaro *et al.* 2018).

Statistical correlation tests were performed and Pearson's coefficients were calculated with the aim of analysing the correlations between temperature values and Legionella and NTM counts. Therefore, we considered the following ranges of values: 0-0.3 (weak correlation); 0.3-0.7 (moderate correlation); 0.7-1 (strong correlation). The statistical analysis was carried out using the SPSS software package, version 17.0.1.

RESULTS. – In the Emergency Department (ED) at the initial monitoring phase before the start of the monochloramine disinfection, all six sites resulted positive for *Legionella pneumophila* sg 1 ST269 with a mean count of $7.2x10^4$ (± $5.3x10^3$) CFU/L. No sample resulted positive after treatment as long as the concentration of MC remained at 2 mg/L. However the ST269 strain was cultured in further instances (May 2011; October and November 2012; July 2013; July 2014) as a consequence of a failure of the monochloramine generator device, during which the release of disinfectant was interrupted for around 24 hours. In these occasions Legionella was isolated in all six sites with a mean counts of $8.8x10^4$ (± $3.5x10^4$) CFU/L (**Figure 1**). During the whole period of study, a mean temperature value of 42 ± 3.2°C was detected. Temperature lowering has been observed during Legionella colonization in hot water networks. In fact, we observed a moderate correlations between the increase of Legionella counts and the decrease of temperature values (r= - 0.49). NTM cells were not isolated before the water chemical disinfection. From March 2011, following the increase of hot water temperature, NTM were detected. During the period between 2011 and 2018, a NTM mean count of $1.4x10^3$ (± $5x10^2$) UFC/L was detected (**Figure 2**). We observed a moderate correlations between the increase of NTM counts and the increase of temperature values (r= - 0.43).

DISCUSSION. – Drinking water quality is a requirement aimed at ensuring the water safety for exposed people and the European Directive 98/83/EC represent the only legislative tool which requires the assessment and the management of water risk (The Council of the European Union, 1998). This document mention the possible microbiological hazards present in water supplies, pipes, boilers, ect., ensuring a tight control of water for consumers. Despite microbiological parameters, such as the *E.coli* and fecal streptococci, are considered for routine tests, no detailed mention is reported for further microbiological hazards as Legionella, NTM, and other environmental opportunistic human and animal pathogens, which may colonize hot and cold waters (Lavania *et al.* 2014; Totaro *et al.* 2017). The growth of these microorganisms could be due to some changes linked to water physical-chemical parameters as the temperature (Totaro *et al.* 2018).

In this study we evaluated the correlation between the presence of waterborne pathogens (*Legionella* spp. and NTM) and the water increase/decrease. As described in literature, *Legionella* spp. is a waterborne pathogen frequently associated with nosocomial infections. Large and ancient hospital water networks, high volume hot water storage tanks and a temperature range of 20-45°C provide optimal conditions for Legionella colonization (Italian National Institute of Health 2015). On the other hand, NTM may growth in water pipelines, also in hot water networks (higher than 45°C) (Whiley *et al.* 2014; Whiley *et al.* 2019).

In conclusion, temperature changing is an important risk factor for the occurrences of waterborne pathogens proliferation in hot and cold water networks. For this reason we highlight the need of routine microbiological tests aimed to ensure the water safety, mostly for hospitalized high risk people, such as immuno-suppressed patients. Therefore, to avoid the occurrence of biological risk factors a wider assessment of microbial indicators presence is recommended.

REFERENCES

Bédard E., Fey S., Charron D., Lalancette C. *et al.* (2015). Temperature diagnostic to identify high risk areas and optimize Legionella pneumophila surveillance in hot water distribution systems. *Water Research* 71: 244-256.

Casini B., Baggiani A., Totaro M. *et al.* (2018). Detection of viable but non-culturable legionella in hospital water network following monochloramine disinfection. *The Journal of Hospital Infection* 98: 46-52.

Dai D., Raskin L., Xi C. (2017). The effect of interactions between a bacterial strain isolated from drinking water and a pathogen surrogate on biofilms formation diverged under static vs flow conditions. *Journal of Applied Microbiology* 123: 1614-1627.

Dai D., Rhoads W.J., Edwards M.A., Pruden A. (2018). Shotgun Metagenomics Reveals Taxonomic and Functional Shifts in Hot Water Microbiome Due to Temperature Setting and Stagnation. *Frontiers in Microbiology* 9: 2695.

Delpla I., Jung, A.V., Baures E. *et al.* (2016). Impacts of climate change on surface water quality in relation to drinking water production. *Environment International* 35: 1225-1233.

Edberg S.C., Allen M.J. (2004). Virulence and risk from drinking water of heterotrophic plate count bacteria in human population groups. *International Journal of Food Microbiology* 92: 255-263.

Falkinham J.O., Norton C.D., LeChevallier M.W. (2001). Factors influencing numbers of *Mycobacterium avium*, *Mycobacterium intracellulare*, and other *Mycobacteria* in drinking water distribution systems. *Applied Environmental Microbiology* 67: 1225-1231.

Inkinen J., Jayaprakash B., Siponen S. *et al.* (2019). Active eukaryotes in drinking water distribution systems of ground and surface waterworks. *Microbiome* 7: 99.

International Organization for Standardization (2017). *ISO 11731 Water Quality-Detection and Enumeration of Legionella*; IOS, Geneva, pp. 1-38.
Ji P., Rhoads W.J., Edwards M.A., Pruden A. (2017). Impact of water heater temperature setting and water use frequency on the building plumbing microbiome. *The ISME Journal* 11: 1318-1330.
Keinath C.M., Garimella S. (2017). An energy and cost comparison of residential water heating technologies. *Energy* 128: 626-633.
Lavania M., Turankar R., Singh I. *et al.* (2014). Detection of *Mycobacterium gilvum* first time from the bathing water of leprosy patient from Purulia, West Bengal. *International Journal of Mycobacteriology* 3: 286-289.
Proctor C.R., Dai D., Edwards M.A. *et al.* (2017). Interactive effects of temperature, organic carbon, and pipe material on microbiota composition and *Legionella pneumophila* in hot water plumbing systems. *Microbiome* 5: 130.
Rhoads W.J., Ji P., Pruden A. *et al.* (2015). Water heater temperature set point and water use patterns influence *Legionella pneumophila* and associated microorganisms at the tap. *Microbiome* 3: 67.
Telenti A., Marchesi F., Balz M. *et al.* (1993). Rapid identification of mycobacteria to the species level by polymerase chain reaction and restriction enzyme analysis. *Journal of Clinical Microbiology* 31: 175-178.
The Council of the European Union 1998. *Council Directive 98/83/EC of 3 November 1998 on the Quality of Water. Intended for Human Consumption*. The Council of the European Union: Bruxelles, pp. 1-23.
Totaro M., Casini B., Valentini P. *et al.* (2018). Assessing natural mineral water microbiology quality in the absence of cultivable pathogen bacteria. *Journal of Water and Health* 16: 425-434.
Totaro M., Valentini P., Costa A.L. *et al.* (2018). Rate of *Legionella pneumophila* colonization in hospital hot water network after time flow taps installation. *The Journal of Hospital Infection* 98: 60-63.
Valdivia-Garcia M., Weir P., Graham D.W. *et al.* (2019). Predicted Impact of Climate Change on Trihalomethanes Formation in Drinking Water Treatment. *Scientific Report* 9: 9967.
Whiley H., Hinds J., Xi J. *et al.* (2019). Real-Time Continuous Surveillance of Temperature and Flow Events Presents a Novel Monitoring Approach for Hospital and Healthcare Water Distribution Systems. *International Journal of Environmental Research and Public Health* 16(8). pii: E1332.
Whiley H., Keegan A., Fallowfield H. *et al.* (2014). Detection of *Legionella*, *L. pneumophila* and *Mycobacterium avium* complex (MAC) along potable water distribution pipelines. *International Journal of Environmental Research and Public Health* 11: 7393-7405.

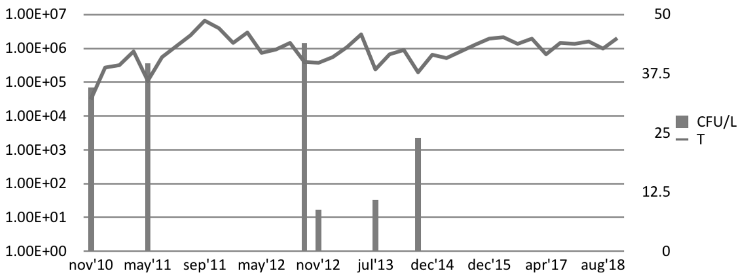


Fig. 1. Mean loads of Legionella (CFU/L) at different temperature values measured in the hospital hot water network.

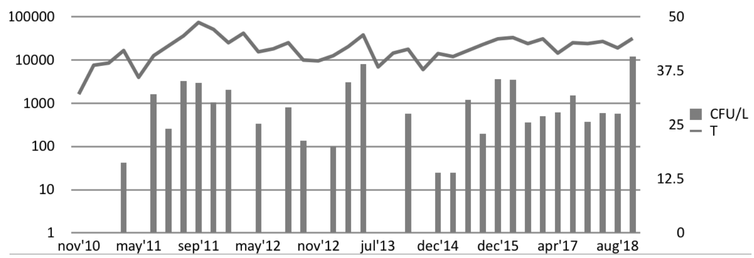


Fig. 2. Mean loads of NTM (CFU/L) at different temperature values measured in the hospital hot water network.

May climate change allow the spread of the Asian tiger mosquito, vector of viruses, in Central Europe?

STEFANO BEDINI, PRISCILLA FARINA, BARBARA CONTI*
Department of Agriculture, Food and Environment, University of Pisa

Keywords: Aedes albopictus, climatic change, photoperiod, temperature, virus vector

ABSTRACT. – *Aedes albopictus*, also known as the Asian tiger mosquito, is a native species of tropical and subtropical areas of Southeast Asia, recently spread also to Europe. *Ae. albopictus* represents a serious threat for human health because it is an important vector of many viruses. The geographical distribution of the mosquito's populations is limited by cold climate. However, according to projections, due to the climate change the species could spread in many regions where it is now not established. The key factor that allows *Ae. albopictus* to colonize new territories in higher latitudes may be the production of cold-tolerant diapausing eggs. The aim of this study is to determine the parameters for the production of diapausing eggs by *Ae. albopictus* and for the eggs hatching. According to our data, the diapausing eggs are induced by a 11 hours of light and 13 of dark photoperiod that, in central Italy, is reached during the middle of October. Thank to this mechanism, the mosquito can avoid the exposition to low temperature of the most susceptible stage of development, the first instar larva, that cannot survive under 10°C. The results are discussed in relation to the scenario of the global warming.

INTRODUCTION. – *Aedes albopictus* (Skuse, 1894) (*Diptera Culicidae*), also known as the Asian tiger mosquito, is a native species of tropical and subtropical areas of Southeast Asia (Caminade *et al.* 2012). In the past few decades, this species has spread to many areas of North, Central and South America, Africa, Australasia and Europe (Gubler 2003). *Ae. albopictus* represents a serious threat for human health because its typical daytime flight and blood-feeding and because it is a vector of many pathogens, including the yellow fever, Dengue, Zika and Chikungunya viruses (Hochedez *et al.* 2006; Bedini *et al.* 2018). In the only first six months of 2019, in Italy, 46 cases of Dengue, 11 cases

*Corresponding author: barbara.conti@unipi.it

of Chikungunya and two of Zika, have been reported (Italian National Institute of Health 2019).

Due to its climatic suitability, the range of *Ae. albopictus*' populations is limited by cold climate and to date, in Europe, it is well established only in the southern regions (Medlock *et al.* 2012). However, projections by modelling methodologies indicate that due to the climate change, in the near future, the species will spread in many regions where it is not established yet. Regions currently characterized by a rather low or moderate suitability have the potential for invasion by mid-century, due to the raise of temperature caused by the global warming. In particular, according to studies at the continental scale, it can be inferred that, within the next fifty years, suitable climatic conditions will be achieved in western Europe (Belgium, France, Luxembourg and the Netherlands), central Europe (Germany) and southern United Kingdom. Furthermore, the climatic projections indicate that, while suitability for *Ae. albopictus* will continue to be high in southern France and most of Italy, it will decrease in the western Mediterranean coast of Spain, as a consequence of the increased dry conditions during Summer (Caminade *et al.* 2012).

According to several studies, the key factor that allows *Ae. albopictus* to colonize new territories and to establish in higher latitudes (Mitchell 1995) is the production of cold and dry-tolerant diapausing eggs (Toma *et al.* 2003).

The aim of this study is to determine the parameters for the production of diapausing eggs by *Ae. albopictus* and those for the eggs hatching. The results are discussed in relation to the scenario of the global warming expected by climate changes previsions.

MATERIALS AND METHODS. – To collect the eggs of *Ae. albopictus*, 20 plastic black pots were put in a garden (about 3000 m^2) of the entomology laboratory at the Department of Agriculture, Food and Environment, University of Pisa (Italy). The experiments were conducted from May 2017 to March 2018. To allow the wild females to lay the eggs, four Masonite sticks were put in each pot. The Masonite sticks with the eggs on the surface were then collected and kept under laboratory conditions (natural photoperiod, 23.0 ± 2.0°C).

DURATION OF PREIMAGINAL STAGES. – For the first experiment, conducted in June, 10 sticks of Masonite with 10-20 eggs/stick (0-24 h) collected as above reported were kept in laboratory conditions (natural photoperiod, 23.0 ± 2.0°C) in 50 mL glass tubes each, at the surface of the water, to allow the eggs' hatching. Each of the newly emerged larvae was then transferred in a 50 mL glass tube with water and a small amount of cat food. The hatching of the eggs and the different preimaginal stages' moults were recorded to evaluate the duration of the different instars and the duration of the complete ontogenetic cycle.

Influence of photoperiod on the production of diapausing eggs. – For the second experiment, Masonite sticks with the eggs were collected in alternate days from June to October and kept singularly in laboratory in 50 mL glass tubes, at the surface of the water, until hatching. The exact time of hatching and the number of larvae obtained were recorded.

Influence of photoperiod on the hatchability of eggs. – For the last experiment, Masonite sticks with the eggs were collected in alternate days from June to October and kept in laboratory for 150 days in dry conditions (R.H. ≅ 60%). After the dry period, the Masonite sticks were submerged in water allowing the hatching and the number of the newly emerged larvae was recorded.

Results and Discussion. – The embryonic duration of the non-diapausing eggs and the duration of the preimaginal instars of *Aedes albopictus*, under laboratory conditions, is shown in Tab. 1. The embryonic development required about 6 days. We observed four larval stages for a total of about seven days of growth. Pupation took place in about four days after the fourth instar. The complete cycle, therefore, lasted about sixteen days. The observed times of development are in line with the ones reported by Delatte *et al.* (2009) who obtained, in controlled conditions, an optimum intrinsic rate of larval growth of *Ae. albopictus* between 25 and 30°C, with the shortest period for immature development at 30°C, corresponding to 8.8 days. In line with our results, Delatte *et al.* (2009) reported, a duration of the complete life cycle of *Ae. albopictus* of 10.4 ± 0.7 days. The longer time of full development observed in this experiment, comparing with the one of Delatte *et al.* (2009), should be due to the different temperature at which the two experiments have been conducted (25 *vs* 23°C).

The hatching percentage of our eggs, let in the water, showed a large variability with significant differences in relation to the month of oviposition ($F = 61.177$; df = 4; $P < 0.001$). The percentage of hatching, if the eggs are maintained in water after the oviposition, varied from 84% in June to 3% in October (Tab. 2). In particular, eggs laid in June showed the highest percentage of hatching, while those laid in October the lowest one (Tab. 2). These differences indicate that summer eggs are not diapausing, while the very low percentage of hatching of the ones laid in October suggests that those are diapausing eggs. Such observation was confirmed by the behaviour of the overwintering eggs. After 150 days, significant differences were observed in the hatching of the eggs ($F = 61.918$; df = 3; $P < 0.001$). In fact, the percentages of eggs' hatching varied from to 15 to 76% for the eggs laid, respectively, in July and October. In particular, the post-hoc test showed that the eggs laid in October had a significant higher percentage of hatching than the ones laid during Summer (Tab. 3).

The production of diapausing eggs has been reported as one of the main adaptations of *Ae. albopictus* responsible for the huge spread of the species, because it allows overwintering in temperate regions (Hawley 1988). According to our data, the production of diapausing eggs is induced by a photoperiod of 11 hours of light and 13 hours of dark that, in central Italy, is reached during the middle of October. By the production of diapausing eggs, the mosquito can avoid the exposition to the winter low temperatures of the most susceptible stage of development, represented by the first instar (Delatte *et al.* 2009). In fact, temperature is one of the main determinants of the *Ae. albopictus* mosquitoes' survival that limits their geographical distribution, together with photoperiod (Brady *et al.* 2013). The minimal threshold for first instar was found at 10.4°C (Delatte *et al.* 2009). In our laboratory, diapausing eggs (laid in October) start hatching 125 days after the oviposition, so at the end of February, when the photoperiod in central Italy corresponds to 10 hours of light and 14 hours of dark.

In Europe, current temperatures allowed the species to settle in the southern coast of Spain, France, Greece and in the whole countries of Italy, Slovenia, Croatia, Albania and Montenegro. Global warming, despite the effort of reducing the raise of temperature to maximum 2°C by many industrial country governments during the summit of Paris 2015 (King and Karoly 2017; Dosio and Fischer 2018), will enable the species to establish in countries where, at the moment, it is not able to survive because of the cold climate. In most of Switzerland, Belgium, Luxembourg, Netherlands, Czech Republic, South United Kingdom and Central France and Germany, the photoperiod suitable for the hatching is reached when the temperatures are too low. However, the raising of few degrees will be enough for allowing *Ae. albopictus*' development and spread. For example, a photoperiod of 10 hours light and 14 hours dark is reached in Brussels in mid-February, where the daily medium temperature is 9°C. Depending of the level of greenhouse gasses emission, by the end of the century (2071-2100), the temperature over Europe is expected to increase between 0.3-1.7°C for the lowest emissions scenario (lowest Representative Concentration Pathway, RCP 2.6) and between 2.6-4.8°C for the highest emissions scenario (RCP 8.5) (IPCC 2013). According to this data, in fifty years the medium temperature in Brussels could reach the minimal threshold of 10.4°C, required by the species for its development.

Since *Ae. albopictus* is the primary vector of many pathogenic viruses, its spread as a consequence of global warming may represent a serious health threat for humans. The increasingly tourism from and to countries in which the viruses are endemic and the increasing migration of people in Europe will provide the reservoir for diseases that may be spread by *Ae. albopictus* to the South and Central European countries. In this scenario, surveillance and control are essential for limiting the density and geographical spread of these mosquitoes, to minimize the risk of a viraemic person coming in contact with them and the outbreak of serious infective diseases.

REFERENCES

Bedini S., Flamini G., Ascrizzi R. *et al.* (2018). Essential oils sensory quality and their bioactivity against the mosquito *Aedes albopictus*. Scientific Reports 8: 17857.

Brady O.J., Johansson M.A., Guerra C.A. *et al.* (2013). Modelling adult *Aedes aegypti* and *Aedes albopictus* survival at different temperatures in laboratory and field settings. Parasites & Vectors 6: 351.

Caminade C., Medlock J.M., Ducheyne E. *et al.* (2012). Suitability of European climate for the Asian tiger mosquito *Aedes albopictus*: recent trends and future scenarios. Journal of the Royal Society Interface 9: 2708-2717.

Delatte G., Gimonneau G., Triboire A. *et al.* (2009). Influence of temperature on immature development, survival, longevity, fecundity, and gonotrophic cycles of *Aedes albopictus*, vector of chikungunya and dengue in the Indian Ocean. Journal of Medical Entomology 46: 33-41.

Dosio A., Fischer E.M. (2018). Will half a degree make a difference? Robust projections of indices of mean and extreme climate in Europe under 1.5°C, 2°C, and 3°C global warming. Geophysical Research Letter 45: 935-944.

Gubler D.J. (2003). *Aedes albopictus* in Africa. The Lancet Infectious Diseases 3: 751-752.

Hawley W.A. (1988). The biology of *Aedes albopictus*. Journal of the American Mosquito Control Association 4: 2-39.

Hochedez P., Jaureguiberry S., Debruyne M. *et al.* (2006). Chikungunya Virus infection in travelers. Emerging Infectious Diseases 12: 1565-1567.

King A.D., Karoly D.J. (2017). Climate extremes in Europe at 1.5 and 2 degrees of global warming. Environmental Research Letters 12: 114031.

Medlock J.M., Hansford K.M., Schaffner F. *et al.* (2012). A review of the invasive mosquitoes in Europe: ecology, public health risks, and control options. Vector Borne and Zoonotic Diseases 12: 435-447.

Mitchell C.J. (1995). Geographic spread of *Aedes albopictus* and potential for involvement in arbovirus cycles in the Mediterranean Basin. Journal of Vector Ecology 20: 44-58.
IPCC, Climate Change (2013). The physical science basis. Contribution of WG I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 1535.
Toma L., Severini F., Di Luca M. *et al.* (2003). Seasonal patterns of oviposition and egg hatching rate of *Aedes albopictus* in Rome. Journal of the American Mosquito Control Association 19: 19-22.
https://ecdc.europa.eu/en/disease-vectors/facts/mosquito-factsheets/aedes-albopictus.
https://www.epicentro.iss.it/arbovirosi/bollettini.

TABLE 1. – *Duration of preimaginal stages of* Aedes albopictus *in controlled conditions.*

Stage	**Hatching**	**L1**	**L2**	**L3**	**L4**	**Pupae**	**Total**
Time[a]	5.6±1.3	1.9±0.7	1.6±0.8	1.6±0.8	2.1±1.0	3.5±1.0	16.3±2.2

[a], days. Data are expressed as mean ± standard error.

TABLE 2. – *Percentage of hatching of* Aedes albopictus *eggs laid at different times in Summer and Autumn.*

Month of spawning	**N. of eggs laid**	**N. of hatched eggs**	**% hatching**
June	179.5±21.0	152.0±18.1	83.7±3.1a
July	314.2±5.3	206.0±10.5	64.7±2.8b
August	286.0±25.5	198.50±37.7	69.8±7.5ab
September	567.0±12.9	335.7±22.3	59.7±2.8b
October	741.7±38.3	24.7±2.7	3.4±0.3c

Data are expressed as mean ± standard error. Values followed by different letters are significantly different by Tukey B test ($P \leq 0.05$).

TABLE 3. – *Percentage of hatching of* Aedes albopictus *eggs laid at different times in Summer and Autumn after dry treatment.*

Month of spawning	**N. of eggs laid**	**N. of hatched eggs**	**% hatching**
July	796.5±76.0	127.5±11.1	15.2±1.5a
August	812.7±66.2	130.7±28.1	16.8±3.2a
September	568.5±23.1	90.2±7.5	15.4±1.1a
October	509.5±45.3	406.2±53.4	75.7±6.5b

Data are expressed as mean ± standard error. Values followed by different letters are significantly different by Tukey B test ($P \leq 0.05$).

Arthropod-borne diseases: spreading of pathogens transmitted by hematophagous arthropods of human and veterinary concern

VALENTINA VIRGINIA EBANI*

Department of Veterinary Sciences, University of Pisa, Viale delle Piagge, 2 - 56124 Pisa

Keywords: ticks, bacterial pathogens, zoonosis, One-Health

ABSTRACT. – Arthropod-borne diseases are caused by several bacterial, viral and protozoal species and transmitted through the bite of hematophagous arthropods, mainly ticks whose spreading is strictly related to the climatic conditions. Most etiologic agents are zoonotic bacteria able to cause mild or severe clinical forms both in animals and humans. Some of these pathogens are well known, such as *Borrelia burgdorferi sensu lato* responsible for the Lyme disease and *Rickettsia conorii*, etiologic agent of the Mediterranean Spotted Fever. However, other arthropod-borne bacteria are circulating in Central Italy: *Anaplasma phagocytophilum, Bartonella henselae* and other *Bartonella* species, *Coxiella burnetii,* and *Ehrlichia canis*. In view of the One-Health concept, a regular monitoring of the spreading of these pathogens is necessary to give information of veterinary and human interest.

INTRODUCTION. – Arthropod-borne diseases are emerging infectious diseases frequently reported worldwide, including Europe. They are caused by bacteria, viruses and protozoa transmitted through the bite of hematophagous arthropods, mainly ticks but also fleas, mosquitoes and lice. Most of these pathogens are bacterial agents able to infect animals and humans, in which can determine illness varying from sub-clinical to severe forms. The spread of the arthropod-borne diseases is obviously related to the distribution of arthropod species that depends on several factors: agricultural and wildlife management, deforestation and climatic conditions. The bacterial arthropod-borne pathogens most frequently detected in our country are discussed below, with particular emphasis to the prevalence observed in domestic and wild animals living in Central Italy.

*valentina.virginia.ebani@unipi.it

Ehrlichia canis. –This is an obligate intracellular Gram-negative bacterial agent belonging to the family *Anaplasmataceae*, order *Rickettsiales*. It mainly parasitizes the cells of the mononuclear phagocyte system and causes the canine monocytic ehrlichiosis (CME) characterized by clinical and hematological abnormalities such as fever, anorexia, vomiting, diarrhea, lymphadenopathy, petechial hemorrhages, bleeding tendency, anemia, and thrombocytopenia. CME after a subclinical or acute form can determine chronic infection that can persist for years.

E. canis is able to cause infection in other canids and cats, too (Sainz *et al.* 2015). Moreover, a role as zoonotic agent has been supposed after the detection of this pathogen in clinical samples of human beings with clinical signs similar to those of CME (Perez *et al.* 2006). *E. canis* is usually transmitted by the brown dog-tick *Rhipicephalus sanguineus*, even though other ticks may be involved in the transmission (Sainz *et al.* 2015).

E. canis is largely spread in the Italian canine population, as demonstrated by reported clinical cases and serological and/or molecular investigations. A 16.18% seroprevalence was detected in dogs from Central Italy during the period 2013-2017 (Ebani 2019a), showing an increased spreading of this pathogen compared with the previous period 2008-2012 when the detected value was 7.07% (Ebani *et al.* 2014). A seroprevalence of 6.42% was found in domestic cats during 2005-2011 (Ebani & Bertelloni 2014). *E. canis* seems to be spread among wild canids in Central Italy, too: a molecular prevalence of 44.44% was detected in red foxes (*Vulpes vulpes*) (Ebani *et al.* 2017b).

Anaplasma phagocytophilum. – It is a Gram-negative bacterium of the family *Anaplasmataceae*, with tropism for granulocytes, mainly neutrophils. It infects dogs, other canids, cats, horses, domestic and wild ruminants, in which can cause diseases ranging from sub-clinical to severe forms (Stuen *et al.* 2013). Furthermore, *A. phagocytophilum* is a zoonotic agent, responsible for the human granulocytic ehrlichiosis (HGE) or anaplasmosis (HGA) characterized by influenza-like symptoms that on rare occasions could have a fatal conclusion. *Ixodes ricinus* ticks are considered the main vectors of *A. phagocytophilum* in Europe. Moreover, vector competence has been proven for other *Ixodes* species in other geographic areas. *A. phagocytophilum* DNA has been detected in *Dermacentor* spp., *Haemaphysalis* spp. and *Amblyomma americanum* that are supposed, but not proven, to be involved in the transmission of this microorganism (Stuen *et al.* 2013).

The presence of *A. phagocytophilum* in Italy has been proven by several serological and molecular surveys in domestic and wild animals. Different prevalence values were detected in relation to the population investigated, the environment where the animals live and the sampling period.

Molecular studies in wildlife in Central Italy found prevalences of 72.41% in roe deer (*Dama dama*) (Ebani *et al.* 2007), 40% in red deer (*Cervus elaphus*) (Ebani *et al.* 2016c), 1% in wild boars (*Sus scrofa*) (Ebani *et al.* 2017a), 16.6% (2007-2008) and 0.65% (2014-2016) in red foxes (*V. vulpes*) (Ebani *et al.* 2011, 2017b), whereas in domestic animal populations found values of 25.62% in horses (Ebani *et al.* 2015b) and 2.5% in hunting dogs (Ebani *et al.* 2015c).

Coxiella burnetii. – It is a Gram-negative bacterium, agent of the zoonosis Q Fever. This infection is usually related to reproductive failure in domestic ruminants, which shed high loads of coxiellae to the environment around the breeding season. Infected animals may excrete the bacteria in feces, too. The main sources of infection for domestic animals and humans are exposure to parturient secretions by inhalation of contaminated aerosols and ingestion of raw milk and fresh dairy products (Berri *et al.* 2002). Human disease can be mild or severe with pneumonia, hepatitis and endocarditis. Furthermore, women who are infected during pregnancy may be at risk for miscarriage, stillbirth, pre-term delivery, or low infant birth weight. However, *C. burnetii* may be transmitted by infected ticks, too and wildlife can contribute to the maintenance of *C. burnetii* in the environment.

Molecular investigations carried out in no-farm animals living in Central Italy found prevalence values of 5.1% in hunting dogs (Ebani *et al.* 2015c), 2.5% in horses (Ebani *et al.* 2015b), 10% in red deer (*C. elaphus*) (Ebani *et al.* 2016c), 1.96% in red foxes (*V. vulpes*) (Ebani *et al.* 2017b). Moreover, *C. burnetii* was found in wild avifauna: 5.95% in feral pigeons (*Columba livia*) (Ebani *et al.* 2016a) and 3% in waterfowl (Ebani *et al.* 2019c).

Spotted Fever group Rickettsia *spp.* – The genus *Rickettsia* comprises obligate intracellular Gram-negative bacteria transmitted by several tick species. Spotted Fever Group (SFG) includes several *Rickettsia* species responsible for disease, often serious, in animals and humans. *Rickettsia conorii* is the etiologic agent of the Mediterranean Spotted Fever (MSF) that represents the most widespread SFG rickettsiosis in the Mediterranean countries including Italy, especially in the Southern and Central regions. In Italy, several SFG rickettsiae are circulating, as mainly demonstrated by molecular investigations on tick populations. In particular, DNA of *R. conorii, R. helvetica*, *R. massiliae*, *R. slovaca*, *R. monacensis*, *R. aeschlimannii*, *R. raoultii*, and *R. africae* have been detected (Ebani 2019b). In Central Italy, clinical human cases of TIBOLA (*tick-borne lymphadenopathy*) or DEBONEL (*dermacentor-borne necrosis-erythema-lymphadenopathy*) caused by *R. slovaca* have been reported, as well as similar clinical cases related to *R. raoultii* (Selmi *et al.* 2009). Serological investigations carried out in dogs and horses found prevalences of 23.87% and 15.03%, respectively (Ebani 2019a,b). *Rickettsia* spp. DNA was detected in 20.78% of ticks collected from wild animals (Ebani *et al.* 2015a) and in 5.95% of pigeons (*C. livia*) from Tuscany (Ebani *et al.* 2016a).

BORRELIA BURGDORFERI SENSU LATO – *B. burgdorferi s.l.* is a spirochetal bacterium which causes the Lyme disease mainly in humans and dogs. Lyme borreliosis is characterized in people by an early set of skin-related and flu-like symptoms and, in the absence of treatment, may be followed by arthritic or neurologic complications.

The canine disease is often mild with non-specific clinical manifestations, commonly characterized by lameness, fever, anorexia, lethargy, and lymphadenopathy. Arthritis and neurologic dysfunction have been observed in infected dogs and horses. *B. burgdorferi* is usually transmitted by *Ixodes* sp. ticks, in particular in Europe the main vector is *I. ricinus*. Human Lyme borreliosis was first recognized in Italy in 1985 (Crovato *et al.* 1985) and actually is endemic in several regions. In Tuscany, the presence of *B. burgdorferi s.l.* in ticks has been previously reported. In particular, Stefanelli *et al.* (1994) found *Borrelia garinii* in *I. ricinus* in an area of coastal Tuscany, where neuroborreliosis was reported in people, whereas *Borrelia lusitaniae* and *Borrelia afzelii* were detected in *I. ricinus* ticks collected in a Tuscanian natural reserve (Bertolotti *et al.* 2006; Ragagli *et al.* 2011).

More recently, *B. burgdorferi s.l.* DNA was found in 3% of wild boars (*S. scrofa*) (Ebani *et al.* 2017a), 3.33% of red deer (*C. elaphus*) (Ebani *et al.* 2016c), 15.47% of pigeons (*C. livia*) (Ebani *et al.* 2016a), 3.12% of horses (Ebani *et al.* 2015b) and 6.49% of ticks (Ebani *et al.* 2015a). Moreover, seroprevalence values of 5.8% and 24.3% were found in hares (*Lepus europaeus*) and horses, respectively (Ebani *et al.* 2016b; Ebani *et al.* 2012b).

Bartonella spp. – Bartonellosis is an emerging infectious disease of animals and human beings caused by several bacterial species of the genus *Bartonella*. These pathogens are facultative intracellular, haemotropic Gram-negative bacteria, usually transmitted by blood-sucking arthropods. Most bartonellae are zoonotic causing human diseases with sub-clinical or severe forms. Several animal species act as reservoir hosts for bartonellae: cats for *Bartonella henselae*, *Bartonella clarridgeiae* and *Bartonella koehlerae*, dogs for *Bartonella vinsonii* subsp. *berkhoffii*, cattle for *Bartonella bovis*. However, bartonellae have been detected in numerous domestic and wild animal species (Guptill 2010). The most common bartonellosis is the Cat Scratch Disease (CDS) caused by *B. henselae* and transmitted mainly by the flea *Ctenocephalides felis.* An investigation among domestic cats living in Tuscany found 33.3% of seropositive cats and 11.1% of the same animals were bacteremic (Ebani *et al.* 2012a). DNA of *Bartonellae* belonging to other species was detected in 20.5% of hunting dogs (Ebani *et al.* 2015c), 2.38% of pigeons (Ebani *et al.* 2016a) and 37.66% of ticks (Ebani *et al.* 2015a). A recent study carried out in horses and donkeys living in the same region found 58.69% of animals seropositive to *B. henselae*; moreover nine horses were PCR positive for *Bartonella* spp. and three donkeys for *B. henselae* (Magni *et al.* 2017).

Conclusion. – Previous serological and molecular surveys carried out among domestic and wild animal populations showed the large presence of bacterial pathogens transmitted by hematophagous arthropods in Central Italy. Infected animals can develop severe disease or act as clinically healthy hosts, but in all cases they are involved in the epidemiological cycle of the arthropod-borne pathogens. Seasonality, distribution and prevalence of arthropod-borne diseases are influenced by climate factors, mainly temperature and rainfall that may affect disease outbreaks by altering biological variables such as vector population size and density and vector survival. Considering that the spreading of arthropod-borne diseases is a growing concern and in view of the One-Health concept, the regular surveillance of these infections in animals, mainly those with frequent contact with humans, is necessary to verify the appearance of new pathogens in a geographic area and the prevalence variations of those already present.

REFERENCES

Berri M., Rekiki A., Boumedine A. *et al.* (2009). Simultaneous differential detection of *Chlamydophila abortus*, *Chlamydophila pecorum*, and *Coxiella burnetii* from aborted ruminant's clinical samples using multiplex PCR. BMC Microbiology 9: 130.

Bertolotti L., Tomassone L., Tramuta C. *et al.* (2006). *Borrelia lusitaniae* and Spotted Fever Group Rickettsiae in *Ixodes ricinus* (Acari: Ixodidae) in Tuscany, Central Italy. Journal of Medical Entomology 43: 159-165.

Crovato F., Nazzari G., Fumarola D. *et al.* (1985). Lyme disease in Italy: first reported case. Annals of Rheumatic Diseases 44: 570-571.

Ebani V.V. (2019a). Serological Survey of *Ehrlichia canis* and *Anaplasma phagocytophilum* in Dogs from Central Italy: An Update (2013–2017). Pathogens 8(1). pii: E3. doi: 10.3390/pathogens8010003.

Ebani V.V. (2019b). Serological Evidence of *Anaplasma phagocytophilum* and Spotted Fever Group *Rickettsia* spp. Exposure in Horses from Central Italy. Pathogens 8(3) pii: E88. doi: 10.3390/pathogens8030088.

Ebani V.V., Bertelloni F. (2014). Serological evidence of exposure to *Ehrlichia canis* and *Anaplasma phagocytophilum* in Central Italian healthy domestic cats. Ticks and Tick Borne Diseases 5: 668-671.

Ebani V.V., Bertelloni F., Cecconi G. *et al.* (2017a). Zoonotic tick-borne bacteria among wild boars (*Sus scrofa*) in Central Italy. Asian Pacific Journal of Tropical Medicine 7: 141-143.

Ebani V.V., Bertelloni F., Fratini F. (2012a).Occurrence of *Bartonella henselae* types I and II in Central Italian domestic cats. Research in Veterinary Sciences 93: 63-66.

Ebani V.V., Bertelloni F., Mani P. (2016a). Molecular survey on zoonotic tick-borne bacteria and chlamydiae in feral pigeons (*Columba livia domestica*). Asian Pacific Journal Tropical Medicine 9: 324-327.

Ebani V.V., Bertelloni F., Pinzauti P. *et al.* (2012b). Seroprevalence of *Leptospira* spp. and *Borrelia burgdorferi sensu lato* in Italian horses. Annals of Agricultural and Environmental Medicine 19: 237-240.

Ebani V.V., Bertelloni F., Torracca B. *et al.* (2014). Serological survey of *Borrelia burgdorferi sensu lato*, *Anaplasma phagocytophilum*, and *Ehrlichia canis* infections in rural and urban dogs in Central Italy. Annals of Agricultural and Environmental Medicine 21: 671-675.

Ebani V.V., Bertelloni F., Turchi B. *et al.* (2015a). Molecular survey of tick-borne pathogens in Ixodid ticks collected from hunted wild animals in Tuscany, Italy. Asian Pacific Journal of Tropical Medicine 8: 714-717.

Ebani V.V., Cerri D., Fratini F. *et al.* (2007). *Anaplasma phagocytophilum* infection in a fallow deer (*Dama dama*) population in a preserve of Central Italy. New Microbiologica 30: 161-165.

Ebani V.V., Nardoni S., Bertelloni F. *et al.* (2015b) Tick-borne infections in horses from Tuscany, Italy. Journal of Equine Veterinary Science 35: 290-294.

Ebani V.V., Nardoni S., Fognani G. *et al.* (2015c). Molecular detection of vector-borne bacteria and protozoa in healthy hunting dogs from Central Italy. Asian Pacific Journal of Tropical Medicine 5: 108-112.

Ebani V.V., Nardoni S., Giani M. *et al.* (2019c). Molecular survey on the occurrence of avian haemosporidia, *Coxiella burnetii* and *Francisella tularensis* in waterfowl from Central Italy. International Journal of Parasitology: Parasites and Wildlife 10: 87-92.

Ebani V.V., Poli A., Rocchigiani G. *et al.* (2016b). Serological survey on some pathogens in wild brown hares (*Lepus europaeus*) in Central Italy. Asian Pacific Journal of Tropical Medicine 9: 465-469.

Ebani V.V., Rocchigiani G., Bertelloni F. *et al.* (2016c). Molecular survey on the presence of zoonotic arthropod-borne pathogens in wild red deer (*Cervus elaphus*). Comparative Immunology, Microbiology and Infectious Diseases 47: 77-80.

Ebani V.V., Rocchigiani G., Nardoni S. *et al.* (2017b). Molecular detection of tick-borne pathogens in wild red foxes (*Vulpes vulpes*) from Central Italy. Acta Tropica 172: 197-200.

Ebani V.V., Verin R., Fratini F. *et al.* (2011). Molecular survey of *Anaplasma phagocytophilum* and *Ehrlichia canis* in red foxes (*Vulpes vulpes*) from Central Italy. Journal of Wildlife Diseases 47: 699-703.

Guptill L. (2010). Bartonellosis. Veterinary Microbiology 140: 347-359.

Magni E., Bertelloni F., Sgorbini M. *et al.* (2017). *Bartonella* infection in asymptomatic horses and donkeys from Tuscany, Central Italy. Asian Pacific Journal of Tropical Medicine. 10: 1077-1079.

Perez M., Bodor M., Zhang C. *et al.* (2006). Human infection with *Ehrlichia canis* accompanied by clinical signs in Venezuela. Annals of the New York Academy of Sciences 1078: 110-117.

Ragagli C., Bertolotti L., Giacobini M. *et al.* (2011). Transmission dynamics of *Borrelia lusitaniae* and *Borrelia afzelii* among *Ixodes ricinus*, lizards, and mice in Tuscany, Central Italy. Vector Borne and Zoonotic Diseases 11: 21-28.

Sainz Á., Roura X., Miró G. *et al.* (2015). Guideline for veterinary practitioners on canine ehrlichiosis and anaplasmosis in Europe. Parasites and Vectors, 8, 75, doi: 10.1186/s13071-015-0649-0.

Selmi M., Martello E., Bertolotti L. *et al.* (2009). *Rickettsia slovaca* and *Rickettsia raoultii* in *Dermacentor marginatus* ticks collected on wild boars in Tuscany, Italy. Journal of Medical Entomology 46: 1490-1493.

Stefanelli S., Paladini A., Conforti P.L. *et al.* (1994) Isolation of *Borrelia burgdorferi* in Tuscany (Italy). New Microbiologica 17: 333-336.

Stuen S., Granquist E.G., Silaghi C. (2013). *Anaplasma phagocytophilum* - a wide spread multi-host pathogen with highly adaptive strategies. Frontiers in Cellular and Infection Microbiology 3: 1-33.

SESSION 2
EFFECTS ON ANIMAL HEALTH

Genomic adaptation of Mediterranean and Alpine local cattle breeds to the climate variables

ROBERTA CIAMPOLINI[*]
Dipartimento di Scienze Veterinarie, Università di Pisa

Keywords: cattle, climate, genetics, local adaptation, SNP

ABSTRACT. – Adaptive ability of livestock to climate variations is a factor of first importance in the context of global climate change. Domestic species such as cattle represent attractive biological models to characterize the genetic basis of short domestication history. Local cattle breeds are valuable genetic resources to decipher the molecular mechanisms of cattle adaptation to their specific environments. Using newly generated dense SNP genotyping data, we assessed the structuring of genetic diversity of 21 Mediterranean and 24 Alpine cattle breeds and performed genome-wide association analyses with covariables discriminating the different Mediterranean and Alpine climate subtypes. This provided insights into both the demographic and adaptive histories. A detailed functional annotation of genes surrounding variants associated with climate variations highlighted several biological functions involved in Mediterranean and Alpine climate adaptation such as thermotolerance, UV protection, pathogen resistance or metabolism with strong candidate genes identified. Accordingly, our results suggest that main selective pressures affecting cattle in Mediterranean and Alpine area may have been related to variation in heat and UV exposure, in food resources availability and in exposure to pathogens. Taken together, our results highlight the genetic uniqueness of local Mediterranean and Alpine cattle breeds and strongly support conservation of these populations.

INTRODUCTION. – In recent decades, changes in climate have caused impacts on natural and human systems on all continents. The Mediterranean region is a global "hot-spot" of climate change both in the South (southern Mediterranean regions) where climate conditions are already stressful, and the North (Europe) where droughts and heat waves are recurrent. During this century, the climate will profoundly

[*]roberta.ciampolini@unipi.it

change, and with it the context of livestock production. The forecasted global climate change will deeply impact ecosystems and will not spare agriculture and livestock productions. In the border lands of the Mediterranean sea, the so-called "Mediterranean climate", characterized by the wet winter/dry summer seasonality of rainfall will be affected in these following ways: i) a significant warming, ii) an increase of precipitations in winter and a decrease in summer, iii) a decline of annual precipitations over much of the region, exacerbating drought conditions, and iv) an increased frequency of extreme events (droughts or heatwaves). As a consequence, the regional livestock production systems will have to face various stresses, such as: i) feeding and water resources scarcity, ii) heat stress, which reduces male and female reproduction and production abilities, increases mortality risk and increases water requirements and iii) disease stress, due to the spread of pathogens or the spatial and seasonal changes in disease distributions that may expose livestock populations to new diseases. According to these forecasts, adaptive traits, such as body reserve management, disease and heat resistance, feed and water scarcity tolerance related to a poor-quality environment will gain a dramatic importance. In the different Mediterranean environments, for centuries farmers have developed production systems adapted to the local resources availability along the seasons and to their own objectives (milk, meat, manure...), taking advantage of the adaptive traits of local breeds. However, in order to adapt to the effects of climate change, management practices have to be modified.

A production system embeds a breeding system into the whole food chain process at the local level. The production objectives determine a set of decisions to make at each step of the livestock activity. In a breeding program adapted to a harsh environment, breeders have: i) to choose the most appropriate breeds to use in a given production system and ii) to follow suitable selection goals that match the production system constraints (Mirkena *et al.* 2010). The use of animal genetic diversity in relation to system management diversity in contrasted agroecological situations should allow the identification of the most adapted genotypes and management practices capable of coping with the environmental challenges posed by production systems. Adaptability is the ability to survive, grow and reproduce itself within a defined environment, or the degree to which an animal can remain adapted to a wide range of environments (Mirkena *et al.* 2010). Adaptation abilities include adaptation to heat stress (thermotolerance), nutritional stresses (low metabolic requirements, ability to reduce metabolism, fat deposition as feed reserve) and presence of parasites and diseases. All these adaptation abilities mainly rely on functional traits such as reproductive, metabolic, neurological, immunological traits and hair coat characteristics and depend on complex interactions among anatomical and physiological factors. From a breeder's point of view, these traits are usually characterized by: measurement problems, low heritability, important genotype/environment interactions and underlying antagonistic biological relationships with production traits (Mirkena *et al.* 2010). As, the causal physiological or genetic mechanisms of adaptation traits are largely unknown, the direct study of adaptive traits is difficult to perform. This is particularly the case in southern Mediterranean countries where performance and pedigree recordings are far from being set up.

Understanding how species and ecosystems respond to climate change has become a crucial focus in ecology, biodiversity conservation and management. The recent availability of genome-wide SNP panels (high density SNP chips) allows providing background information concerning genome structure in domestic animals, opening new perspectives to livestock genetics. Several approaches have been performed in landscape genomics to detect adaptation to different climate pressure by correlations between genomic data and climate variables. The International Project GALIMED "Genetic Adaptation of Bovine Livestock and production systems in MEDiterranean region", has developed an integrated approach that combines the analysis of SNP markers and bioclimatic variables to identify genotypes able to respond to climate change and provided a genomic map of climate adaptation in Mediterranean cattle breeds.

A Genomic Map of Climate Adaptation in Mediterranean Cattle Breeds (Flori, L., Moazami-Goudarzi, L., Alary, V. *et al.* Contributor: Roberta Ciampolini. Molecular Ecology 2019; 28: 1009-1029. © 2019 John Wiley & Sons Ltd. *https://doi.org/10.1111/mec.15004*). – Domestic species represent attractive biological models to characterize the genetic basis of short-term evolutionary response to abiotic selective pressure such as climate. Indeed, during their human mediated migration from restricted domestication centres, they colonized a wide range of new environments and differentiated into a variety of populations or breeds shaped by the combined action of natural and artificial selection, and genetic drift. For instance, cattle (*Bos tau-*

rus) have been domesticated ca. 10,000 years before present (YBP) in two independent domestication centers, located in the Fertile Crescent for taurine (*Bos t. taurus*) and in the Indus Valley for the zebu (*Bos t. indicus*) (Loftus *et al.* 1994). These cattle populations then migrated with farmers on the different continents leading to more than 800 different cattle breeds now recognized worldwide (Felius *et al.* 2014). Standing at a crossroad of several early cattle migration routes, the Mediterranean basin appeared as a central area for European and African population exchanges. Indeed, the Near East Neolithic farmer populations followed two main routes through Europe migrating from 9,000 YBP to Central Europe via the so-called Danubian route (*i.e.*, through Anatolia, Thrace and the Balkans), and to Southern Europe via the so-called Mediterranean route (*i.e.*, using a maritime route by the Mediterranean sea) reaching Italy, France and Spain, 6,000 to 6,500 YBP (Payne & Hodges 1997). Conversely, in Africa, taurine cattle were introduced through Egypt along the Mediterranean littoral, 6,500 YBP, although migrations from Southern Europe via Mediterranean islands also possibly occurred (Payne & Hodges 1997). Finally, if zebu cattle were first introduced in Africa via the Suez route, 3,500 YBP, their two major introductions occurred later via maritime routes to the Horn of Africa with Muslim expansion during the 7th century AD and following the rinderpest epidemics of 19th century (Payne & Hodges 1997). Zebu then spread gradually to the entire African continent, including Mediterranean regions and probably in Southern Europe, as suggested by the indicine ancestry detected in some Italian and Greek breeds (D'Angelo *et al.* 2006; Gautier *et al.* 2010). During this complex colonization history, and over the course of less than 1,500 generations, cattle became adapted to a variety of local climatic conditions across the Mediterranean basin (Gautier *et al.* 2007). Indeed, although the Mediterranean climate is mainly characterized by dry summers and mild and moist winters, a wide range of climate subtypes still persists from "dry-summer temperate" in Southern Europe to "dry-summer subtropical" in North Africa (Peel *et al.* 2007). Capitalizing on the genomic resources available for cattle, and in particular in SNP genotyping assays, it is now possible to scan the genome for regions involved in adaptation to local environment. To that end, Genome-Environment Association (GEA) analyses have facilitated identification of genetic variants associated with population-specific environmental covariables (Gautier 2015). When combined with a functional annotation of candidate genes or variants, such a population genomics approach has proved to be efficient at highlighting candidate genes or physiological pathways affected by climate variation in both animal (Gao *et al.* 2017; Lv *et al.* 2014) and plant (Frachon *et al.* 2018) species. Here, using a newly developed genotyping data set, we aimed at providing insights into both the demographic and adaptive histories of Mediterranean cattle, with a focus on climate adaptation. More precisely, was analyzed the structure of the genetic diversity across 21 local cattle breeds inhabiting eight different countries on both sides of the Mediterranean sea (Spain, France, Italy, Greece, Cyprus, Egypt, Algeria and Morocco) and infer their relationships with other breeds. The bovine genome was then scanned to identify footprints of adaptation to the Mediterranean climate using the methods implemented in the Baypass software (Gautier 2015) and climatic variables associated with the cattle sampling locations. A detailed functional annotation of the identified candidate genes using system biology tools (Flori *et al.* 2014) uncovered the main physiological pathways mobilized during cattle adaptation to the Mediterranean climate. The newly developed medium density SNP genotyping data set demonstrates a clear structuring of the genetic diversity of local breeds across the Mediterranean basin resulting from a complex recent demographic history with admixture events involving the three major cattle groups. Yet, most of the local breeds we considered can be viewed as stabilized in the sense that they displayed a high degree of within population genetic homogeneity. This led us to consider the population or breed as the appropriate level of organization to draw a bovine genomic map of short-term adaptive response to local Mediterranean climate variation that was mainly captured by climatic covariables related to temperature, precipitation, radiation and humidity (Fig. 1). Strikingly, the indepth functional analysis we carried out based on the 55 candidate genes found associated with climatic covariables highlighted several functions or physiological pathways (*e.g.,* cancer, pigmentation, metabolism or infection and immunity) already reported in other similar GEA performed in human and sheep to be important in climate adaptation (Lv *et al.* 2014). More specifically, our results suggested a central role of genes involved in cancer, cellular growth and proliferation while highlighting the impact of heat stress and UV exposure on physiology. Some plausible candidate genes were identified, such as METTL3, which regulates the UV-induced DNA damage response (Xiang *et al.* 2017) and LEF1, which could be related to thermotolerance and UV protection, as suggested by its central role in hair pigmentation (Guenther *et al.* 2014) and its location in a QTL for UV protective eye area pigmentation in cattle (Pausch *et al.* 2012). In addition, LEF1 was also found under adaptive differentiation across Mediterranean breeds in our study and across Chinese local cattle breeds (Gao *et al.* 2017). The functional annotation of the candidate genes also identifies genes involved in the development and function of the nervous system such as CTNNA2, NRG1 and RFX4 (Dominguez *et al.* 2018), the latter being also reported as associated with climate covariable in Chinese cattle (Gao *et al.* 2017). These genes might be important to adapt to varying Mediterranean climatic conditions via their action on thermal regulation, behavioural and sensory system development. Other candidate genes play also a role in development such as NDUFB3 and FBN1 that are involved in morphology and stature (Alston *et al.* 2016). This might be viewed as support for the hypothesis that climate strongly influences body size with positive correlations between heat and aridity, and smaller size (Franks & Hoffmann 2012). Finally, several candidate genes were found to be involved in amino acid metabolism (*e.g.,* GADL1, GLDC, NRG1, SLC46A1) and in cardiovascular system or in development of urinary tract (*e.g.*, ALDH1A2, AMER1, CDH4, EYA1, FBN1, LAMC1, MST1, MYC, NOG, PTGS2, PTPRF, SHH, SLC19A1, SMO, SST, TP53, VEGFA, VHL) which could be speculatively interpreted as resulting from physiological adaptations required to cope with drought in some Mediterranean areas. Interestingly, some of the genes found associated with climate were actually involved in infectious disease resistance (*e.g.*, ANTXR2, MAP3K8, MLST8 and SMYD3), perhaps implicating pathogens with distributions that are influenced by climate. The most striking example is represented by ANTXR2 that was found both under selection and associated with climate covariables, suggesting that anthrax could have exerted a strong selective pressure on Mediterranean cattle breeds. Indeed, this gene encodes the major receptor mediating in vivo lethality of the toxin produced by Bacillus anthracis (Arévalo *et al.* 2014) responsible for anthrax, the oldest known zoonosis with a worldwide distribution, severely affecting human and ruminants. This disease, is thought to have originated in Egypt and Mesopotamia and to be depicted in ancient writings since 1,491 BC (Schwartz 2009). In Europe, it was described in a 10th century collection of veterinary writings, was responsible for enormous domestic livestock losses in Europe from the 17th to the 19th century (Schwartz 2009) and also occurred more recently, at the end of the last century, in the Mediterranean countries of Southern Europe, especially in Spain, Italy, Turkey and Greece. A link between climatic factors (*i.e.*, temperature, precipitation pattern and solar radiation) and the onset of anthrax outbreaks have been established, as the spores of Bacillus anthracis are especially resistant in contaminated soils, where they can survive for years. In particular, areas in Europe with a pronounced dry season, such as Mediterranean countries, have a higher prevalence of animal anthrax. This disease could also have exerted strong selective pressure in cattle from other areas, ANTXR2 being found under selection in West-African cattle, and in other susceptible species since this gene was also found associated with climate variables in humans and sheep (Lv *et al.* 2014) and correlated with pathogen diversity in humans. In addition to ANTXR2 and LEF1, were identified other genes, VDAC1, TCF7 and SKP1, that were all associated with climatic covariables and located in a genomic region displaying strong evidence of adaptive differentiation on BTA7. Interestingly, the strongest differentiation signal in this region is obtained close to TCF7, which, as LEF1, is a main downstream effector of a signalling pathway (*i.e.,* Wnt/β catenin) and both genes have recently been found to be involved in a regulatory feedback loop controlling taste cell renewal in the circumvallate papilla epithelium and loss of gustatory nerve fibres in mice (Gaillard *et al.* 2017). Similarly, a SNP proximal to LEF1 is also associated with feeding behaviour and eating efficiency in Duroc pigs (Ding *et al.* 2017). Although difficult to characterize, it is nevertheless important to note that other human-mediated or natural selective pressures may also have driven the adaptive genetic diversity of the Mediterranean local cattle breeds. Overall, genome scan for association with climate covariable on breeds representative of various local Mediterranean conditions provided a global picture of the main targeted candidate physiological adaptations. This illustrates in turn the originality and genetic potential of Mediterranean cattle breeds in particular in the context of global warming (Segnalini *et al.* 2013). In addition to the identification of the genetic variants underlying adaptive response of Mediterranean cattle breeds to local climatic variation, characterizing their origin may thus be critical to promote the conservation of genetic resources and the associated traditional herding systems that are threatened by the increasing use of a small number of commercial breeds (Bruford *et al.* 2015). The structuring of genetic diversity of Mediterranean local cattle breeds and their recent post-domestication history makes it unlikely that locally favourable genetic variants arose by new mutations. Instead, adaptation to local climate conditions may have rather relied on standing genetic variation that existed in both domesticated and wild European cattle during the period when domestication took place and as a consequence of early farmer migration, or may be the result of more recent adaptive introgression of indicine origin (both hypotheses being of course mutually nonexclusive). Zebu that diverged from taurine between 84,000 and 275,000 YBP (Ho *et al.* 2008), have been subjected for a longer time to tropical and arid conditions and are now well adapted to these specific conditions while African taurine, which diverged from European taurine several thousand years ago (Stock *et al.* 2013), are also well adapted to tropical humid climate. Although the current lack of genetic data on local aurochs individuals prevents us from assessing their contribution, our characterization at the genome-wide scale demonstrates an admixture with (a) zebu ancestry in Southern Europe with an East to West decreasing gradient for Cyprus, Greek, Maremmana and Romagnola Italian and Corsican breeds, which confirms and refines previous studies (Gautier *et al.* 2010), (b) African taurine ancestry in Maghreb (Tidili, Oulmes Zaër, Brune de l'Atlas and Chelifienne breeds) and (c) both zebu and African taurine ancestries in Maghreb (Cheurfa and Guelmoise breeds), Egypt and Cyprus. Taken together, this observed pattern of cattle genetic ancestry for the Mediterranean breeds remains concordant with the known migration history of Neolithic farmers from the taurine domestication centre in the Fertile Crescent toward the West through the Mediterranean coasts and major islands (*e.g.,* cattle arriving in Corsica around 5,000 YBP), following the Mediterranean route; the migration of taurine from North-Africa to Spain after their introduction in Africa through Egypt 6,500 bc; and the crossing in Egypt of the various migration routes taken by settled communities towards Europe and Africa presumably leading to interbreeding of the cattle populations. Cattle with indicine ancestry were probably brought in Southern Europe by the Silk Road route (~200 bc to 1,720 ce) connecting Asia to the Mediterranean sea (and stopping in Italy), in agreement with the decreasing gradient of indicine ancestry observed from Sicily to Italy mainland and Corsica. Overall, due to their various origins, Mediterranean cattle breeds represent attractive models to further assess the relative contribution of the major bovine ancestries in climate adaptation.

BOVITA Project Autofunded - Genomic Adaptation of Local Cattle Breeds in the Alpine Massif (Ciampolini *et al.* 2019. ASPA 23rd Congress, Sorrento, June 11-14. Book of abstracts ISSN: 1828-051X, Communication code 0039, *https://www.tandfonline.com/tjas*. – Understanding adaptive ability of livestock is a key factor in the context of global climate change and become a crucial focus in conservation and management for a sustainable farming in a changing environment. One way to better understand adaptation abilities is to identify genes underlying adaptation phenotypes. This goal can be achieved by genetically characterizing livestock species and detecting footprints of selection in the animal genome. The recent availability of genome-wide SNP panels allows providing background information concerning genome structure in domestic animals, opening new perspectives to livestock genetics. In order to investigate the genetic regions with a potential adaptive role, we investigate 24 cattle breeds, (high productive specialized breeds and several autochthonous populations) reared in six different neighboring nations from East to West Alpine Massif (Fig. 2). Several analyses have been performed to detect footprints of selection and genomic regions associated with climate variables. More precisely, using breed GPS coordinates, four climatic variables (annual mean temperature, annual precipitation, annual mean radiation, and annual mean moisture index) were extracted from the Climond database (Fig. 2). In order to identify footprints of selection, a whole genome scan for adaptive differentiation were performed using Bovine 50K SNP chip genotyping data with the XtX model implemented in the BAYPASS software. In addition, across-population whole genome scans for association with the population-specific climatic variables were performed using the AUX model. Footprints of selection were detected on BTA6 and BTA18 pointing out several candidate genes (*i.e.,* LCORL, PDGFRA, KDR and SPG7); moreover different genomic regions (on BTA 6, 10, 19 and 20) were associated with annual mean radiation. Ongoing analyses will specify candidate regions and genes involved in local adaptation in the Alpine massif.

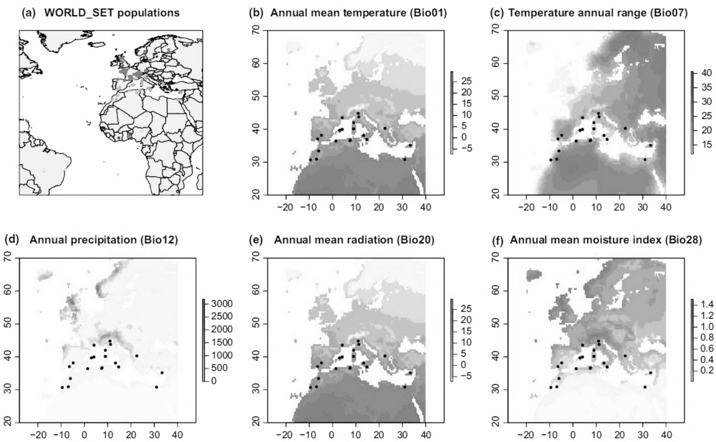


FIG. 1. Cattle breed location and geographic pattern of the annual mean values of the five main climatic variables. (a) Location of the 62 breeds of the WORLD-Set, including the 21 breeds of the MED-Set. EUT, AFT, ZEB are indicated in red, blue, green, respectively, and the breeds located in the Mediterranean area (from the MED-Set), in orange. ANA and TUR hybrids breeds, not considered in the MED-Set are in black. (b) to (f) Geographic pattern of the annual mean temperature (b), the temperature annual range (c), the annual precipitation (d), the annual mean radiation (e) and the annual mean moisture index (f), with the location of Mediterranean breeds (MED-Set) [Colour figure can be viewed at wileyonlinelibrary.com]. From Flori, L., Moazami-Goudarzi, L., Alary, V. *et al.* Contributor: Roberta Ciampolini. Molecular Ecology 2019, 28: 1009-1029. © 2019 John Wiley & Sons Ltd. *https://doi.org/10.1111/mec.15004*.

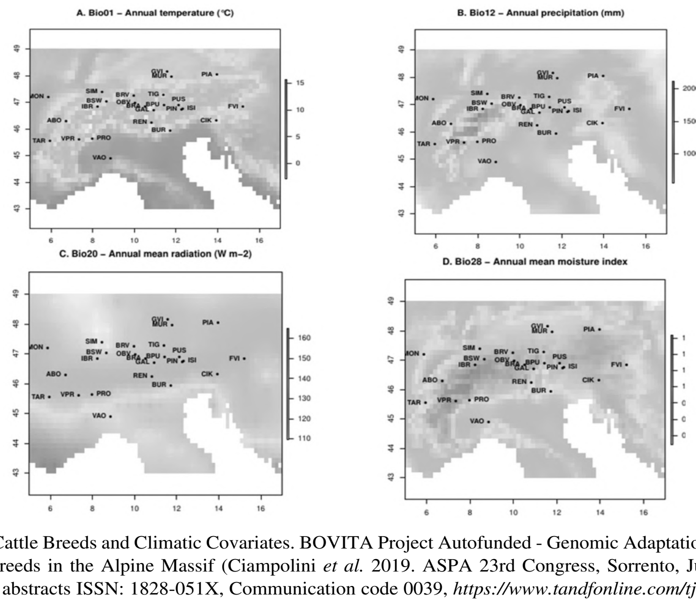


FIG. 2. Cattle Breeds and Climatic Covariates. BOVITA Project Autofunded - Genomic Adaptation of Local Cattle Breeds in the Alpine Massif (Ciampolini *et al.* 2019. ASPA 23rd Congress, Sorrento, June 11-14. Book of abstracts ISSN: 1828-051X, Communication code 0039, *https://www.tandfonline.com/tjas*).

ACKNOWLEDGEMENTS. – This work was supported by the INRA Metaprogramme ACCAF grant 2012 (GALIMED project) and the Animal Genetics Division of INRA (INRA AIP "Bio-Resourcels", BOVDIV project) for the Mediterranean Cattle Breeds. For the Alpine Cattle Breeds the work was supported by the Autofunded BOVITA Project and the Animal Genetics Division of INRA. The author would like to thank all the Colleagues who collaborated on the projects mentioned above. Thanks to their scientific expertise and their work they have made possible to obtain the results described in this summary.

REFERENCES

Alston, C.L., Howard C., Oláhova M. *et al.* (2016). A recurrent mitochondrial p.Trp 22Arg NDUFB3 variant causes a distinctive facial appearance, short stature and a mild biochemical and clinical phenotype. Journal of Medical Genetics 53: 634-641.

Arévalo M.T., Navarro A., Arico C.D. *et al.* (2014). Targeted silencing of anthrax toxin receptors protects against anthrax toxins. Journal of Biological Chemistry 289: 15730-15738.

Bruford M.W., Ginja C., Hoffmann I. *et al.* (2015). Prospects and challenges for the conservation of farm animal genomic resources, 2015-2025. Frontiers in Genetics 6: 314.

Ciampolini R., Flori L., Moazami-Goudarzi K. *et al.* (2019). Communication code O039 - ASPA 23rd Congress, Sorrento, June 11-14, 2019 Book of Abstracts.

Ding R., Quan J., Yang M. *et al.* (2017). Genome-wide association analysis reveals genetic loci and candidate genes for feeding behavior and eating efficiency in Duroc boars. PLoS One 12, e0183244.

Dominguez S.L., Hegde G., Hanson J.E. *et al.* (2018). Antibody-mediated stabilization of NRG1 induces behavioral and electrophysiological alterations in adult mice. Scientific Reports 8, 8239. *https://doi.org/10.1038/s41598-018-26492-4*.

D'Angelo F., Ciani E., Sevi A. *et al.* (2006). The genetic variability of the podolica cattle breed from the Gargano Area. Preliminary results. Italian Journal of Animal Science 5: 79-85.

Felius M., Beerling M.L., Buchanan D.S. *et al.* (2014). On the history of cattle genetic resources. Diversity 6: 705-750.

Flori L., Thevenon S., Dayo G.K. *et al.* (2014). Adaptive admixture in the West African bovine hybrid zone: Insight from the Borgou population. Molecular Ecology 23: 3241-3257.

Flori L., Moazami-Goudarzi K., Alary V. *et al.* (2019). A genomic map of climate adaptation in Mediterranean cattle breeds. Contributor: Roberta Ciampolini. Molecular Ecology 28: 1009-1029. © 2019 John Wiley & Sons Ltd, *https://doi.org/10.1111/mec.15004*.

Frachon L., Bartoli C., Carrère S. *et al.* (2018). A genomic map of climate adaptation in *Arabidopsis thaliana* at a micro-geographic scale. Frontiers in Plant Science 9: 967.

Franks S.J., Hoffmann A.A. (2012). Genetics of climate change adaptation. Annual Review of Genetics 46: 185-208.

Gaillard D., Bowles S.G., Salcedo E. *et al.* (2017). ß-catenin is required for taste bud cell renewal and behavioral taste perception in adult mice. PLoS Genetics 13, e1006990.

Gao Y., Gautier M., Ding X. *et al.* (2017). Species composition and environmental adaptation of indigenous Chinese cattle. Scientific Reports 7, 16196.

Gautier M. (2015). Genome-wide scan for adaptive divergence and association with population-specific covariates. Genetics 201: 1555-1579.

Gautier M., Faraut T., Moazami-Goudarzi K. *et al.* (2007). Genetic and haplotypic structure in 14 European and African cattle breeds. Genetics 177: 1059-1070.

Gautier M., Laloë D., Moazami-Goudarzi K. (2010). Insights into the genetic history of French cattle from dense SNP data on 47 worldwide breeds. PLoS One 5, e13038.

Gautier M., Hocking T.D., Foulley J.L. (2010). A Bayesian outlier criterion to detect SNPs under selection in large data sets. PLoS One 5, e11913.

Guenther C.A., Tasic B., Luo L. *et al.* (2014). A molecular basis for classic blond hair color in Europeans. Nature Genetics 46: 748-752.

Ho S., Larson G., Edwards C.J. *et al.* (2008). Correlating Bayesian date estimates with climatic events and domestication using a bovine case study. Biology Letters 4: 370-374.

Loftus R.T., MacHugh D.E., Bradley D.G. *et al.* (1994). Evidence for two independent domestications of cattle. Proceedings of the National Academy of Sciences 91: 2757-2761.
Lv F.H., Agha S., Kantanen J. *et al.* (2014). Adaptations to climate-mediated selective pressures in sheep. Molecular Biology and Evolution 31: 3324-3343.
Mirkena T., Duguma G., Haile A. *et al.* (2010). Genetics of adaptation in domestic farm animals: A review. Livestock Science 132: 1-12.
Pausch H., Wang X., Jung S. *et al.* (2012). Identification of QTL for UV-protective eye area pigmentation in cattle by progeny phenotyping and genome-wide association analysis. PLoS One 7, e36346.
Peel M.C., Finlayson B. L., McMahon T. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 11: 1633-1644.
Schwartz M. (2009). Dr. Jekyll and Mr. Hyde: A short history of anthrax. Molecular Aspects of Medicine 30: 347-355.
Segnalini M., Bernabucci U., Vitali A. *et al.* (2013). Temperature humidity index scenarios in the Mediterranean basin. International Journal of Biometeorology 57: 451-458.
Stock F., Gifford-Gonzalez D. (2013). Genetics and African cattle domestication. African Archaeological Review 30: 51-72.

Agroforestry system for mitigation and adaptation to climate change: effects on animal welfare and productivity

MARCELLO MELE[1*], ALBERTO MANTINO[2], DANIELE ANTICHI[1], MARCO MAZZONCINI[1], GIORGIO RAGAGLINI[2], ALICE CAPPUCCI[1], ANDREA SERRA[1], FRANCESCO PELLERI[3], PIERMARIO CHIARABAGLIO[3], GIUSTINO MEZZALIRA[4], ENRICO BONARI[2]
[1] Centro di Ricerche Agro-ambientali "E. Avanzi", Università di Pisa, Pisa
[2] Istituto di Scienze della Vita, Scuola Superiore S. Anna, Pisa
[3] Centro di Ricerche Foresta e Legno, CREA
[4] Veneto Agricoltura, Padova

Keywords: animal welfare, livestock production, greenhouse gases

ABSTRACT. – Climate change alters the thermal environment of animals, affecting animal health, reproduction, and the feed conversion efficiency. Environmental stress and, more specifically, thermal stress directly affect productivity and health of livestock resulting in significant economic losses. Agroforestry is a land-use strategy to cope with climate change and provide environmental, economic, and social benefits. Agroforestry system may contribute to alleviate the effects of heat stress, by providing thermal comfort to the animals. Specific studies, in fact, demonstrated that the presence of trees and their arrangement in the agroforestry systems provide better microclimate conditions and animal thermal comfort in pastures. However, large part of the information about the effect of agroforestry systems on livestock production is related to tropical and subtropical environment, whereas data from temperate zone are still scarce. In 2017, a multidisciplinary research team has been established to evaluate the transition of a conventional specialized system towards agroforestry in Tuscany. Preliminary data about the effect of agroforestry systems on livestock production are presented and discussed.

INTRODUCTION. – Livestock sector needs to face environmental issues associated to animal products. At the same time, the efficiency of the system should be improved, in order to produce more food without increasing land consumption (Pulina *et al.* 2017; Tilman *et al.* 2011). According to the last estimations, livestock sector produces nearly half of the greenhouse gas emission of the whole agricultural sector

*Corresponding author: marcello.mele@unipi.it

(Cassandro *et al.* 2013). Moreover, ruminants are responsible of the major part of the methane emission of the agricultural sectors, as a consequence of the physiological production of methane during the process of fibre digestion in the rumen (Buccioni *et al.* 2015).

Increasing concentration of the greenhouse gases is associated with the greenhouse effect, which, in turn, results in global warming and global climate change. There is a general consensus about the effects of climate change on global temperature, precipitation, atmospheric carbon dioxide (CO_2) levels, and water availability. At the same time, there is increasing evidences about the effect of climate change on productivity of crop and livestock systems (Hatfield *et al.* 2008). As regard livestock systems, climate change alters the thermal environment of animals, affecting animal health, reproduction, and the feed conversion efficiency. Environmental stress and, more specifically, thermal stress directly affect productivity and health of livestock resulting in significant economic losses (Bernabucci and Mele, 2014). During the last 10 years, meteorological extreme event, such as heat waves, happened more and more frequently in the summer season also in the Mediterranean area (Bernabucci *et al.* 2014). In the next 50 years an increasing frequency of heat waves is expected, with consequences on the total length of the summer season and on the number of heat days (IPCC, 2007; Segnalini *et al.* 2013). As a consequence of this scenario, in both temperate and tropical areas there is an increasing concern about the effect of heat waves on livestock production and welfare (Nardone *et al.* 2010).

In the figure 1, the main effect of climate changes on livestock production and reproduction traits are reported.

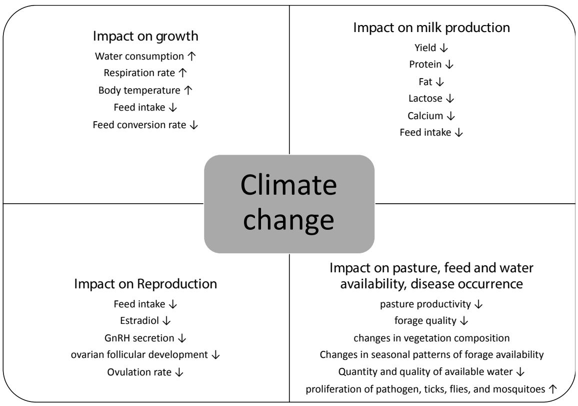


Fig. 1. Impact of climate change on livestock production and reproduction traits.

THE AGROFORESTRY SYSTEMS. – Agroforestry (AF) is a land use practice integrating woody perennials (trees or shrubs) with crops and/or animals on the same land unit (Nair 1993). More specifically, AF is the deliberate integration of woody vegetation (trees and/or shrubs) as an upper storey on land, with pasture (consumed by animals) or an agricultural crop in the lower storey (Mosquera-Losada *et al.* 2018). There is a general consensus of both international researchers and policy makers that AF is a land-use strategy to cope with climate change and provide environmental, economic, and social benefits (Lasco *et al.* 2014).

Recent studies in Italy highlighted the historic importance of traditional and innovative AF systems and their capacity to produce climate-smart food and sustainable high value timber production (Paris *et al.* 2019). During the past century, the tradition of separating between science and practice in agriculture and in forestry has left many opportunities for a functional use of trees in the agroecosystem unexploited (van Noordwijk *et al.* 2018). Latawiec *et al.* (2014) recently reported that integrated crop, livestock and forestry systems, namely AF systems, can increase agricultural productivity and sustainability of animal products. Agroforestry systems, in fact, are able to provide several benefits:

- To mitigate greenhouse gas emission from livestock sector
- To improve the adaptability of livestock to the climate change effects
- To improve the nutritional quality of animal derived food.

As regards the first point, it is well known that specialized livestock production systems are land, energy and water consuming. In tropical areas, AF systems have been proposed as a model of sustainable intensification for beef production, allowing to counteract the greenhouse gas emissions of livestock, by the carbon oxide sink derived from photosynthesis of the trees (De Oliveira *et al.* 2016). Similar results are expected also in temperate areas, although specific data still lacks.

Agroforestry system may contribute to alleviate the effects of heat stress, by providing thermal comfort to the animals. Specific studies, in fact, demonstrated that the presence of trees and their arrangement in the agroforestry systems provide better microclimate conditions and animal thermal comfort in pastures (Karvatte *et al.* 2016). Thus, agroforestry systems may improve the adaptability of livestock to the climate change effects.

Large use of pasture in the diet of ruminants leads to an improvement of nutritional quality of milk and meat (Mele 2009). In the

Mediterranean area, agroforestry systems may enlarge the grazing period by mitigating the effect of heat waves on both pasture and grazing animals. As a consequence, the availability of fresh forage in the diet of ruminants might be higher.

Finally, AF systems coupled with extensive animal rearing may contribute to the recovery of abandoned lands in Europe and to preserve high nature value farmland, by increasing labour and farm income (Lasanta *et al.* 2015). For this reason, in the framework of the Tuscany Rural Development Program, an operational group about AF has been proposed and recently funded by the Tuscany Region.

THE NEWTON OPERATIONAL GROUP (OG). – The NEWTON OG is composed by nine partners: three farms, four research institutions (Centro di Ricerche Agro-ambientali "E. Avanzi", University of Pisa; Istituto di Scienze della Vita, Scuola Superiore S. Anna di Pisa; IBIMET-CNR, CREA – Foresta e Legno) and two no-profit organizations. The NEWTON OG promotes AF with a participatory transfer of the innovative knowledges among all the stakeholders in order to: (i) recover the traditional AF systems and (ii) promote innovative AF systems.

This objective will be reached through the transfer of knowledges and the application and dissemination of the innovations. The specific objectives of NEWTON are: (1) to create a regional network of knowledges for the AF systems, (2) to develop a network of the innovations through case studies in private or public farms, (3) to disseminate knowledges and innovative strategies with a new web-platform for the AF systems in Tuscany (www.newton.eu) and (4) to valorize the AF productions.

A network of farmers and stakeholders will be created in order to disseminate and transfer the innovations through a participatory approach and with interactive systems such as the web-platform and gamification. A specific WP of the project will be dedicated to the constitution of the "Agroforestry school" in which seminars, meetings, courses and study visits will be used for training and information.

The project will favor the network with other European projects on the topic such as: H2020 project AFINET, the European Agroforestry Federation EURAF (www.agroforestry.eu) and European Innovation Partnership EIP-AGRI. At national level the communication among the stakeholders of the OG of different Italian regions will be favored through the National Rural Network. At regional level NEWTON will organize workshops inviting the members of other OG from Tuscany. The innovative strategies proposed by NEWTON will be applied in four farms in Tuscany in case studies in which environmental and economic parameters will be evaluated at field scale to disseminate information about the effects of the adoption of AF systems.

The web-platform developed in the project will be aimed at: (i) visualizing informative maps on the presence of AF systems and on the suitability of the territory for the establishment of new systems in Tuscany, (ii) favoring the interactive communication among partners and stakeholders, (iii) disseminating the project news.

THE ARNINO LONG TERM EXPERIMENT. – Starting from 2017, a multidisciplinary team is focusing on the design and the establishment of a 40-ha Long Term Experiment (LTE), to evaluate the transition of a conventional specialized system towards AF in Tuscany. The purpose of the LTE is to assess the sustainability and the feasibility of AF compared with conventional arable, grazeland and forestry systems as well as the potential transferability to real farm conditions. The research team has the priority to investigate synergies and trade-offs among the components of the AF system, in order to evaluate whether a diversification, based on annual and perennial herbaceous and woody species consociation, may enhance the resilience of cropping and livestock systems to variability of weather conditions. Secondly, it is mandatory to evaluate the potential of AF systems to climate change mitigation and efficient resource exploitation, considering, in particular, the effects on carbon storage, soil fertility, biodiversity, animal welfare and productivity, quality and availability of forage.

The LTE, established in 2018, is located at the Centre for Agro-Environmental Research “Enrico Avanzi” of the University of Pisa, San Piero a Grado (Pisa) (43.667205 N, 10.313160 E). The field trial was established on soils derived from alluvial sediments, with loam to clay-loam textures, sub-alkaline pH and soil organic matter varying from 1.5 to 2%. Two AF systems, Silvo-Arable (SA) and Agro-Silvo-Pastoral (ASP), are compared with the respective controls, Arable (AR) and Mixed (MX) systems. The AR and SA rotation consists in durum wheat, sorghum and faba bean. In MX and ASP, the 3 annual crops are followed by a 4-year meadow of Italian ryegrass, orchard-grass, tall fescue, sulla and alfalfa. In SA and ASP, oak (*Quercus robur* L.) and poplar

(*Populus* spp.) have been planted alternate on the row every 5 m, along one side of each field, 2 m away from drainage ditches, corresponding to a density of 60 trees ha^{-1}. The space between tree rows and ditches is managed as semi-permanent buffer strips to support functional biodiversity and to limit nutrient leaching. Forestry control fields are two pure stands of poplar and oak and a polycyclic plantation based on oak, poplar, hazelnut and alder (Figure 2). In this preliminary stage, different management options for the establishment of trees in rainfed condition and to contrast the action of wild animals are under evaluation.

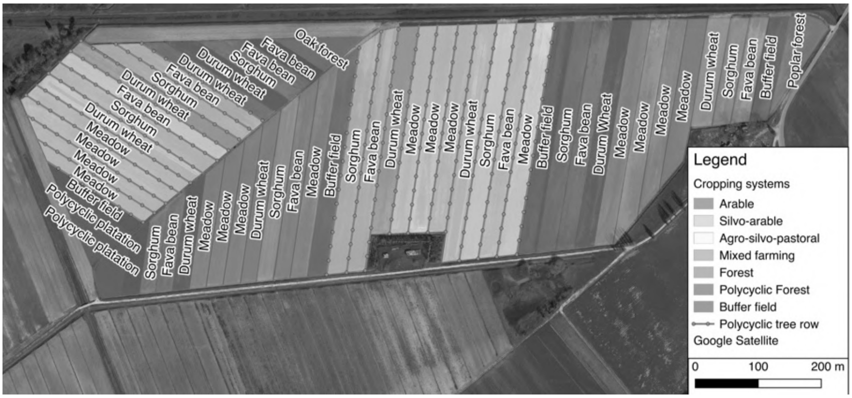


FIG. 2. Location and overview of the agroforestry Long-term Experiment in Pisa.

AGROFORESTRY SYSTEMS AND ANIMAL WELFARE PRELIMINARY AND EXPECTED RESULTS. – In the last three years, preliminary results have been obtained from mature AF systems located in the Tenuta di Paganico (TPA) farm, a partner of the Newton OG. In this farm, thanks to a specific project financed by the Tuscany Rural Development Program, measure 16.2, the first data about the adaptive response of beef cattle to the warm season in Maremma have been recorded.

Two groups of beef steers maintained on pasture with (agroforestry) or without (grazeland) the presence of native trees (mainly oak) were compared. During the hot season, in July, the temperature humidity index (THI) remained below the alert level in the AF area, whereas grazeland area without trees was characterized by higher levels of THI, above the alert threshold (Figure 3).

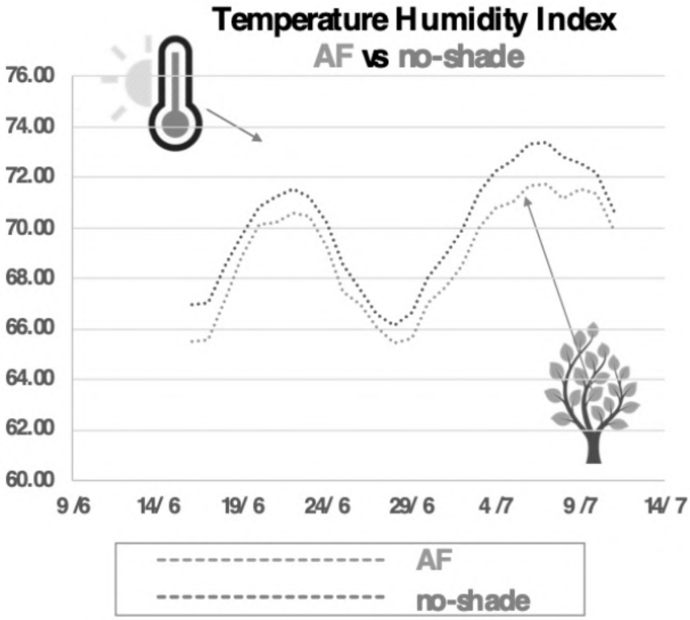


FIG. 3. Variation of THI in AF or no-shade pasture area.

This preliminary result confirmed what previously reported in tropical areas where the AF systems are successfully adopted as a strategy to mitigate the hot weaves (Karvatte *et al.* 2016). For instance, a silvopastoral systems based on native trees in the State of São Paulo, Brazil, presented lower radiant thermal load than the full-sun pasture, achieving differences up to 22% (Pezzopane *et al.* 2019). Specific studies on the effect of shade on animal welfare and productivity have already demonstrated that beef cattle with access to shade had smaller panting scores, which suggests improved welfare, and had better feed efficiency (Sullivan *et al.* 2011).

In the next future, microclimatic and physiologic data will be collected in order to better characterize the environment and the animal adaptive response. In this way, the real contribute of AF systems in the mitigation of the effects of climate change will be better defined. Data will be collected in both mature (TPA farm) and transition (Arnino LTE) AF systems.

REFERENCES

Bernabucci U., Mele M. (2014). Effect of heat stress on animal production and welfare: the case of dairy cow. Agrochimica 58: 53-60.

Bernabucci U., Biffani S., Buggiotti L. *et al.* (2014). The effects of heat stress in Italian Holstein dairy cattle. Journal of Dairy Science 97: 471-486.

Buccioni A., Cappucci A., Mele M. (2015). Methane Emission from Enteric Fermentation: Methanogenesis and Fermentation. In: “Climate Change Impact on Livestock: Adaptation and Mitigation” (V. Sejian *et al.* eds). Springer India.

Cassandro M., Mele M., Stefanon B. (2013). Genetic aspects of enteric methane emission in livestock ruminants. Italian Journal of Animal Science 12: e73.

De Oliveira S.R., Barioni L.G., Hall J.A.J. *et al.* (2016). Increasing beef production could lower greenhouse gas emissions in Brazil if decoupled from deforestation. Nature Climate Change 6: 493-497.

Hatfield J., Boote K., Fay P. *et al.* (2008). Agriculture. In: The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC, p. 362.

IPCC (2007). The Intergovernmental Panel on Climate Change. 4th Assessment Report. Available at: *http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm#2*.

Karvatte N., Klosowski E.S., de Almeida R.G. *et al.* (2016). Shading effect on microclimate and thermal comfort indexes in integrated crop-livestock-forest systems in the Brazilian Midwest. International Journal of Biometeorology 60: 1933-1941.

Lasanta T., Nadal-Romero E., Arnez J. (2015). Managing abandoned farmland to control the impact of re-vegetation on the environment. The state of the art in Europe. Environmental Science and Policy 52: 99-109.

Lasco R.D., Delfino R.J.P., Catacutan D.C. *et al.* (2014). Climate risk adaptation by smallholder farmers: the roles of trees and agroforestry. Current Opinion in Environmental Sustainability 6: 83-88.

Latawiec A.E., Strassburg B.B.N., Valentim J.F. *et al.* (2014). Intensification of cattle ranching production systems: socioeconomic and environmental synergies and risks in Brazil. Animal 8: 1255-1263.

Mele M. (2009). Designing milk fat to improve healthfulness and functional properties of dairy products: From feeding strategies to a genetic approach. Italian Journal of Animal Science 8: 365-373.

Mosquera-Losada M.R., Santiago-Freijanes J.J., Pisanelli A. *et al.* (2018). Agroforestry in the European common agricultural policy. Agroforestry Systems 92: 1117-1127.

Nair P.R. (1993). An introduction to agroforestry. Springer Science & Business Media, Berlin.

Nardone A., Ronchi B., Lacetera N. *et al.* (2010). Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science 130: 57-69.

Paris P., Camilli F., Rosati A. *et al.* (2019). What is the future for agroforestry in Italy? Agroforestry Systems (*in press*).

Pezzopane J.R.M., Nicodemo M.L.F., Bosi C. *et al.* (2019). Animal thermal comfort indexes in silvopastoral systems with different tree arrangements. Journal of Thermal Biology 79: 103-111.

Pulina G., Francesconi A.H.D., Mele M. *et al.* (2011). Sfamare un mondo di nove miliardi di persone: Le sfide per una zootecnia sostenibile. Italian Journal of Agronomy 6 (suppl. 2): 39-44.

Segnalini M., Bernabucci U., Vitali A. *et al.* (2013). Temperature humidity index scenarios in the Mediterranean basin. International Journal of Biometeorology 57: 451-458.

Sullivan M.L., Cawdell-Smith A.J., Mader T.L. *et al.* (2011). Effect of shade area on performance and welfare of short-fed feedlot cattle. Journal of Animal Science 89: 2911-2925.

Tilman D., Balzer C., Hill J. *et al.* (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences 108: 20260-20264.

van Noordwijk M., Duguma L.A., Dewi S. *et al.* (2018). SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry? Current Opinion in Environmental Sustainability 34: 33-42.

The effects of climate change on livestock production systems: the cases of mycotoxins in animal feed and animal heat stress

FABIO LABANCA[1], ARIANNA RAIMONDI[1], MARCO FONTANELLI[1], CLAUDIA PISUTTU[1], GIOVANNI RALLO[1,2], FRANCESCA GALLI[1], GIUSEPPE CONTE[1,2*], ELISA PELLEGRINI[1,2]

[1]Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto, 80 - 56124 Pisa

[2]CIRSEC, Center for Climatic Change Impact, University of Pisa, Via del Borghetto, 80 - 56124 Pisa

Keywords: crop-livestock systems, changing climate conditions, management strategies

ABSTRACT. – Climate change (CC) will have important effects on the productivity and quality of crops and livestock production systems. This contribution addresses two specific and likely impacts of CC on livestock production systems: the contamination of livestock feed by mycotoxins and animal health under heat stress (HS) conditions. Regarding the former, mycotoxins – secondary metabolites, harmful to both human health and food security, produced by filamentous fungi. Harmful consequences are either direct, through the consumption of contaminated food, or indirect, through the intake of milk and other products obtained from livestock fed with contaminated feeds, which also affects animal health and wellbeing. Another effect of CC relates to animal HS, which occurs when the body temperature is higher than the optimal range specified for the normal activity. Heat-stressed animals change their metabolism and physiology in response to weather conditions. This contribution discusses these two key issues based on literature and presents the experimental tests that are being conducted in the Department of Agriculture, Food and Environment of the University of Pisa in order to assess the effects of different farming systems on mycotoxins levels in *Zea mais* L. and the wellness of animals under HS conditions.

INTRODUCTION. – The evolution of mixed crop-livestock systems will be of critical importance in helping to meet an overall growing food demand (expected to rise by 60-110% by 2050, Steinfeld *et al.* 2006) and align with the changes in food consumption patterns and diet composition, also linked to urbanization and income growth, particularly in developing countries (Alexandratos & Bruinsma 2012). It has

*Corresponding author: giuseppe.conte@unipi.it

been suggested that climate change (CC) is responsible for up to a 1/3 of yield variability in key staple commodities on a global basis (Ray *et al.* 2013), with profound impacts on food security, and in different continents. Climate change may have numerous and significant impacts on crop and livestock production systems as well (Nardone *et al.* 2010). Changing climate conditions will determine not only crop productivity and quality variations linked to plants, but also on pests and pathogens, and on host-pathogen interactions (Medina *et al.* 2017). Among other consequences, the contamination of animal feed by mycotoxins (*i.e.*, secondary metabolites harmful to both humans and animals) and animal health under heat stress (HS) conditions are particularly relevant.

The world demand for commodities commonly used in the manufacture of animal feed, such as maize, wheat, and soybean has been steadily rising in recent years, driven by high demands for livestock production. This has led to an increased awareness of animal feed safety issues as feed consumption is a potential route for chemical hazards for the human food chain. Mycotoxins represent a serious threat to the feed supply chain, animal and human health. Despite the difficulties in providing precise figures on the economic costs of mycotoxins, the Food and Drug Administration has estimated losses on the American agricultural sector as $ 932 million/year (CAST Report 2003), of which $ 9 million/year linked to the reduction of the productive performances of the animals that ingest these substances. FAO has estimated that losses due to mycotoxins in the poultry sector alone (one of the most affected sectors), would exceed $ 100 million/year on a global scale (Devegowda *et al.* 2005).

This contribution acknowledges that a more detailed understanding of the impact of CC on mycotoxins formation and the effects of HS on animal health are needed for the benefit of crop and livestock systems. This allows eventually to elaborate more suitable adaptation strategies and solutions to face CC now and in the future.

The next sections frame the two key problems (*i.e.*, cases) – mycotoxins in animal feed and animal HS – and describe, for each one, the research that is currently ongoing in the Department of Agriculture, Food and Environment (DAFE) of the University of Pisa to address those issues and suggest possible solutions.

Case 1. Contamination of livestock feed by mycotoxins: key research questions and available solutions. – Almost all mycotoxins present in food and feeds are produced in the field (Battilani *et al.* 2016), influenced by key factors, such as temperature, relative humidity, water availability, and insects' attacks. Some of these fungi exhibit a tremendous physiological plasticity, which has contributed to their ability to adapt to, and thus colonize, a wide range of ecological niches including many staple foods, including cereals (Stevenson *et al.* 2016). In fact, cereals are the main source of mycotoxin contamination in the human food chain, either directly, through the consumption of contaminated food, or indirectly, through the intake of milk and other products obtained from livestock fed with contaminated feeds. Global warming (GW) and changes in rainfall amount and distribution will probably bring about shifts in the onset and length of growing seasons and in the geographical range of certain crops (Thornton *et al.* 2014). In addition, they will likely lead to crops being subjected to an increased number of biotic and abiotic stress combinations, which affect the interaction between crops and fungal pathogens (Pandey *et al.* 2017). Consequently, the infection of crops by *Aspergillus flavus* and the concomitant risk of aflatoxin formation in the field could be favored.

Regulatory agencies have established limits to keep levels of mycotoxins in animal feed under control. The legislation applicable in the EU to products intended for livestock feed is very strict and can block export of feed from developing countries to their European trading partners. Nonetheless, the legislation on mycotoxins does not consider the frequently reported and worrying scenario of multi-mycotoxin contamination of single commodities and animal feed. Mycotoxin formation is a complex and multi-dimensional phenomenon and the worldwide contamination and distribution patterns are predicted to be significantly affected by CC because of the appearance of favorable environmental conditions for fungal proliferation in uncommon places.

In Italy, cereals (*i.e.*, maize and wheat) are the most important agricultural commodities that may be contaminated by mycotoxins and the main effective way to reduce their presence in crops is hindering its development during crop production in the field and in post-harvest phases. A non-additive effect seems to be involved and other factors, such as environmental conditions and agricultural practices could play a role in mycotoxins occurrence and modulation. The ways to reduce fungal growth and mycotoxins contamination involves practices that are employed in pre-harvest, during harvest and drying, and in post-harvest (including detoxification approaches; Marroquín-Cardona *et al.* 2014). Pre-harvest strategies primarily consist of practices designed to reduce infection by ear-rot fungi. Different farming systems (*e.g.,* conventional *vs* organic) and practices (*e.g.,* soil tillage and crop rotation) may influence the mycotoxins concentrations in cereal grains. Another approach that may contribute to pre-harverst management decisions is to predict mycotoxin concentrations based on environmental conditions (*i.e.*, temperature and water activity) and other risk factors. Mycotoxin production is fostered by high water activity and to slow down kinetics and biotransformation of these molecules, the moisture content must be maintained below a certain critical level for each commodity (Mannaa & Deok Kim 2017).

An appropriate time after maturation of plants and adequate moisture content of harvesting are critical steps to reduce risk of fungal infection. For this reason, harvesting operations and drying techniques have been developed in order to reduce the vulnerability of the grain to toxigenic fungi and to minimize the risk of mycotoxin development. In addition, multiple storage practices have been proposed to prevent and/or mitigate mycotoxin exposure. These include primary prevention strategies, which aim to avoid exposure (*e.g.,* the maintenance of proper storage conditions) and secondary intervention strategies, which modulate metabolism, thereby detoxifying mycotoxins and reducing their internal dose. Several physical and chemical remediation/detoxification strategies have been developed (Luo *et al.* 2018). They are commonly separated into physical, chemical, and biological methods.

New strategies supported by predictions and modelling approaches should be adopted in order to reinforce mycotoxins management, to prevent human and animal exposure and related health risk (Battilani *et al.* 2016). Management and supporting tools could be developed to (i) highlight optimum/marginal conditions for growth and mycotoxin productions (*e.g.,* water activity and temperature), (ii) anticipate potential control options and (iii) predict future scenarios.

ONGOING RESEARCH ACTIVITY IN MYCOTOXINS MANAGEMENT STRATEGIES. – An experimental study was performed in the framework of PRA 2018-2019 project (entitled Management strategies of mycotoxins in maize) financed by the University of Pisa. Field trials were conducted at the Centre for Agro-Environmental Research "Enrico Avanzi" of the

University of Pisa, located in San Piero a Grado, Italy. The aim was to study the effect of different farming systems (conventional *vs* organic) on mycotoxins levels in *Zea mais* L. The differences between conventional and organic maize cultivation concerned the fertilization and the weed control strategy. Post-emergence harrowing or in-row flaming *plus* precision soil cultivation were used for weed control within the organic farming system. Post-emergence in-row flaming or herbicide application *plus* soil cultivation were used for weed control within the conventional farming system. Leaf, soil and grain samples were collected at 0, 15, 30, 45, 60, 75, 90, 105 and 120 days from the sowing. At the same time, the crop-soil water status and the content of aflatoxins were measured. In particular, water activity inside the plant and/or soil samples was measured by using an innovative bench psychrometer. This monitoring will allow analyzing how the water status of the crop soil water status influences the aflatoxin content and accumulation in each segment of the maize production. A vision based weeds identification was performed.

Case 2. Animal health under heat stress conditions. – Animals go through HS when the body temperature is higher than the optimal range specified for the normal activity because the total heat load is greater than the capacity for heat dissipation (Bernabucci *et al.* 2010). The thermal comfort zone for temperate-region adult cattle is in the range between 5 and 15°C (as proposed by Hahn *et al.* 2003). McDowell (1972) revealed that significant changes in feed intake and physiological processes occur with temperatures greater than 25°C. However, the thermal comfort zone is also related to several other factors, including relative humidity and air speed, genotype, physiological state, thermal susceptibility, acclimation and diet.

Animals attempt to maintain the body temperature increasing heat loss and reducing heat production by physiological and behavioral responses. Behavioral adaptation to cope with environmental conditions is the learning process habituation. Welfare is a characteristic of an animal, which varies from poor to very good and can be defined by discrete measures, such as changes in hormone level, body temperature, and normal behavior. Poor welfare will develop when an animal has difficulty in coping with its environment. There is a lot of overlap between productive and welfare measures, such as disease, mortality risk, growth, milk yield and reproduction.

The initial responses are homeostatic mechanisms and include an increase of water intake, loss of body fluids due to sweating, panting, heart rate during short-term exposure to heat and a concomitant reduction in fecal and urinary water losses and feed intake. When the exposure to thermal load is prolonged, heat acclimation is achieved and includes reduction of growth hormone, catecholamine, glucocorticoid, and thyroid hormones, with consequent reduction of the basal metabolic rate and thus heat production (Bernabucci *et al.* 2010).

During HS, rumination is reduced, and a lower blood flow to rumen epithelium is observed. In heat-stressed animals, the fractional rate of digesta passage in the gastrointestinal tract is slower, which reflects reduced intake, ruminal activity, and motility. Nevertheless, changes in microclimatic conditions can induce alterations in the activity and function of the digestive system, which are independent of changes in feed intake. The primary negative effect of high temperature is a depression of rumination time, which subsequently led to a reduction of the feed intake, followed by a decline in milk yield.

A different daily pattern of feed intake was observed in heat-stressed cows and, considering the relationship between dry matter intake and rumination time, a different daily behavior of rumination time in the hot season could be expected.

Three management strategies have been identified to minimize the effects of HS: (i) physical modification of the environment, (ii) genetic development of heat tolerant breeds and (iii) improved feeding and nutritional management practices. Reduced feed intake occurring in animals exposed to hot environments partly explains the biological mechanism by which HS impacts production and reproduction (Bernabucci *et al.* 2010). Heat stress is becoming a serious problem because of the negative impacts on ruminant performance. This will become more severe in the future, as a consequence of GW and genetic selection for milk yield.

Heat-stressed animals change their metabolism and physiology in response to CC. The direct and indirect effects of HS affect gastrointestinal health and functionality strongly influencing the efficiency of diet utilization. The changes in nutrient partitioning and the alteration of rumen and intestine functionality should be taken into account when nutritionists will approach the formulation of "hot diets". Some studies showed that diets rich in starch and poor in fiber reduced HS in lactating dairy cows because the metabolized energy from high concentrate diets is used with greater efficiency than the metabolized energy from high forage diets. However, dietary fiber is necessary in adequate amounts to ensure a correct rumen activity, considering the negative effect of HS on ruminal temperature, saliva production and salivary bicarbonate content, decline in rumen motility, and altered acid-base balance (Conte *et al.* 2018).

RESEARCH ACTIVITY IN HEAT-STRESSED ANIMALS. – In order to assess the wellness of an animal HS conditions, tests are being conducted with the DAFE. In particular, the aims of this experiment are to evaluate physiological responses of beef cattle kept in feedlot or pasture, during the Mediterranean hot season, by the estimation of relationship between hair cortisol and rectal temperature.

CONCLUSION. – The new challenges that agriculture is facing (CC, increased demand for animal products, reduction in arable land) impose new strategies to improve the national and global production systems. With this objective in mind, the activities described in this contribution aim to assess how to cope with new needs to improve livestock production in relation to the sharp rise in temperatures and the growing problem of food contamination for animal nutrition.

ACKNOWLEDGMENTS. – This study was performed in the framework of PRA 2018_17 project entitled “Management strategies of mycotoxins in maize” financed by the University of Pisa.

REFERENCES

Alexandratos N., Bruinsma J. (2012). World Agriculture Towards 2030/2050. FAO, Rome, 160 pp.

Battilani P., Toscano P., Van der Fels-Klerx H.J. *et al.* (2016). Aflatoxin B1 contamination in maize in Europe increases due to climate change. Scientific Reports 6: 24328.

Bernabucci U., Lacetera N., Baumgard L.H. *et al.* (2010). Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Animal 4: 1167-1183.

CAST Report (2003). Mycotoxins: risks in plant, animal, and human systems. In: “Council for Agricultural Science and Technology Task Force Report No. 139” (Richard J.L., Payne G.A. Eds). Ames, Iowa, USA.

Conte G., Ciampolini R., Cassandro M. *et al.* (2018). Feeding and nutrition management of heat-stressed dairy ruminants. Italian Journal of Animal Science, doi: 10.1080/1828051X.2017.1404944.

Devegowda G., Murthy T.N.K, Diaz D.E. (2005). Mycotoxins: their effects in poultry and some practical solutions. In “The mycotoxin blue book” (Diaz DE ed.). Nottingham University Press, Nottingham, UK, pp. 25-56.

Hahn G.L., Mader L., Eigenberg A. (2003). Perspective on development of thermal indices for animal studies and management. Environmental Stress and Amelioration in Livestock Production 7: 31-44.

Luo Y., Liu X., Li J. (2018). Updating techniques on controlling mycotoxins. A review. Food Control 89: 123-132.

Mannaa M., Deok K. (2017). Influence of temperature and water activity on deleterious fungi and mycotoxin production during grain storage. Mycobiology 45: 240-254.

Marroquín-Cardona A.G., Johnson N.M., Phillips T.D. *et al.* (2014). Mycotoxins in a changing global environment - A review. Food and Chemical Toxicology 69: 220-230.

McDowell R.E. (1972). The animal body in warm environment. In "Improvement of livestock production in warm climates" W.H. and company, Freeman, San Francisco, pp. 65-100.
Medina Á., González-Jartín J.M., Sainz M.J. (2017). Impact of global warming on mycotoxins. Current Opinion in Food Science 18: 76-81.
Nardone A., Ronchi B., Lacetera N. *et al.* (2010). Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science 130: 57-69.
Pandey P., Vadivelmurugan I., Bagavathiannan M. *et al.* (2017). Impact of combined abiotic and biotic stresses on plant growth and avenues for crop improvement by exploiting physio-morphological traits. Frontiers in Plant Science 8: 537.
Ray D.K., Mueller N.D., West P.C. *et al.* (2013). Yield trends are insufficient to double global crop production by 2050. PLoS ONE 8: e66428.
Steinfeld H., Gerber P., Wassenaar T. *et al.* (2006). Livestock's long shadow. FAO, Rome, 377 pp.
Stevenson A., Hamill P.G., Medina Á. *et al.* (2016). Glycerol enhances fungal germination at the water-activity limit for life. Environmental Microbiology 19: 947-967.
Thornton P.K., Ericksen P.J., Herrero M. *et al.* (2014). Climate variability and vulnerability to climate change: a review. Global Change Biology 20: 3313-3328.

Organic farming systems for adaptation to and mitigation of climate change: effects on soil fertility and resource use efficiency

MARCO MAZZONCINI[1], DANIELE ANTICHI[1*], MASSIMO SBRANA[2], PAOLO BÀRBERI[3], STEFANO CARLESI[3], LORENZO GABRIELE TRAMACERE[2], MARCELLO MELE[2]
[1]Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto, 80 - 56124 Pisa
[2]Centre for Agro-environmental Research "Enrico Avanzi", Via Vecchia di Marina, 6 - 56122 San Piero a Grado, Pisa
[3]Institute of Life Sciences, Scuola Superiore S. Anna, Pisa

Keywords: diversification, cropping systems, agroecology, green manure, soil organic carbon

ABSTRACT. – Organic farming is pointed as one of the most sustainable farming practices in terms of environmental sustainability and climate change mitigation potential. At the core of organic farming practices there are practices aimed at improving soil fertility, increasing soil C content and enhancing system biodiversity. A long-term field experiment (LTE) (MASCOT) was started on 2001 in San Piero a Grado, Pisa (Italy) with the aim to compare two different cropping systems, one managed organically and one conventionally, in terms of agronomical, economic and environmental sustainability. In 2016, the MASCOT was redesigned as a full system trial and the organic system was reshaped according to up to date agroecological standards. Climate change adaptation capacity of the two systems is being assessed through agronomic and economic parameters, whilst greenhouse gas emission mitigation potential is mainly expressed in terms of soil C sequestration.

ORGANIC FARMING AND CLIMATE CHANGE. – Although agriculture is one of the human activities more affected by climate change, it is also claimed to contribute to it significantly. According to the most recent report from the IPCC (2019), it is estimated in 23% the contribution of agriculture, forestry and other land uses to total human greenhouse gas emissions (GHGs). Besides conversion of natural soils to agriculture, the most important agricultural GHG direct sources are ruminant fermentation and soil respiration. In addition, intensive agricultural practices have led to deforestation, overgrazing and soil fertility degradation. Sustainable farming methods are thus needed to enhance the capacity

*Corresponding author: daniele.antichi@unipi.it

of agricultural systems to “adapt to unpredictable and extreme weather conditions such as droughts and floods, reduce greenhouse gas emissions in primary food production and halt or reverse carbon losses in soils” (Niggli *et al.* 2007).

Organic agriculture is widely considered as one of the most sustainable approaches in food production. According to its definition by the Codex Alimentarius Commission, “organic agriculture is a holistic production management system that avoids use of synthetic fertilizers, pesticides and genetically modified organisms, minimizes pollution of air, soil and water, and optimizes the health and productivity of interdependent communities of plants, animals and people” (Codex Alimentarius Commission 2001). Organic farming emphasizes the use of natural resources internal to the agroecosystems, the recycling of organic matter and practices supporting soil fertility and diversity at all levels. Soil fertility is at the core of organic farming since its first definitions and applications, and farming practices aimed at increasing soil organic matter content are of paramount importance to sustain the productivity of the land in the long term. Among these practices, the cultivation of green manures and cover crops, the application of organic amendments (*e.g.*, animal manure, composts) to the soil, the diversification of cropping systems through crop rotations and mixed cropping (*e.g.,* intercropping, agroforestry systems, variety mixtures and polycultures) to increase and diversify the organic matter returning to the soil are the most impacting on soil carbon (Scialabba and Müller-Lindenlauf 2010).

Thanks to the intensive use of these practices, organic management has been shown to store, on average, 3.5 Mg ha^{-1} more C in the soil than conventional management, as reported in the metanalysis of Gattinger *et al.* (2012). This amount explains the great interest that organic farming is drawing as potential climate change mitigation strategy, given the very low share of land managed organically in the world, estimated in only 1.4% in 2017 (Willer and Lernoud 2019). The potential of organic agriculture to contribute to the mitigation of GHG emission could be even higher if also indirect GHG savings (*e.g.,* N_2O emissions reduced by avoiding the use of mineral fertilisers) are considered (Scialabba and Müller-Lindenlauf, 2010).

In terms of adaptation, compared to conventional systems, organic agriculture systems are expected to be more resistant and resilient against adverse climatic conditions and its implications (*e.g.,* increasing prices of fossil fuel-derived technical means). This is mostly due to the reduced use of external inputs and the normally higher diversity of crops and animals grown in organic farms than in conventional ones (Scialabba and Müller-Lindenlauf 2010).

MEASURING THE PERFORMANCES OF ORGANIC SYSTEMS: THE MASCOT LTE. – Long-term experiments (LTEs) are field trials where experimental factors are being applied repeatedly on the same piece of land for many years, with the aim to test scientific hypotheses dealing with phenomena unravelling only in the long run or producing significant information only on an extended time frame. Cropping systems are often tested in LTEs, due to their complexity and wide range of performance indicators included, for instance, in sustainability assessment framework (*i.e.*, economic, agronomical, environmental parameters). Studying organic cropping systems requires also a holistic approach as the contribution of single components of the cropping system is less important than the whole set of functions and interactions among all the elements.

The MASCOT (Mediterranean Arable System COmparison Trial) is a LTE started in 2001 at the Centre for Agri-environmental Research "Enrico-Avanzi" (CiRAA) of the University of Pisa, San Piero a Grado, Pisa, Italy, and managed by CiRAA and Scuola Superiore Sant'Anna (SSSA), Pisa, Italy (Bàrberi and Mazzoncini, 2006). In the MASCOT, two arable cropping systems, one organic (OS) and one conventional (CS) have been compared on a loam soil until 2016, based on the same crop rotation (5-yr sequence with cereals and industrial crops), without any forage crop nor animal manure application ("stockless") and in rainfed conditions. Besides crop rotation, other elements of the cropping systems were constant between OS and CS, namely crop variety and soil tillage.

The first fifteen years of crop rotation practiced in these experimental conditions allowed for highlighting important general trends. Compared to CS, OS was shown to significantly improve soil fertility, in particular soil organic matter, microbial activity and soil biodiversity (Mazzoncini *et al.* 2010). From the energy efficiency point of view, OS was demonstrated to use less inputs per unit of land area respect to CS (Mazzoncini *et al.* 2011). CS conditions increased the yield of all the cereals in crop rotation, whilst less N-demanding crops yielded similar in the two systems. Crop produce quality was also investigated (Mazzoncini *et al.* 2015).

THE REDESIGN OF THE MASCOT LTE. – The layout of the MASCOT allowed anyway for a critical revision of the systems at the end of each cycle of the crop rotation, in order to readjust the management for embedding innovative practices or fine-tuning problematic components of the systems. This opportunity was exploited to replace crops which became out of business for farmers due to policy decisions (*e.g.,* sugarbeet in 2006), or to adjust the technique for cover crop management. In the meanwhile, the global context of the organic farming completely changed, thus making outdated the initial research questions. In the age of "organic agriculture 3.0" (Rahmann *et al.* 2016), it makes still not sense to investigate whether organic management of arable crops could perform similarly or not to conventional. The organic farming movement has been rewarded of full trust also in the science community, but at the same time is now challenged also in terms of contribution to big societal challenges as climate change mitigation.

That is why in 2016 it was decided to shift towards a full systemic approach and to redesign the two systems, taking into account also the agroecological principles establishing the new sustainability paradigms behind both organic and "conventional" systems (Antichi *et al.* 2018). In the OS, the crop sequence was enlarged to 8-yr rotation including emmer wheat (*Triticum turgidum* subsp. *dicoccum*), a 3-yr alfalfa (*Medicago sativa* L.) meadow, common wheat (*Triticum aestivum* L.), grain sorghum (*Sorghum bicolor* (L.) Moench.), grain millet (*Panicum miliaceum* L.), a grain legume (chickpea - *Cicer arietinum* L.) and two legume cover crops (pigeon bean - *Vicia faba* var. *minor* Beck., hairy vetch - *Vicia villosa* Roth.). Fertilization strategy includes the use of organic fertilisers to supply C to the soil (simulating availability of animal manure produced by a number of animals sustainable for the considered acreage and crop rotation), and tillage was differentiated respect to the crops in order to achieve a good weed suppression and a good soil structure. In the CS, the crop rotation was reduced to 4 years, and sod-seeding of winter wheat was introduced, aiming at improving soil fertility and reducing cultivation costs. The new market-oriented crop rotation includes common wheat, chickpea, durum wheat (*Triticum turgidum* subsp. *durum* (Desf.) Husn.) and grain sorghum.

EXPECTED FUTURE RESULTS. – This shift in the methodological approach is expected to increase the impact of the MASCOT on local farmer community and to provide more robust scientific results in the mainstream of agroecological transition of current agricultural systems towards the target of climate change mitigation and adaptation. The redesigned OS is more likely to become a reference for organic farmers in the region as it was designed embedding also the standard practices suggested by some of them.

The experimental protocol of the MASCOT includes periodical sampling of soil cores to assess the effect of the two cropping systems on soil fertility, with a special focus on organic carbon, its fractions (*i.e.*, labile and stabile fractions) and interactions with soil physics and microbial activity. Recording also the amount of C outcoming or incoming the systems each year, it will be possible to estimate the C sequestration rate (*i.e.*, the amount of C that is stocked into the soil each year per area unit) and the C budget. Both indicators will provide a clear picture on the GHG emission mitigation potential of the two systems.

Monitoring crop performances across years respect to specific weather conditions, it will be possible also to determine the capacity of the two systems to adapt to current climatic conditions and see whether this ability would change at different ages of the systems.

Finally, as the elementary plots of the MASCOT have a real field size (0.35-1 ha), it will be possible to compute also energetic and economic efficiency of the two systems, allowing to estimate also the cost of the implementation of climate smart practices.

POSSIBLE COLLABORATIONS. – The MASCOT is an open-air laboratory available for scientists from other disciplines. We foresee the potential for fruitful collaborations with colleagues studying direct GHG emissions, water balance, biodiversity (*e.g.,* insects, microorganisms), microclimatic modifications, plant pathology, agricultural economy and social sciences.

ACKNOWLEDGEMENTS. – The authors acknowledge the staff of CiRAA for their precious support and enormous efforts in conducting the LTE.

REFERENCES

Antichi D., Mazzoncini M., Barberi P. *et al.* (2018). The re-design of the MASCOT long-term experiment: shifting towards a full system approach. 2nd International GRAB-IT workshop 2018 Organic farming and agro-ecology as a response to global challenges. Capri.

Bàrberi P., Mazzoncini M. (2006). The MASCOT (Mediterranean Arable Systems Comparison Trial) long-term experiment. In: Raupp J., Pekrun C., Oltmanns M., Kopke U. (Eds), Long-term Field Experiments in Organic Farming. ISO-FAR Scientific Series, Verlag Dr. Köster, Berlin, pp. 1-14.

Codex Alimentarius Commission (2001). Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods. First Revision. Joint Food and Agriculture Organisation (FAO) and World Health Organisation (WHO) Food Standards Program, Rome, Italy. Available at *http://www.codexalimentarius.net/download/standards/360/CXG_032e.pdf*.

Gattinger A., Muller A., Haenia M. *et al.* (2012). Enhanced top soil carbon stocks under organic farming. Proceedings of the National Academy of Sciences 49: 18226-18231.

IPCC (2019). IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems.

Mazzoncini M., Antichi D., Silvestri N. *et al.* (2015). Organically *vs* conventionally grown winter wheat: effects on grain yield, technological quality, and on phenolic composition and antioxidant properties of bran and refined flour. Food Chemistry 175: 445-451.

Mazzoncini M., Canali S., Giovannetti M. *et al.* (2010). Comparison of organic and conventional stockless arable systems: a multidisciplinary approach to soil quality evaluation. Applied Soil Ecology 44: 124-132.

Mazzoncini M., Migliorini P., Belloni P. *et al.* (2011). Long-term arable cropping system experiments in Tuscany reveal higher energy efficiency with organic than conventional management. Proceedings of the 1st Congress of RIRAB (Italian Research Network on Organic Farming), 7-8 November 2011. Catania, p. 52. ISBN: 978-88-8286-250-3.

Niggli U., Fliessbach A. (2007). Organic Farming and Climate Change. Technical Paper of the ITC. Geneva, Switzerland.

Rahmann G., Ardakani M.R., Bàrberi P. *et al.* (2016). Organic Agriculture 3.0 is innovation with research. Organic Agriculture, doi 10.1007/s13165-016-0171-5.

Scialabba N.H.E., and Müller-Lindenlauf M. (2010). Organic agriculture and climate change. Renewable Agriculture and Food Systems 25: 158-169.

Willer H., Lernoud J. (Eds) (2019). The World of Organic Agriculture. Statistics and Emerging Trends 2019. Research Institute of Organic Agriculture, Frick, and IFOAM - Organics International, Bonn.

SESSION 3
EFFECTS ON AGROECOSYSTEMS

The phenological phases monitoring of perennial species as a marker of environmental changes: the case-study of apricots grown in the Tyrrhenian coastal area at the experimental fields of Pisa University

SUSANNA BARTOLINI[1*], ROSSANO MASSAI[2], CALOGERO IACONA[2], ROLANDO GUERRIERO[2], RAFFAELLA VITI[2]
[1]Institute of Life Sciences, Scuola Superiore Sant'Anna, Piazza Martiri della Libertà 33 - 56127 Pisa
[2]Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto, 80 - 56124 Pisa

Keywords: Prunus armeniaca, apricot, blooming date and blooming intensity, chilling units

ABSTRACT. – Since the 1970s, at the experimental site of the Department of Agriculture, Food and Environment of Pisa University located along the Tyrrhenian coastal area of Tuscany, a germplasm collection of apricot varieties is present. It is one of the most wide collection of UE, grouping more than 350 Italian and foreign genotypes coming from the main apricot world counties. After a long-term period of study, some important information were acquired about the biological and agronomical behaviour of varieties grown in a typical Mediterranean area. Over the years, particularly since the 1990s**,** the winter climate has shown a tendency to become progressively milder. This event greatly affected key biological processes such as the overcoming of flower bud endodormancy, blooming date and entity. Some cultivars had a certain plasticity to face changing environmental climatic conditions being able to overcome the bud endodormancy. Nevertheless, they showed important blooming delays and a constant decrease of the flowering intensity which nowadays reached values of 50%. The irregular autumn-winter cold rate of last years may highlight that substantial impacts will be expected about the site of apricot orchards, imposing the finding of resilient genotypes as main requisite to achieve worthy yields.

INTRODUCTION. – Germplasm collections represent a very useful tool for studying the perennial species over long-term times. In this way, it is possible carrying out constant observations on the main yearly biological and physiological processes of plants and to define their relationship with the changing environmental and climatic conditions, variable out of human control.

[*]Corresponding author: susanna.bartolini@santannapisa.it

Since the 1970s, the Department of Agriculture, Food and Environment of Pisa University instituted a germplasm collection of apricot varieties *(Prunus armeniaca* L.) along the Tyrrhenian coastal area of Tuscany (Venturina, Livorno). It is one of the most wide collection of EU, counting more than 350 Italian and foreign genotypes coming from the main apricot world countries. For over 40 years, studies have been carried out aiming to observe the behaviour of different accessions under the same climatic conditions. Phenological phases (blooming and ripening date and intensity), amount and quality of fruits were recorded annually. Moreover, the most interesting varieties were included in specific experimental trials on understanding crucial aspects such as the dormancy evolution of buds, the flower biology, the physicochemical and nutraceutical traits of fruits. Some valuable varieties were used as parents in breeding programs, obtaining patents of new appreciated apricot cultivars such as Antonio Errani, Pisana, Dulcinea (Guerriero *et al.* 2006a), widespread in the main apricot cultivation areas.

The genotype-specific environmental conditions requirement is a crucial feature to ensure a regular life cycle, guaranteeing constant yields over years. Regardless of the causes, in these last years the tendency of winters to become milder has been significantly disturbing important biological and physiological processes of many fruit species, including apricot (Guo *et al.* 2015). Climate models are forecasting for an increase of temperatures by the end of the 21st century, especially for the Mediterranean basin areas and southwestern regions. Thus, in a context of global warming, we can therefore expect that warmer winter temperatures could greatly compromise the satisfaction of chilling requirement (CR) for the overcoming of flower bud endodormancy which depends on the perception of certain amount of cold temperatures. As a consequence, negative repercussions could arise on the resumption of bud growth, flowering and fruit-set, considering that the plants have been giving probe of reliable bio-indicators of climate change by phenological variations as a function of vulnerable environmental conditions (White *et al.* 2009).

In this paper we report the results obtained from a long-term period of biological and agronomical observations (1973-2016) carried out on a large number of apricot cultivars (> 40), grown in the same mesoclimatic conditions and subjected to the same routine conventional horticultural managements (pruning, thinning, fertilization, pest and disease protection) at the Unipi's experimental fields in Venturina. Analysis were particularly focused on crucial biological processes, such as endodormancy release of flower buds and blooming intensity, on which fruit yield depends. Their understanding will provide useful suggestions tools for the future prediction of apricot fruiting success under climate change.

THE TREND OF CHILLING TEMPERATURES OVER A 40-YEAR PERIOD AND ITS INFLUENCE ON ENDODORMANCY RELEASE OF FLOWER BUDS AND BLOOMING OF APRICOTS. – During the autumn-winter season, the plant elaborates mechanisms for survival under unfavorable growing conditions by adopting a dormancy strategy to cold temperature acclimation. Meristem activity becomes insensitive to growth-promoting signals preserving the buds in a quiescent state under potentially damaging environmental conditions (Ćechová *et al.* 2012). Bud dormancy starts with the perception by the plant of rest-signals under the influence of short and cool days; this process finishes after an accumulation of chilling temperatures. Thus, autumn-winter temperature trends are related to the need for a specific satisfaction of CR for dormancy breaking. An unfulfilled CR, due to winter mild temperatures, exerts a decisive influence on endodormancy release, development of flower buds, appearance of floral anomalies, leading to a loss of productivity (Viti *et al.* 2006; Guerriero *et al.* 2010).

CHILLING UNITS. – Under our environmental conditions and over the autumn-spring seasons, temperatures were logged by instruments (thermo-hydrometers and data-loggers) located inside the orchards able to record daily measurements of hourly air temperatures used for the calculation of chill accumulation, according to the Chilling Units (CU) model (Richardson *et al.* 1974).

Since 1976, from November to the end of January, the CU amount gradually decreased up to 2016 when just over 800 CU were recorded (Fig. 1). At this time, a strong CU decrease (around 40% of 1300 CU recorded in 1970s) occurred by an average loss of about 60 CU/five-year. However, the most dramatic losses were found from 2000s, when the 1000 CU threshold, crucial for the endodormancy overcoming of most apricot cultivars needing a low-medium chilling requirement, was no longer attained (Bartolini *et al.* 2019). A similar trend, towards a reduction in chilling accumulation, has been also verified in several other perennial fruit crop areas (Campoy *et al.* 2011).

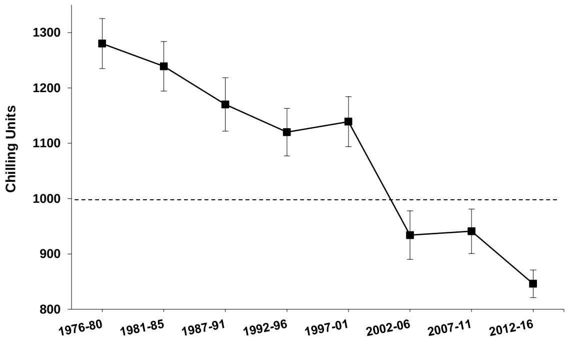


FIG. 1. Cumulated chilling units up to January 31th, from 1976 to 2016. Data are shown as 5-year averages (± SE). Dotted line indicates the 1000 CU threshold-amount.

In the last fifteen years, the lower effectiveness of temperatures able to determine a good CU number has been mainly due to an increase of warmer autumn-winter seasons. This climatic trend frequently caused a very late attainment of 1000 CU, often after March 10th. In order to elucidate the temperature efficacy on CU accumulation, several regression analysis were carried out by minimum, maximum and average temperatures of single or joint autumn-winter months. In Figure 2 the most significant inverse relationships obtained from three temperature (T) sets are shown: i) average daily T of November (R^2 = 0.7976); ii) average of minimum T of November (R^2 = 0.6803); iii) average daily T from November to January (R^2 = 0.5437). The highest coefficient obtained by the daily average T of November confirmed that, over the autumn season, maximum and minimum daily temperature range during this month can play a key role for the chilling accumulation.

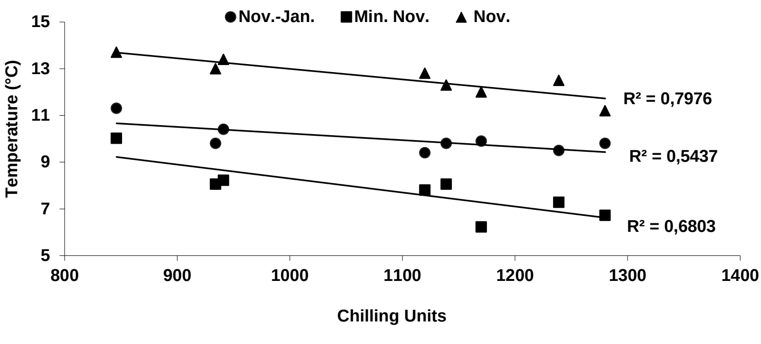


FIG. 2. Linear regression ($P \leq 0.05$) between cumulated chilling units and three sets of temperatures (T,°C): i) average T from November to January; ii) average T of November; iii) average minimum T of November. Data, from 1976-2016, are referred to 5-year periods.

Endodormancy release of flower buds. – The dormancy evolution of flower buds was studied over a 25 years period in two "model" cultivars characterized by different biological traits (Bartolini & Viti 2019): "San Castrese", at medium CR and reference-cultivar for the Italian regions with a high adaptability to different climatic locations, and "Orange Red", at high CR with problems concerning climatic adaptation in temperate production areas. The endodormancy release was estimated by the "forcing test" able to define the capacity of buds to respond to warm temperatures after exposure to low temperatures (Guerriero *et al.* 2006b). The studied apricot cultivars were able to overcome the dormancy of flower buds, showing a different match between endodormancy release and CUs accumulation (Fig. 3).

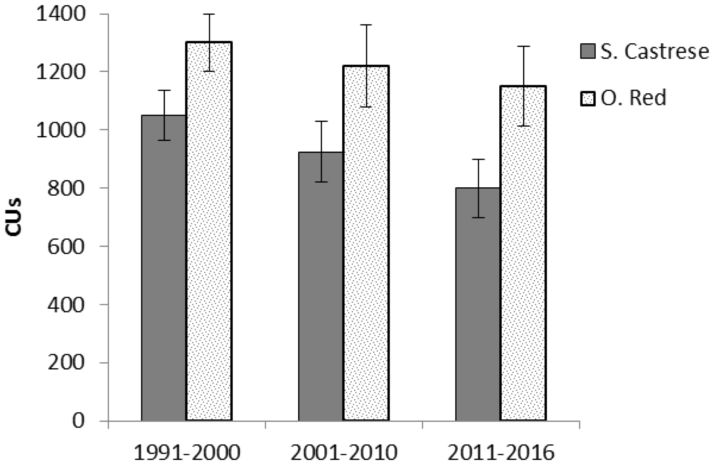


Fig. 3. Chilling Units (CUs) at the endodormancy release in "San Castrese" and "Orange Red" apricot cultivars, over a 25-year period (1991-2016). Data are means (±SD).

The weaker variations were observed in "Orange Red", although it showed an irregularity of yield mainly in years characterized by milder winters (*i.e.,* 2000, 2006, 2013). As a consequence, the endodormancy of flower buds was not broken causing a total lack of flowering. In other circumstances, the capacity to satisfy, at least partially, its high CR could be explained with the ascertained delay of useful chilling temperatures which, under our environmental conditions, can often occur in late winter (end February-mid March). Thus, this cultivar would have had time to recover valuable temperatures for its dormancy breaking.

In "San Castrese", the time of endodormancy breaking markedly changed over years, going from about 1000 in the 1990s to the current 800 CU. This occurrence could indicate a sort of adaptation to the ongoing changes of the autumn-winter temperatures which are able to drive the dormancy release in early cultivars like "San Castrese" (Andreini *et al.* 2014). The capacity to adjust to the environment could arise from activating synchronously those biological processes leading to blooming and fruiting. However, these changes caused disturbances on flowering, producing negative repercussions on yield performances even in "San Castrese", valuable cultivar for its well-known environmental adaptation. It is possible that, an increase of the daily minimum temperatures, mainly responsible to drive the dormancy release in early apricot cultivars (Andreini *et al.* 2014), can negatively interact with the dormancy process. In this cultivar stronger repercussions were observed by a constant decrease of the flowering intensity which nowadays reached values of 50%. Moreover, a substantial blooming delay of about ten days was recorded.

Blooming time and intensity. – During the last four decades, the blooming time of the studied 40-apricot cultivars, belonging to different blooming classes (early, mid and late), occurred over about one month. The average blooming date (F_{50}) was from February 24th (55 JD) to March 25th (84 JD). Between the last considered period (2012-16) and the first decade (1973-82), an overall blooming shift (BS) was recorded (Fig. 4).

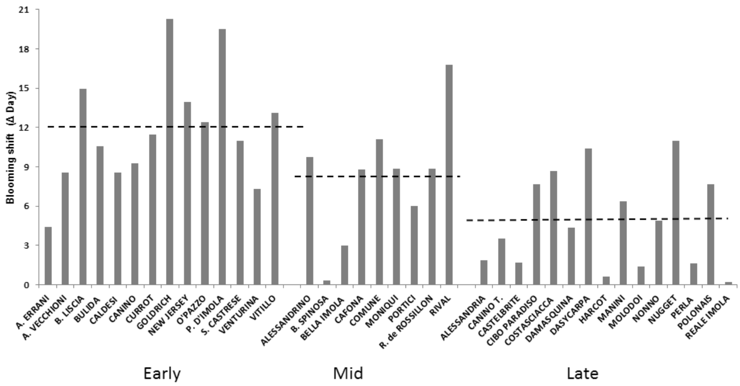


Fig. 4. Blooming time shift (BS, Δ-day) between last (2012-16) and first (1973-82) observation period of apricot cultivars ordered according to blooming classes (early, mid, late). For each cultivar group, dotted lines represent the BS average.

Cultivars belonging to the early-blooming class showed the highest average BS of around 12 days, while in the other ones a lowest but reliable BS change of about 8 (mid-blooming) and 5 days (late-blooming) was recorded (Bartolini *et al.* 2019a). Within each cultivar-class, the BS varied greatly with changes: from 4 to 20 days for the early cvs "Antonio Errani" and "Goldrich", respectively; from 1 to 17 days for the mid cvs "Boccuccia Spinosa" and "Rival", respectively; from 1 to 11 days for the late cvs "Harcot" and "Nugget", respectively. Regardless the fruiting habitus, chill temperatures seems to be the factor mainly involved in regulating the blooming time as documented in other temperate woody species that under inadequate chilling by warm autumn temperatures showed delayed and erratic budburst in the following spring (Darbyshire *et al.* 2017). Recently, a considerable flowering delay for peach and apricot cultivars has been observed in years characterized by low chilling accumulations (Martinez-Luscher *et al.* 2017). Under our environmental conditions too, the constant reduction of CU accumulated up to January 31st could have affected the blooming time producing the above-mentioned shifts. This statement was corroborated by the inverse relationships found between blooming time and CU (Fig. 5). As previously observed for BS, correlation analysis gave evidence of the highest coefficient for the early-blooming cultivars ($R^2 = 0.8354$) which showed a more clear tendency to postpone the flowering date once CU were reduced.

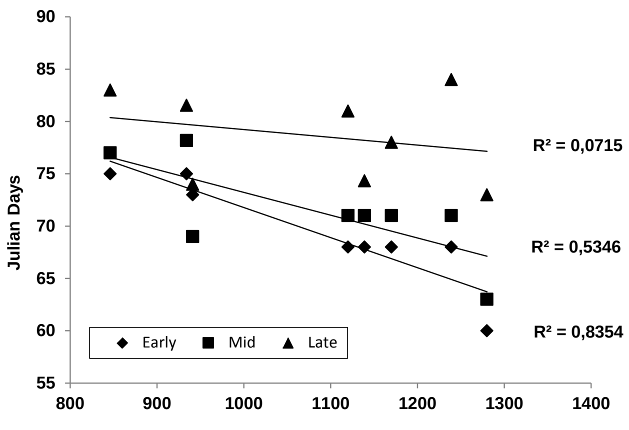


FIG. 5. Linear regression ($P \leq 0.05$) between blooming time (Julian Days) and chilling units accumulated at January 31st, over forty years (1976-2016). Apricot cultivars are grouped according to early, mid and late blooming class. Each point represents average data per 5-year periods.

As regards the blooming intensity, a general decrease was observed over years, particularly from the end of 1990s (Fig. 6). However, the early- and mid-blooming cultivars were able to maintain a valuable flowering entity (≥ 3) up to 2009, showing good performances under our environmental conditions. Climatic events occurred in the following years could have been responsible for the blooming intensity loss which reached values below 2.5. Indeed, particularly for the early-cultivars, blooming scores felt to levels around 50% with respect to previous periods (Bartolini *et al.* 2019a).

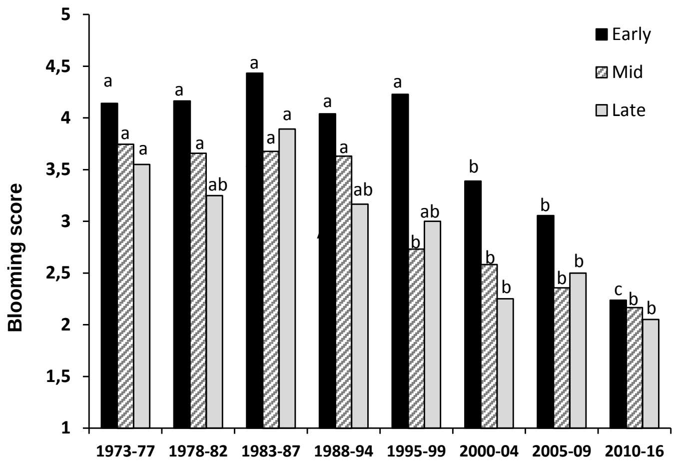


Fig. 6. Blooming scores (rate on a scale of 1-5, scanty-abundant) assigned to 40 apricot cultivars grouped according to different blooming time classes: early, mid and late. Data are shown by average of 5-year periods, from 1973 to 2016. Within each blooming class, different letters are significantly different ($P \leq 0.05$) according to Kruskal-Wallis's test.

The regression analysis between blooming score and CU amount at January 31th showed a positive and significant relationships by high coefficient values ($R^2 = 0.7543$-0.8853) for all cultivar-class. This result denoted as the strong decline of CU accumulation, during the deepest dormancy period of apricot flower buds (November-January), negatively affected the quality of buds leading to a flowering entity decrease. This occurrence confirmed the chilling accumulation as a key factor contributing to ensure a regular flower bud endodormancy overcoming. In addition, mild climate conditions may cause high rate of floral anomalies and unbroken flower buds as recorded in the main apricot production districts, with serious repercussions on fruit-set and, consequently, economical losses for producers.

CONCLUDING REMARKS. – The trend towards a later start of chilling and lower CU accumulation had consequences on the critical phase of endodormancy release time which influenced the blooming date and intensity. Significant changes were also noted for cultivars, like "San Castrese", well known for high adaptation to different environmental conditions. It was able to conform its dormancy to the progressive warming of autumn-winter season but, this ability to face the ongoing changing of the environmental conditions did not prevent the onset of biological and physiological disorders resulting in a delay of blooming date as well as a drastic reduction of flowering intensity. Based on the irregular autumn-winter cold rate of the last years serious alterations of the biological processes of apricot leading to yield losses are expected in traditional sites of apricot culture, imposing the finding of resilient genotypes as main requisite to achieve worthy yields.

In the future, a possible geographic shift for apricot cultivation areas towards more potential suitable regions located northernmost will be predictable. Thus, to face the challenge of the coming years, special efforts to find resilient genotypes are required to preserve the apricot culture under the climate conditions of the Mediterranean areas.

REFERENCES

Andreini L., García de Cortázar-Atauri I. *et al.* (2014). Understanding dormancy release in apricot flower buds *(Prunus armeniaca* L.) using several process-based phenological models. Agricultural and Forest Meteorology 184: 210-219.

Bartolini S., Viti R. (2019). Local climate change affects the apricot blooming in Tuscany (Italy). Acta Horticulturae (*in press*).

Bartolini S., Massai R., Iacona C. *et al.* (2019). Forty-year investigations on apricot blooming: evidences of climate change effects. Scientia Horticulturae 244: 399-405.

Campoy J.A., Ruiz D., Egea J. (2011). Dormancy in temperate fruit trees in a global warming context: A review. Scientia Horticulturae 130: 357-372.

Ćechová J., Baránek M., Krska B. *et al.* (2012). Screening of differentially expressed genes during the end of endogenous dormancy of flower buds in *Prunus armeniaca* L. Plant Growth Regulation 67: 141-150.

Darbyshire R., Farrerac I., Martinez-Lüscherd J. *et al.* (2017). A global evaluation of apple flowering phenology models for climate adaptation. Agricultural and Forest Meteorology 240: 67-77.

Guerriero R., Monteleone P., Iacona C. (2006a). Apricot breeding in Pisa: some new selection for Italian growers. Acta Horticulturae 701: 341-346.

Guerriero R., Monteleone P., Viti R. (2006b). Evaluation of end of dormancy in several apricot cultivars according to different methodological approaches. Acta Horticulturae 701: 99-103.

Guerriero R., Viti R., Iacona C. *et al.* (2010). Is apricot germplasm capable of withstanding warmer winters? This is what we learned from last winter. Acta Horticulturae 862: 265-272.

Guo L., Dai J., Wang M. *et al.* (2015). Responses of spring phenology in temperate zone trees to climate warming: a case study of apricot flowering in China. Agricultural and Forest Meteorology 201: 1-7.

Martínez-Lüscher J., Hadley P., Ordidge M. *et al.* (2017). Delayed chilling appears to counteract flowering advances of apricot in Southern UK. Agricultural and Forest Meteorology 237: 209-218.

Richardson E.A., Seeley S.D., Walker R.D. (1974). A model for estimating the completion of rest for Red Haven and Elberta peach. Horticultural Science 9: 331-332.
Viti R., Bartolini S., Guerriero R. (2006). Apricot floral biology: the evolution of dormancy and the appearance of bud anomalies in several Italian genotypes. Advances in Horticultural Science 20: 267-274.
White M.A., Beurs D., Kirsten M. *et al.* (2009). Intercomparison, interpretation,and assessment of spring phenology in North America estimated from remote sensing for 1982-2006. Global Change Biology 15: 2335-235.

Sustainable management of water and soil in olive orchards and vineyards under climate change

GIOVANNI CARUSO*, GIACOMO PALAI, CLAUDIO D'ONOFRIO, RICCARDO GUCCI
Department of Agriculture Food and Environment, University of Pisa

Keywords: carbon, grapevine, irrigation, precision agriculture, remote sensing

ABSTRACT. – Water scarcity and soil degradation are major threats to agricultural production in the Mediterranean basin. Due to climate change, drought events are occurring more frequently in many regions worldwide, while strong water competition for urban and industrial needs is reducing water availability for agriculture. Tree fruit crops are particularly threatened by the risk of water scarcity because of their perennial habit and the potential long-term effects of severe droughts. On the other hand, there is also evidence of an increasing occurrence of heavy rainfall events that further expose the soil to erosion and degradation. Therefore, improving the water use efficiency and contrasting soil erosion and degradation in orchards and vineyards is essential to mitigate possible negative effects of climate change and to maintain high-quality fruit productions in their traditional areas. In this paper we report some results from studies carried out by our research group on sustainable management of water and soil in orchard and vineyards. An additional focus on the new technologies for orchard management based on precision agriculture is also included.

SUSTAINABLE WATER MANAGEMENT. – Water is an increasingly scarce resource worldwide and irrigated agriculture remains one of the largest and most inefficient users of this resource. Deficit irrigation strategies have emerged as potential ways to increase water savings in agriculture with only marginal decreases of yield. Several irrigation strategies have been proposed for fruit trees and grapevines, differing in the intensity and timing of water deficit. Common deficit irrigation strategies are regulated deficit irrigation (RDI) and sustained deficit irrigation (SDI). The former restricts water volumes at specific phenological stages, the latter consists in applying suboptimal water volumes throughout the irrigation period. A moderate water deficit improves fruit quality and reduces excessive tree vigour in many perennial crops. Although many studies have been carried out to evaluate the effects of both SDI and RDI on fruit yield and quality,

*Corresponding author: giovanni.caruso@unipi.it

the impact of water stress on important secondary metabolites of fruit trees is yet to be elucidated.

Over the years irrigation trials have been carried out in a high-density olive (*Olea europaea* L. cv. Frantoio) orchard located at the experimental field of the Department of Agriculture Food and Environment of the University of Pisa, to evaluate the effect of different levels of irrigation regimes (SDI and RDI) and light environment on vegetative growth, flowering, yield components and virgin olive oil (VOO) quality. The results have been published in Caruso *et al.* (2013, 2014, 2017) and Gucci *et al.* (2019). Tree growth was reduced by SDI, but return bloom was not. The oil yield and oil yield efficiency of the SDI treatment were 82 and 110% that of FI trees, respectively. A level of about 50% deficit proved sustainable to irrigate trees for oil production. Irrigation had negligible effects on free acidity, peroxide value, and fatty acid composition of VOO, but strongly influenced its phenolic concentration. Trees with high water status yielded oils with lower concentrations of total phenols and O-diphenols with respect to oils from severely stressed trees (Caruso *et al.* 2013, 2014). Gucci *et al.* (2019) imposed water stress either prior to pit hardening (RDI 1) or after endocarp sclerification during the initial phase of oil accumulation (RDI 2). The fruit yields of RDI 1 and RDI 2 trees were 70 and 81% of fully irrigated ones, respectively, but the yield efficiency was similar across all treatments. An early water stress was more effective to increase the phenolic concentration of olive oil compared with a late deficit or full irrigation. In the experiments carried out by Benelli *et al*. (2015) and Caruso *et al*. (2017) olive fruits were harvested from three canopy positions (intercepting approximately 64%, 42% and 30% of above canopy radiation) of fully-productive trees subjected to full, deficit or complementary irrigation. Fruits receiving 61-67% of above canopy radiation showed the highest fruit weight, mesocarp oil content and maturation index, whereas those intercepting only 27-33% showed the lowest values. Total phenols and palmitoleic and linoleic acids increased in oils obtained from fruits exposed to high light levels, whereas oleic acid and the oleic-linoleic acid ratio decreased.

Studies have also undertaken on young grapevines. Caruso *et al.* (*submitted*) carried out an experiment on 5-year-old potted grapevines (*Vitis vinifera* L. cvs. Merlot and Sangiovese) plants to evaluate the combined effect of two rootstocks (SO4 and 1103 Paulsen) and three irrigation regimes (Full Irrigation and two RDI strategies) on leaf gas exchange, fruit quality and yield. Control grapevines (FI) were fully-irrigated from budburst through harvest; RDI 1 and RDI 2 vines were subjected to water deficit from fruit set through veraison and from veraison through harvest, respectively, whereas they were fully irrigated for the rest of the irrigation period. Significant differences in stomatal conductance (g_s) and net photosynthetic rate (Pn) between RDI 1 and the other two irrigation treatments were detected seven days after the beginning of the differentiation at the stage of fruit set. Similarly, RDI 2 grapevines showed lower values of g_s and Pn 6 days after water deficit was applied at veraison. The highest and lowest yield per plant were measured in RDI 2-Sangiovese-1103 Paulsen and in RDI 1-Merlot-SO4 grapevines, respectively. The RDI 1-SO4 grapevines produced the smallest berries in Merlot, whereas there were no significant differences across the different combination of irrigation and rootstock in Sangiovese.

SUSTAINABLE SOIL MANAGEMENT AND PROVISIONAL MODELS FOR CARBON ASSIMILATION. – Soil management can markedly affect soil properties and moisture although responses vary depending on soil type, slope, equipment used, and environmental conditions. Conventional tillage causes soil losses, runoff, structure degradation, acceleration of organic matter mineralization with consequent formation of compacted layers and negative effect on porosity along the profile. The use of a plant cover is currently the recommended practice for protection of the orchard floor. The presence of a cover crop not only has positive effects on soil properties, but also determines better biochemical fertility and greater bacterial biomass and diversity than tilled soils (Turrini *et al.* 2017; Vignozzi *et al.* 2019).

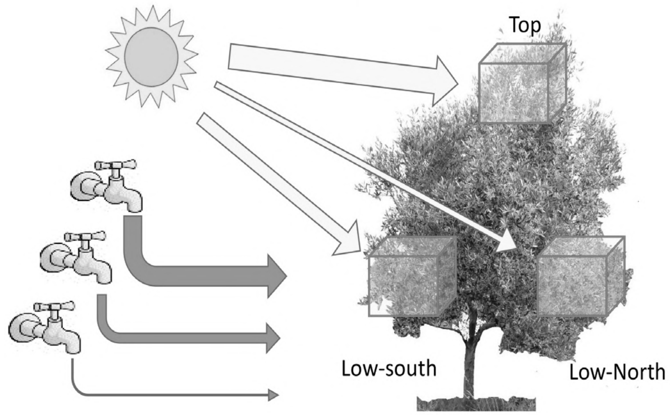


FIG. 1. Schematic representation of the experiment carried out by Caruso *et al.* (2017) at the experimental field of the University of Pisa at Venturina (LI).

Gucci *et al.* (2012) reported the long-term effects of plant covers on yield and oil quality in olive orchards. We compared performance of *Olea europaea* trees grown under either tillage (CT) or permanent natural cover (NC) in a sandy-loam soil over five years and determined changes in soil properties. Fruit yield and oil yield of NC trees were 65 and 69% to those of CT ones, respectively (means of five years), however, when expressed on a TCSA basis, they resulted 87 and 95%, respectively. There were no differences in free acidity, peroxide value, spectrophotometric indexes, and fatty acid composition, but phenolic concentrations of the NC treatment were slightly higher than those of CT oils. Soil macroporosity in the topsoil was 5.2 and 2% for the NC and CT treatments, respectively. Water infiltration rate in CT plots was lower than in NC ones because of soil surface crusting (Fig. 2). NC had higher values of total organic carbon and total extractable carbon than CT, whereas the humic carbon content was unaffected.

The need to reduce the expected impact of climate change is one of the most important challenges of the twenty-first century, that means finding sustainable ways to maintain or increase the carbon (C) sequestration capacity and productivity of agricultural systems. In spite of the potential of orchards and vineyards to sequester atmospheric C and to mitigate climate change, relatively little is known regarding the C-fluxes in and out of these agro-systems. In this context, Scandellari *et al.* (2016) carried out an experiment with the aim to provide data on the C budget, including net primary productivity (NPP), C removal through production, and C sequestration potential for the vineyards and the main fruit tree species (apple, citrus, olive, and peach) grown in Italy. Aboveground net primary productivity (NPP) ranged between 10 and 20 t ha^{-1} while belowground NPP was less than 20 % of the total NPP. The C leaving the system through fruit production ranged between 2 and 3 t ha^{-1}. All mature fruit tree ecosystems had positive net ecosystem productivity and net ecosystem carbon balance (ranging from 0.6 to 5.9 t C ha^{-1} per year), indicating the potential of these systems to store C rather than emit it.

Field experiments to study the responses of orchards and vineyards to different environmental conditions need to be complemented by simulation models to explore future land atmosphere C feedbacks (Moriondo *et al.* 2019). Brilli *et al.* (2019) calibrated and validated a biogeochemical model (The DayCent) against observed net ecosystem exchange, net primary productivity, aboveground biomass, leaf area index, and yield in two Italian olive groves. In the same study, potential changes in

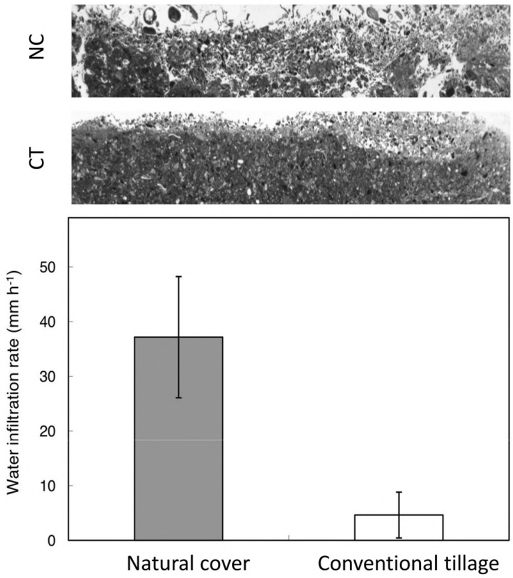


FIG. 2. Macrophotographs of vertically oriented thin sections from the surface layer of naturally covered (NC) or tilled (CT) soil and water infiltration rate measured in the interrow of a high-density olive orchard located at the experimental field of the University of Pisa at Venturina (LI) during the sixth growing season after establishment of different soil management. Histograms are means of four replicates (bars = standard deviations). Modified from Gucci *et al.* (2012).

C-sequestration capacity and productivity were assessed under two types of management (extensive and intensive), 35 climate change scenarios, and six areas across the Mediterranean basin. The results indicated that: (a) the DayCent model, properly calibrated, can be used to quantify olive grove daily net ecosystem exchange and net primary production dynamics; (b) future warming is expected to extend the photosynthetic activity in winter and to prolong the period of photosynthesis inhibition during summer; (c) a substantial decrease in mitigation capacity and productivity of extensively managed olive groves is expected across all Mediterranean areas; (d) adaptation measures aimed at increasing soil water content or evapotranspiration reduction should be considered the mostly suitable for limiting the decrease of both production and mitigation capacity in the next decades.

PRECISION MANAGEMENT OF OLIVE ORCHARDS AND VINEYARDS. – Precision agriculture can be a powerful technology to manage crops for climate change mitigation purposes by optimizing the use of agricultural inputs (*e.g.,* fertilisers, pesticides, fuel) accounting for the spatial and temporal variability of the field. Precision agriculture relies on the understanding of inter and within-field variability to define homogenous zones within the orchard and vineyard. This information is then used to optimize cultural practices with the objective to achieve uniformity of growth and yield. Zoning in heterogeneous orchards and vineyards can be conducted through the measurement and geo-referencing of vine biophysical parameters, such as leaf area, canopy volume, vine vigour and leaf chlorophyll content. These parameters are crucial for orchard and vineyard management as they are related to vegetative growth, nutrient concentrations and water status of the trees and vines.

Several remote sensing techniques are currently being used for estimating biophysical and geometric parameters of trees and vines and for missing plant detection as an alternative to the on-ground field measurements (Caruso *et al.* 2017a; Primicerio *et al.* 2017; Caruso *et al.* 2019). In the last decade unmanned aerial vehicles (UAV) have been proposed for agricultural applications due to their great flexibility in flight scheduling, low operational costs and the increasing availability of dedicated, low-cost, miniaturized sensors. Caruso *et al.* (2019) carried out an experiments in a fully-productive olive orchard (cv. Frantoio) at the experimental farm of University of Pisa at Venturina (Italy) to assess the ability of an unmanned aerial vehicle (UAV) equipped with RGB-NIR cameras to estimate leaf area index (LAI), tree height, canopy diameter and canopy volume of olive trees that were either irrigated or rainfed. The Normalized Difference Vegetation Index (NDVI) was calculated using NIR images and the map algebra technique. Canopy volume, canopy height and diameter were obtained from the digital surface model (DSM) obtained from RGB images acquired from an UAV. The NDVI was linearly correlated with both LAI and leaf chlorophyll measured on the same date ($R^2 = 0.78$ and 0.80, respectively). The correlation between the on ground measured canopy volumes and the ones by the UAV-RGB camera techniques yielded an R^2 of 0.71–0.86. The information derived from NIR-RGB images can be used to improve irrigation management, fruit and oil quality and to estimate biomass production and carbon sequestration both at tree and field level. The use of more representative values of canopy diameter obtained from RGB images also allows a better estimate of crop water requirement. Moreover, the possibility of estimating the tree canopy volume throughout the growing season allows to adopt pruning strategies that improve the light interception at field level and light distribution within the crown. Finally, the high level of accuracy and time saving in estimation of tree canopy volume using the methodology described in this work, make UAV, RGB images and SfM techniques feasible for the above-ground biomass determination and, through specific correlation, the carbon sequestration at tree and field scale.

In another study, Caruso *et al.* (2017b) identified three zones of different vine vigour in a mature vineyard (*Vitis vinifera* "Sangiovese") to test the potential of the Visible-Near Infrared (VIS-NIR) spectral information acquired from an unmanned aerial vehicles (UAV) in estimating the leaf area index (LAI), leaf chlorophyll, pruning weight, canopy height and canopy volume of grapevines (Fig. 3). A significant linear correlation between the normalized differential vegetation index (NDVI) and LAI. The canopy volume of low-vigour (LV) vines was 35 and 45 % of the high-vigour (HV) and medium-vigour (MV) ones, respectively. The pruning weight was linearly correlated with NDVI values of each vigour cohort. A good correlation between the measured canopy volume and UAV-estimated one as well as between measured and estimated canopy height was found. Our results indicated that the combined use of VIS-NIR cameras and UAV is a rapid and reliable technique to determine canopy structure and LAI of grapevine.

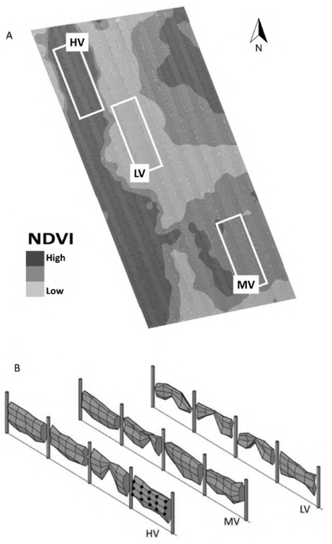


FIG. 3. Normalized difference vegetation index (NDVI) map including the three groups of vines (cv. Sangiovese) used for field measurements (A) and three-dimensional canopy models of High (HV), Medium (MV) and Low Vigor (LV) vines produced from measurement taken in the field (B). Modified from Caruso *et al.* (2017b).

REFERENCES

Benelli G., Caruso G., Giunti G. *et al.* (2015). Changes in olive oil volatile organic compounds induced by water status and light environment in canopies of *Olea europaea* L. trees. Journal of the Science of Food and Agriculture 95: 2473-2481.

Brilli L., Lugato E., Moriondo M. *et al.* (2019). Carbon sequestration capacity and productivity responses of Mediterranean olive groves under future climates and management options. Mitigation and Adaptation Strategies for Global Change 24: 467-491.

Caruso G., Palai G., Nesi S. *et al.* (*submitted*). Combined effects of rootstock and irrigation on gas exchange, fruit quality and yield in "Merlot" and "Sangiovese" grapevines. Proceedings of theVIII International Symposium on Irrigation of Horticultural Crops, Matera, Italy. Acta Horticulturae.

Caruso G., Gucci R., Sifola M.I. *et al.* (2017a). Irrigation and fruit canopy position modify oil quality of olive trees (cv. Frantoio). Journal of the Science of Food and Agriculture 97: 3530-3539.

Caruso G., Gucci R., Urbani S. *et al.* (2014). Effect of different irrigation volumes during fruit development on quality of virgin olive oil of cv. Frantoio. Agriculture Water Management 134: 94-103.

Caruso G., Rapoport H.F., Gucci R. (2013). Long-term effects on yield components of young olive trees during the onset of fruit production under different irrigation regimes. Irrigation Science 31: 37-47.

Caruso G., Tozzini L., Rallo G. *et al.* (2017b). Estimating biophysical and geometrical parameters of grapevine canopies ('Sangiovese') by an unmanned aerial vehicle (UAV) and VIS-NIR cameras. Vitis 56: 63-70.

Caruso G., Zarco-Tejada P.J., González-Dugo V. *et al.* (2019). High-resolution imagery acquired from an unmanned platform to estimate biophysical and geometrical parameters of olive trees under different irrigation regimes. PLoS ONE, 14, Article number e0210804.

Gucci R., Caruso G., Bertolla C. *et al.* (2012). Changes in soil properties and tree performance induced by soil management in a high-density olive orchard. European Journal of Agronomy 41: 18-27.

Gucci R., Caruso G., Gennai C. *et al.* (2019). Fruit growth, yield and oil quality changes induced by deficit irrigation at different stages of olive fruit development. Agricultural Water Management 212: 88-98.

Moriondo M., Leolini L., Brilli L. *et al.* (2019). A simple model simulating development and growth of an olive grove. European Journal of Agronomy 105: 129-145.

Primicerio J., Caruso G., Comba L. *et al.* (2017). Individual plant definition and missing plant characterization in vineyards from high-resolution UAV imagery. European Journal of Remote Sensing 50: 179-186.

Scandellari F., Caruso G., Liguori G. *et al.* (2016). A survey of carbon sequestration potential of orchards and vineyards in Italy. European Journal of Horticultural Science 81: 106-114.

Turrini A., Caruso G., Avio L. *et al.* (2017). Protective green cover enhances soil respiration and native mycorrhizal potential compared with soil tillage in a high-density olive orchard in a long-term study. Applied Soil Ecology 116: 70-78.

Vignozzi N., Agnelli A.E., Brandi G. *et al.* (2019). Soil ecosystem functions in a high-density olive orchard managed by different soil conservation practices. Applied Soil Ecology 134: 64-76.

The effects of global change on UV radiation increase and their consequences on Andean crops

LORENZO GUGLIELMINETTI[*abc], THAIS HUARANCCA REYES[a]
[a]Department of Agriculture, Food and Environment, Via Mariscoglio 34, 56124 Pisa, Italy
[b]Interdepartmental Research Center "Nutraceuticals and Food for Health", University of Pisa, Via del Borghetto 80 - 56124 Pisa, Italy
[c]Centre for Climate Change Impact, University of Pisa, Via del Borghetto 80 - 56124 Pisa, Italy

Keywords: quinoa, maca, tarwi, mashua, high altitude agriculture, ultraviolet

ABSTRACT. – Our research is addressed to study one of the most important environmental stresses due to the global change: increasing ultraviolet (UV) radiation. UV radiation excess can affect plant growth and metabolism especially when crops are cultivated in altitude, as the Andean region, where ozone depletion and high altitude induce the increasing of UV. We focus on understanding the plant mechanisms to survive in severe environmental conditions that can be used in assisted selection of more tolerant and productive Andean crop varieties improving the local agriculture system. Our study involves different Andean crops used from long time ago in South America with increasing interest in the rest of the world due to their energetic and nutraceutical values. Moreover, these crops are characterized for their extraordinary ability to be adapted in marginal lands. In this line, we focus on the following Andean crops: *Lupinus mutabilis* (tarwi), *Lepidium meyenii* (maca), *Tropaeolum tuberosum* (mashua) and *Chenopodium quinoa* (quinoa).

MAIN TEXT. – Plants are sessile organisms able to convert sunlight energy into chemical energy through the process of photosynthesis. In addition of energy source, plants use solar radiation as an important environmental signal to regulate their growth and development. Ultraviolet (UV) radiation is one of the different wavelengths of the electromagnetic radiation contained in the solar radiation, which is conventionally classified into UVC (below 280 nm), UVB (280-315 nm) and UVA (315-400 nm). The stratospheric ozone layer absorbs solar UVC which is the most hazardous UV radiation, while part of UVB and more of UVA radiations penetrate the ozone layer reaching the earth surface. Although small amount of UVB riches the earth surface, numerous studies have been

[*]Corresponding author: lorenzo.guglielminetti@unipi.it

focused on its effect in living organisms since it contains higher energy in comparison with UVA (Stapleton 1992).

In the past decades, synthetic gases known as chlorofluorocarbons (CFCs) were widely used by the population. It was found that CFCs are decomposed in the stratosphere layer and catalyzed the depletion of ozone. This depletion leads to the penetration of UV radiation causing not only severe damages in organisms but also the loss of agricultural production (Weatherhead & Andersen 2006; Ballaré 2011). The Andes is the longest mountain range with over 100 peaks above 6000 m of altitude with a particular environment where the ozone layer is thin, there is high UV radiation because the high altitude and there are long periods of drought and freezing temperatures. However, we can find Andean crops which have evolved under these extreme conditions which nowadays would be considered a marginal land (Cabrol *et al.* 2014). Since it is known that UV radiation affects many aspects of life including DNA damaging, photosynthesis alteration, plant secondary metabolism regulation and limitation in the productivity of many plant species (Fig. 1), makes the Andes a valuable region for studying the effect of increased UV radiation on growth, photosynthesis, gas-exchange, source-sink carbon partitioning, scavenger system and secondary metabolites in Andean crops, which is the objective of our research studies.

The Andes is one of the most important centers of crop origin and diversity in the world (Fig. 2), where important crops have increased worldwide interest due to their energetic value and nutraceutical properties attributed to the presence of phytochemical compounds. Moreover, the Andean crops are important food source not only for the local people but also for all South America rising to 125 million people (Flores *et al.* 2003). Therefore, research studies to improve biotic and abiotic stress management and crop productivity in the Andean region are important to help the preservation and promotion of these crops.

In our research studies, we analyzed the adaptive response mechanisms in different Andean crops to environmental stresses that are a result of factors including climate change, ozone depletion and UV radiation. Plants investigated include maca (*Lepidium meyenii*), quinoa (*Chenopodium quinoa*), tarwi (*Lupinus mutabilis*) and mashua (*Tropaeolum tuberosum*), which were selected for their distribution, economical importance and nutrient/phytochemical source-sink. Maca is a member of the radish family that grows in the Peruvian Central Andes between 3700 and 4500 m of altitude where only highland grasses can survive, and it is known that this root has an important nutritional value, is a powerful energizer and its phytochemical content has several therapeutic applications (Quiroz and Aliaga 1997). Mashua is a tuber cultivar of the Andes that grows between 2400 and 4300 m of altitude. It was determined that mashua contains the highest antioxidant activity within the Andean crops and it is traditionally used for its nutritional and medicinal properties. Furthermore, mashua is occasionally cultivated together with potato taking in advantage the use of its chemical defense content to avoid potato pathogens in the Andean region (Grau *et al.* 2003). Tarwi is an endemic legume traditionally cultivated in the Andes with high interest in international markets due to its high seed protein and oil contents than other lupin species (Atchison *et al.* 2016). Quinoa is a grain crop from the Andean region which has received worldwide interest in the past two decades due to its high protein and well-balanced amino acid content (Jacobsen 2003; Abugoch 2009). In addition, it has been reported that quinoa can grow under high salinity levels (Hariadi *et al.* 2011), drought (Jacobsen *et al.* 2009) and high UV radiation (González *et al.* 2009).

Our studies were carried out at the Department of Agriculture, Food and Environment of the University of Pisa (in collaboration with A. Ranieri and A. Castagna) and in the Junín plateau (Central Andes of Peru), and in collaboration with the Institute of Research on Terrestrial Ecosystems (IRET), National Research Council of Italy (CNR, A. Scartazza), the Center for Translational Medicine (CTM), International Clinical Research Center (ICRC), St. Anne's University Hospital of Czech Republic (A. Pompeiano) and the Pontificia Universidad Católica del Perú (*E.g.,* Cosio).

All the seeds, obtained from Peruvian germplasm center, were sown under natural conditions in open fields or in pots under controlled conditions. Plants grown in Junin and other Andean locations (>4000 m of altitude) were usually separated in three groups: direct solar exposition (open control), under filter that transmits all the ambient solar radiation (filter control), and under 100% UVB cut-off filter. Plants grown in Pisa (almost at sea level) were in open field without any filters. Plants grown in controlled chambers received different UVB doses by using special lamps. All these field and growth chamber treatments helped us to understand (1) the effect of different controlled UVB doses, (2) the different solar UV radiations effects and (3) the complete different natural environmental condition effects on physiological and biochemical traits of Andean crops during their biological cycle. Environmental parameters such as temperature, humidity and solar radiation were monitored. Biometric responses to environmental stresses, focusing on UV radiation, were evaluated at different developmental stage and samples in each point were taken for biochemical analyses. To determine the effects of diverse environmental stresses on the photosynthetic capacity, energy dissipation and photo-protection mechanisms of each species, gas exchange and fluorescence measurements were analyzed in each plant using a LI-6400-40 portable photosynthesis system (Li-Cor) and a miniaturized pulse-amplitude-modulated fluorometer (Mini-PAM). Evaluation of carbon flux from source to sink organs, the amount of the main plant soluble sugars (glucose, fructose and sucrose) and the most abundant storage carbohydrate (starch) were measured at different developmental stage. The activity of the enzymes involved in the UV responses, reactive oxygen species production, secondary metabolites synthesis and mobilization, and yield crop were also determined.

Our project covers the extremely relevant subject of the impact of UV radiation on plant metabolism and primary productivity of selected Peruvian Andean crops. There is growing concern regarding the increasing levels of UV radiation experimented in the tropical and subtropical Andean countries and its impact on vegetation, especially at high altitudes, thus, our research study is opening new perspectives for scientists trying to improve environmental stress management and crop productivity, topics that are more than relevant in the agriculture system. It should be mentioned that our research is having a strong social impact because we are using Andean crops cultivated and used as primary food source by the local people in low economic status regions of South America.

Finally, the interesting results obtained in our studies are explaining some new mechanisms related with the tolerance of these well adapted crops to high altitude environment.

REFERENCES

Abugoch James L.E.Q. (2009). *Chenopodium quinoa* Willd.: composition, chemistry, nutritional, and functional properties. Adv. Food Nutr. Res. 58: 1-31.

Atchison G.W., Nevado B., Eastwood R.J. *et al.* (2016). Lost crops of the Incas: Origins of domestication of the Andean pulse crop tarwi, *Lupinus mutabilis*. Am. J. Bot. 103: 1592-1606.

Ballaré C.L., Caldwell M.M., Flint S.D. *et al.* (2011). Effects of solar ultraviolet radiation on terrestrial ecosystems. Patterns, mechanisms, and interactions with climate change. Photochem. Photobiol. Sci. 10: 226-241.

Cabrol N.A., Feister U., Hader D-P. *et al.* (2014). Record solar UV irradiance in the tropical Andes. Front. Environ. Sci. 2: 1-6.

Flores H.E., Walker T.S., Guimaraes R.L. *et al.* (2003). Andean root and tuber crops: underground rainbows. Hort. Sci. 38: 161-167.

González J.A., Rosa M., Parrado M.F. *et al.* (2009). Morphological and physiological responses of two varieties of a highland species (*Chenopodium quinoa* Willd.) growing under near-ambient and strongly reduced solar UV–B in a lowland location. J. Photochem. Photobiol. B. 96: 144-151.

Grau A., Ortega R., Nieto C. *et al.* (2003). Mashua *Tropaeolum tuberosum* Ruíz & Pav. Promoting the conservation and use of underutilized and neglected crops. 25. Centro Internacional de la Papa, Lima/International Plant Genetic Resources Institute, Rome.

Hariadi Y., Marandon K., Tian Y. *et al.* (2001). Ionic and osmotic relations in quinoa (*Chenopodium quinoa* Willd.) plants grown at various salinity levels. J. Exp. Bot. 62: 185–193.

Huarancca Reyes T., Scartazza A., Castagna A. *et al.* (2018). Physiological effects of short acute UVB treatments in *Chenopodium quinoa* Willd. Sci. Rep. 8: 371.

Huarancca Reyes T., Scartazza A., Pompeiano A. *et al.* (2019). Physiological responses of *Lepidium meyenii* plants to ultraviolet- B radiation challenge. BMC Plant Biol. 19: 186.

Jacobsen S.-E. (2003). The Worldwide Potential for Quinoa (*Chenopodium quinoa* Willd.). Food Rev. Int. 19: 167-177.

Jacobsen S.-E., Liu F., Jensen C.R. (2009). Does root-sourced ABA play a role for regulation of stomata under drought in quinoa (*Chenopodium quinoa* Willd.). Sci. Hortic. 122: 281-287.

Quiroz C., Aliaga R. (1997). Maca (*Lepidium meyenii* Walp.). En Hermann, M. y Heller, J. (editores). Andean roots and tubers: Ahipa, arracacha, maca and yacon. Promoting the conservation and use of underutilized and neglected crops. Institute of Plant Genetic and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute. Roma. 173-197.

Montgomery D.R., Balco G., Willett S.D. (2001). Climate, tectonics, and the morphology of the Andes. Geology 29: 579-582.

Müller-Xing R., Xing Q., Goodrich J. (2014). Footprints of the sun: memory of UV and light stress in plants. Front. Plant. Sci. 5: 474.

Stapleton A.E. (1992). Ultraviolet radiation and plants: Burning questions. The Plant Cell 4: 1353-1358.

Weatherhead E.C., Andersen S.B. (2006). The search for signs of recovery of the ozone layer. Nature 441: 39-45.

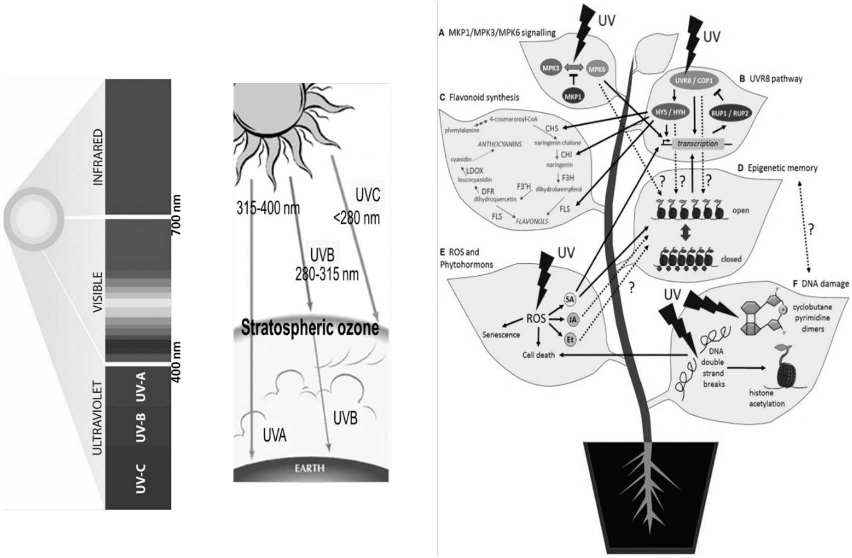


FIG. 1. The stratospheric ozone layer absorbs UV radiation from the sun, but its losing leads to the penetration of UV causing severe damages in organisms. *Source: http://uv-radiation.weebly.com/#/* and Müller-Xing *et al.* (2014).

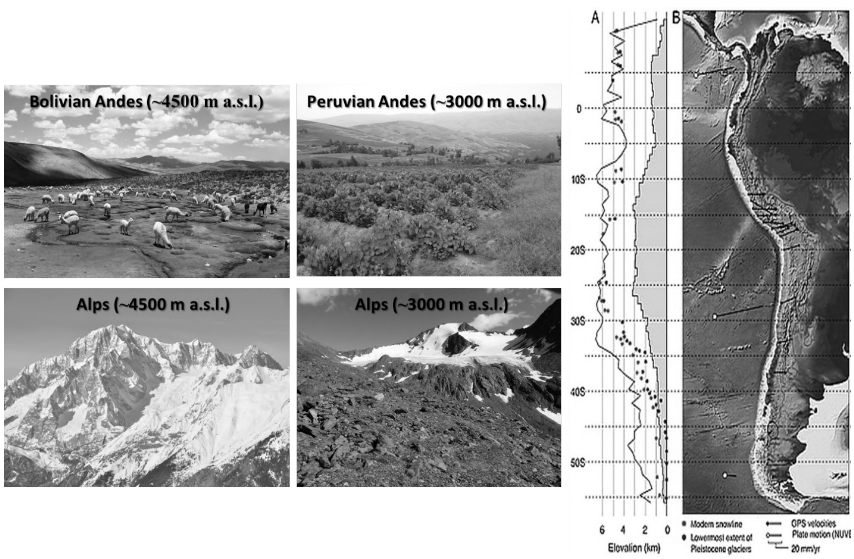


FIG. 2. The Andes is a long mountain chain with over 100 peaks above 6000 m of altitude with harsh environment. However, we can find Andean crops which have evolved under these extreme conditions where nowadays would be considered a marginal land. Source: Montgomery *et al.* (2001).

Agroforestry systems for adaptation to and mitigation of climate change: effects on soil fertility

DANIELE ANTICHI[1*], MARCO MAZZONCINI[1], LORENZO GABRIELE TRAMACERE[2], MASSIMO SBRANA[2], PAOLO BÀRBERI[3], ANNA-CAMILLA MOONEN[3], STEFANO CARLESI[3], ALBERTO MANTINO[3], GIORGIO RAGAGLINI[3], MARCELLO MELE[2]
[1]Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto, 80 - 56124 Pisa
[2]Centre for Agri-environmental Research "Enrico Avanzi", Via Vecchia di Marina, 6 - 56122 San Piero a Grado, Pisa
[3]Institute of Life Sciences, Scuola Superiore S. Anna, Pisa

Keywords: diversification, cropping systems, agroecology, intercropping, soil organic carbon

ABSTRACT. – Agroforestry (AF) systems are gaining pace as good examples of sustainable cropping systems with also a role in climate change mitigation/adaptation. This is mainly because of their huge C sequestration potential and the diversification of the agroecosystem implying high resilience in respect to stressful conditions. At the Centre for Agri-environmental Research "Enrico Avanzi" of the University of Pisa, Italy, a new long-term field experiment has been started in 2018 on 40 ha of arable land with the aim to assess the performances of different cropping systems at different levels of integration between herbaceous crops and trees. Soil organic carbon storage will be one of the main parameters that will be assessed in the long term at different depths and at different distances from the tree rows to assess the importance of the interaction between the system components in terms of soil fertility. The long-term experiment is expected to provide solid data on the contribution of innovative AF systems to climate change mitigation in Mediterranean areas.

AGROFORESTRY SYSTEMS AND CLIMATE CHANGE. – Agroforestry (AF), "the deliberate integration of woody vegetation (trees and/or shrubs) as an upper storey on land, with pasture (consumed by animals) or an agricultural crop in the lower storey", is pointed as a sustainable land-use strategy to cope with climate change and provide environmental, economic, and social benefits (Kay *et al.* 2019). Historically, in Italy and many other countries the combination of tree and herbaceous crops was widely spread until the so called "green revolution", when the sepa-

*Corresponding author: daniele.antichi@unipi.it

ration between science and practice in agriculture and in forestry has left many opportunities for a functional use of trees in the agroecosystem unexploited (Duguma *et al.* 2018). Traditionally, AF systems had been a source of fruits, crops, fodder, building materials, biomass for energy, fiber, crafting materials, all kinds of animal products, etc.

From an agroecological point of view, trees may play an important role in agricultural landscapes through the delivery of important ecosystem services with an impact on crop productivity and reduction of agri-environmental risks (Wezel *et al.* 2014). What really makes a difference between pure stands of arable crops and AF systems is clearly the higher level of planned agrobiodiversity in AF systems, which translates into enhanced symbiotic connectivity between all the agroecosystem biota (*i.e.*, crops, weeds, soil microrganisms, micro-, meso- and macro-fauna) to improve the use of the local resources (EIP-AGRI 2017).

Under the lens of climate change mitigation and adaptation, AF systems are increasingly gaining pace as one of the most effective agricultural solutions as they are able to (EIP-AGRI 2017): i) stabilize the productivity of the land thanks to the integration of different crops/animals that are able to provide different productions; ii) enhance cropping system resistance and resilience to climate change because of the high planned (crops, livestocks) and unplanned (*e.g*., wild flora, beneficial arthropods and microrganisms) biodiversity level; iii) contrast soil desertification by increasing soil organic matter content through root and litter decomposition and by contrasting soil erosion; iv) improve water storage capacity of soils thanks to their deep root systems able to utilize underground water; v) reduce water evaporation from the soils thanks to their shade and to the litter cover on the ground; vi) compensate for greenhouse gas emissions by increased CO_2 sequestration from the atmosphere through photosynthesis and reduced N excess in topsoil due to high N intake of tree root systems; vii) increase fertiliser use efficiency thanks to reduction in nitrate leaching and P availability (through the release of root exudates and interactions with soil microrganisms as mycorrhizas); viii) reduce pesticide use by enhancing the presence of antagonists and predators of pests and diseases that may find food, shelter and nesting spaces on the trees and in other ecological corridors.

THE IMPORTANCE OF SOIL FERTILITY IN A CHANGING CLIMATE. – Soils play an essential role in the global carbon budget (Houghton 2007). Recent studies estimate the carbon (C) sink capacity of soil and vegetation in about one third of the C emitted to the atmosphere through the burning of fossil fuel and cement production (Le Quéré *et al.* 2014). On the other hand, land use changes and agricultural management occurred in the last two centuries has led to a depletion in soil organic C (SOC) of around 70 Gt (Lal 2004a). There is a huge potential in European agricultural soils to store much more C from the atmosphere if proper management practices are applied. These practices should be aimed, on one hand, to increase SOC inputs (*e.g.*, by using cover crops, intercropping, organic amendments, biochar), and to reduce SOC mineralization (*e.g.*, by keeping the soil covered as much as possible, reducing the soil disturbance adopting reduced tillage techniques, modulating soil moisture), on the other. Increasing SOC stocks is often seen as a win-win strategy (Lal 2004a) as it allows decreasing the CO_2 concentration in the atmosphere while improving at the same time soil quality and fertility, thus enabling the crops to grow much better and to sequester more C from the atmosphere (Lal 2004b).

STUDYING THE EFFECT OF AF SYSTEMS ON SOC AND SOIL FERTILITY. – Soil fertility dynamics, and especially SOC dynamics, require long term monitoring in order to be able to detect any significant changes affected by specific agricultural management options. This is because of the chemical nature of the soil organic matter, which is characterized by stable compounds that make its turnover normally taking decades (Dignac *et al.* 2019). These transformation processes are mediated by soil microorganisms, which are in turn affected by any modification in their living habitat.

In agronomy research, the long term effect of agricultural practices on soil fertility have been traditionally studied by setting up "long term experiments" (LTEs), where the application of experimental treatments (*e.g.*, different fertilization strategies, different farming systems) are applied continuously over years in order to detect any change in the studied parameters. These experiments, considered very expensive and less productive than reductionist studies, have been partially disregarded in the last decades. But now they are attracting an increasing interest from scientists and stakeholders in respect to new societal challenges, climate change mitigation and adaptation above all.

AF systems also require by their nature long term monitoring of their effects on agroecosystem functioning and performances. This is first because of the long life of the tree components, but also because their development and growth pass through different stages with different levels of interactions with the other agroecosystem biotic and abiotic components.

THE ARNINO LTE: A LONG-TERM FIELD EXPERIMENT ON AF AND SOIL FERTILITY. – A multidisciplinary team has designed and established a long-term field experiment to evaluate the transition of a conventional arable system towards AF in Tuscany (*https://www.avanzi.unipi.it/index.php/ricerca/itemlist/category/183-agroforestry-long-term-experiment.html*). The purpose of the LTE is to assess the sustainability and performances of AF compared with conventional arable and forestry systems, as well as the potential transferability to real farm conditions. The research focuses on synergies and trade-offs among the two main components of the agroforestry system, *i.e.*, tree and herbaceous crops in order to evaluate whether the diversification of the cropping system may enhance its resilience to variability of weather conditions. Additionally, the LTE will allow to assess in the long term the potential of climate change mitigation/adaptation of AF systems through the monitoring of carbon storage, soil fertility and biodiversity.

The LTE, started in 2018, is located at the Centre for Agro-Environmental Research "Enrico Avanzi" of the University of Pisa, San Piero a Grado (Pisa) (43.667205 N, 10.313160 E). The field trial was established on Xerofluvent soils classified as Typic Haplustert, with loam to clay-loam textures, sub-alkaline pH and soil organic matter varying from 1.5 to 2%. Two AF systems, Silvo-Arable (SA) and Agro-Silvo-Pastoral (ASP), are being compared with the respective controls, *i.e.*, Arable (AR) and Mixed (MX) systems (Table 1). The crop sequence adopted in AR and SA includes durum wheat (*Triticum turgidum* subsp. *durum* Desf.), sorghum (*Sorghum bicolor* L. Moench) and faba bean (*Vicia faba* var. *minor* Beck). In MX and ASP, the three annual crops are followed by a 4-year meadow of Italian ryegrass (*Lolium multiflorum* Lam. var. *italicum*), orchard-grass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* L.), sulla (*Hedysarum coronarium* L.) and alfalfa (*Medicago sativa* L.). This meadow is exploited both to produce hay and for direct grazing of sheep. In SA and ASP, oak (*Quercus robur* L.) and poplar (*Populus* spp.) have been planted alternate on the row every 5 m, along one side of each field, 2 m away from drainage ditches, corresponding to a density of 60 trees ha^{-1}. The space between tree rows and ditches is managed as semi-permanent buffer strips to support functional biodiversity and to limit nutrient leaching. Forestry control fields are two pure stands of poplar and oak and a polycyclic plantation based on oak, poplar, hazelnut (*Corylus avellana* L.) and alder (*Alnus cordata* L.).

PRELIMINARY AND EXPECTED RESULTS. – Besides data on crop yield and quality, animal production and quality, the experimental protocol of the LTE includes collection of data on soil fertility, weed abundance and composition, soil erosion, nitrate leaching and economic budget. Soil fertility will be assessed at the beginning of the trial (*i.e.*, as soon as all the tree plants will be established) and then periodically (at the end of each crop rotation cycle). The sampling protocol will include monitoring soil parameters (*i.e.*, pH, soil organic carbon, total N, available P, Cation Exchange Capacity, Electrical Conductivity, total and active limestone) at different depths (down to 1 m at least to intercept most of the tree roots) and at different distances from the tree rows in order to assess the effect of interaction between the two plant components of the AF systems.

According to the literature, we should expect a huge effect of the presence of trees in the modification of soil parameters, especially for soil C and N, but with different intensity depending on the state of development of the trees. In this LTE two different kind of tree crops were included (*i.e.*, poplar and oak) in order to provide a sufficient tree biomass along all the lifetime of the AF systems. Poplar trees are expected to grow very quick since the beginning and will be periodically cut to provide wood product regularly. Oppositely, oak plants will be able to deliver ecosystem services and wood products only after some decades.

POTENTIAL COLLABORATION. – This LTE is intended as an open-air laboratory open to new collaborations from disciplines other than agronomy and crop/animal production. Given the high complexity of the AF systems and the standard field size of the plots, we foresee potential for future studies, for instance, on mechanization aspects (*e.g.*, how the operational difficulties in field operations caused by the presence of trees could be overcome by innovations in farm machinery), energetic budgets, soil microbiology, water use efficiency, plant and animal genetics, animal biodiversity, social aspects. All these aspects can contribute to enhance the impact of the outcomes by covering most of the sustainability dimensions that need to be considered in the light of climate change adaptation/mitigation.

ACKNOWLEDGEMENTS. – The authors acknowledge the staff of CiRAA for their precious support and enormous efforts in designing, establishing and conducting the LTE.

REFERENCES

Dignac M.F., Derrien D., Barré P. *et al.* (2017). Increasing soil carbon storage: mechanisms, effects of agricultural practices and proxies. A review. Agronomy for Sustainable Development 37: 14.

EIP-AGRI (2017). Final report of the Focus Group Agroforestry: introducing woody vegetation into specialized crop and livestock systems.

Houghton R.A. (2007). Balancing the global carbon budget. Annual Review of Earth Planetary Sciences 35: 313-347.

Kay S., Graves A., Palma J.H.N. *et al.* (2019). Agroforestry is paying off – Economic evaluation of ecosystem services in T European landscapes with and without agroforestry systems. Ecosystem Services 36: 100896.

Lal R. (2004a). Soil carbon sequestration to mitigate climate change. Geoderma 123: 1-22.

Lal R. (2004b). Offsetting China's CO_2 emissions by soil carbon sequestration. Climatic Change 65: 263-275.

Le Quéré C., Peters G.P., Andres R.J. *et al.* (2014). Global carbon budget. Earth System Science Data 7: 521-610.

Van Noordwijk M., Duguma L., Dewi S. *et al.* (2018). SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry? Current Opinion in Environmental Sustainability 34: 33-42.

Wezel A., Casagrande M., Celette F. *et al.* (2014). Agroecological practices for sustainable agriculture. A review. Agronomy for Sustainable Development 34: 1-20.

https://www.avanzi.unipi.it/index.php/ricerca/itemlist/category/183-agroforestry-long-term-experiment.html.

TABLE 1 – *Cropping systems tested in the ARNINO LTE. Within brackets, the length of crop rotation is reported.*

Arable systems	**Agroforestry systems**	**Forestry systems**
Arable (AR) (3yr)	Silvo-arable (SA) (3yr)	Poplar (P) (10yr) Oak (O) (45yr)
Mixed (MX) (7yr)	Agro-silvo-pastoral (ASP) (7yr)	Polycyclic plantation (3P) (45yr)

Agrohydrological sensing and modelling for the analysis of drought and mitigation actions: The experience of the AgrHySMo laboratory

GIOVANNI RALLO[1*], ANDREA SBRANA[1], ÀNGELA PUIG-SIRERA[1], ANTONELLA CALZONE[1], ALESSANDRA MARCHICA[1]
[1]Department of Agriculture, Food and Environment - University of Pisa. Via del Borghetto, 80 - 56124 Pisa

Keywords: models and sensors, drought mitigation, precision irrigation

ABSTRACT. – This paper describes the research activities of the AgroHydrological Sensing and Modelling (AgrHySMo) laboratory and their preliminary results. The main lines of the research activities are to estimate irrigation requirements and scheduling of woody perennial crops in scenarios of climate uncertainties using agro-hydrological modelling and soil moisture-based methods. The researchers propose a new definition and computation of the crop coefficient in the FAO56 paper, which would include the effect of water saving strategies into a new model. Furthermore, the laboratory holds two patents relative to a smart sensor system, which is based on electrically-driven smart membranes. Regarding the outdoor research activities, the implementation of the soil moisture-based wireless sensor network in an extensive pear orchard from Tuscany, saved up to 35% of the water supplied by the farmers.

INTRODUCTION. – Climate change and socioeconomic development are key drivers of water stress. Regarding the last factor, it has been predicted that population dynamics, changing diet preferences, growing demand for fiber, and land-change uses are increasing the competition for water and its pollution. The rising of temperature is projected to be greater than the global average, with also a large reduction of precipitation and an increase in its inter-annual variability (IPCC 2018). Probably, the most affected variables regarding the crop cultivation will be the duration of phenological stages, crop evapotranspiration, irrigation requirements, biomass growth and yield (Tanasijevic *et al.* 2014). As stated in Tabari *et al.* (2011), any change in meteorological variables due to climate change will affect evapotranspiration or crop water requirement.

*Corresponding author: giovanni.rallo@unipi.it

Therefore, it is necessary to understand the specific crop water requirements, to match them with irrigation amounts, but this needs to be coupled with appropriate water management techniques. However, there is a knowledge gap on woody perennial crops water use under precision irrigation systems, which hinders the development of sound water management tools in Mediterranean countries.

Crop water requirements can be obtained using a plant and/or soil-based systems, micrometeorology and agrohydrological modelling approaches. Sensing and modelling approaches constitute practical and simpler tools to estimate crop water requirements for irrigation scheduling to optimize water use efficiency (Rallo *et al.* 2017). For these reasons, the Italian Ministry of Agricultural, Food, Forestry and Tourism Policies (MIPAAFT), through the Guidelines approved with the DM 31/07/2015, wants to spur the technical-scientific community and regional administrations. The main objective is to set up support services, to both collective and farm irrigation, capable of providing a rapid decision support system.

Simplified models, such as FAO paper number 56 (Allen *et al.* 1998), focuses on the simulation of the soil water depletion (D_e). Crop coefficients are used extensively and are currently considered as the standard functional way to estimate the crop water requirement. Although site-specific crop coefficients are probably best, the tabled crop coefficients for a generic orchard are often used for water management, due to a lack of reliable information on tree water use. The actual water fluxes terms are obtained from the water stress function K_s=f(D_e), being K_s a reduction coefficient for the water stress (K_s, 0-1.0). In Tanasijevic *et al.* (2014), the authors demonstrated that there will be a decrease of the K_s factor in 2050, and therefore a large increase of water stress over Mediterranean areas. Net irrigation requirements are expected to increase of about 18% in this region for the 2050 horizon. Agro-hydrological models and sensors are able to provide details about the responses of crops under climate change. These are tools to design management practices to maximize the crop yield by optimizing the water supplied and the time of application during the crop growth cycle. Therefore, using these expert systems, the local farmers will be able to diminish the impact of climate change on local water resources (Moratiel *et al.* 2011).

This paper is centered into the main scientific and third mission activities produced by the AgrHySMo laboratory. First, the paper presents a discussion about the knowhow and the contributes in agrohydrological sensing and modelling. Second, the paper illustrates the technology demonstrator (TD) and the high-throughput screening (HTS) system developed to study the crop water requirement and the crop drought-salinity stress response. Finally, it shows an expert wireless sensor network (WSN) for irrigation feed-back control and drought monitoring.

THE AGRHYSMO LABORATORY: KNOW-HOW AND CONTRIBUTION IN AGROHYDROLOGICAL SENSING AND MODELLING. – AgrHySMo lab joins current and innovative hydraulic and hydrological skills for the design and the management of irrigation requirements and scheduling, at tree and/or field scale. The laboratory studies systems under sparse vegetation, where there is a need to partition the evapotranspiration term in its two components, *e.g.*, evaporation and transpiration, because only the latter is related to the beneficial part of the water use.

The integration of third mission activities with the agronomic-based research sectors contemplates the optimal irrigation management in an integrated way, which includes the management of water stress, rather than avoiding it, with the most modern water saving strategies. For this purpose, all the used/suggested technologies/protocols to schedule irrigation are associated with the feed-forward and feed-back control irrigation protocols. In the first case, the crop water requirements and its aliquot to be supplied are simulated by agrohydrological models. On the other hand, with a feed-back control of the irrigation, the farmer maintains the soil-crop water status within a certain pre-defined range and acquire awareness of the status through sensors systems installed at local o distributed scale. Finally, the physical aspect is implemented in a cybernetic platform, where the user can easily use the information returned by the sensors and being informed about the status (Fig. 1).

The technology to support the farmer, introduced the concept of supplemental irrigation (ICID resource) in water resources management, which suggests that the irrigation can be optimized at the minimum essential. In this way, the amount of water and the timing of irrigation are not scheduled to provide moisture-stress-free conditions, but rather to ensure that the minimum amount of water required for optimal (not maximum) yield is available during the critical stages of crop growth.

The laboratory collaborates with different research groups widespread in Europe, Africa and USA (Tab. 1). Research lines are addressed in: i) monitoring the water status of the soil-plant-atmosphere continuous system using the field spectroscopy, agro-hydrological sensors and micrometeorology; ii) development of water-salt stress functions in heterogeneous cropping systems; iii) application of agro-hydrological and spectral modelling (numerical and functional) to predict the soil and crop water status and to schedule precision irrigation; iv) development of simplified procedures for the site-specific calibration of the soil water sensors. Moreover, the laboratory carries out "third mission" activities and projects to strengthen dialogue and interaction between farms and the irrigation industry.

Contribution in Agrohydrological modelling for feed-forward scheduling irrigation. – These research activities encompassed the analysis of long series of eco-physiological, hydrological and agronomical data to perform agrohydrological models that estimate the crop water requirements (*e.g.,* in woody crops). Moreover, this activity allows acquiring know-how for managing the water resource at field scale in woody perennial crops.

The research team extracted valuable information for the feed-forward irrigation scheduling in citrus orchard, which was based on a strong data set provided from the research group of University of Valencia (Spain). In Puig-Sirera *et al.* (2019), the authors studied the effects of several regulated deficit irrigation (RDI) treatments, applied during the three stages of fruit growth, on soil-plant water relations of drip irrigated mandarin trees. A strong relationship between the amount of water supplied (precipitation plus irrigation) in the stage II of the fruit growth and the corresponding normalized cumulated stress (Myers, 1988), was observed in the most severe water deficit (25% of the potential evapotranspiration, ET_p). This robust relationship fits with the result of Rallo *et al.* (2017), and confirms that the S represents a good indicator to predict the total irrigation depth, to achieve a desired stress level during the fruit growth. Figure 2 depicts the water supply and the cumulated water stress (S_{MSWP}), which was based on measurements of midday stem water potential (*MSWP*). This relationship confirms that the regulation of the deficit (its magnitude and timing), related to the adopted water saving strategy, assumes an important role in the quantification of WUE. When considering the average depth applied in each irrigation event and in the periods of water restriction, the values of S_{MSWP} are still correlated with the average irrigation depth, with a slope of the regression curve that declines at increasing of irrigation depth (Fig. 3-left plot).

Therefore, under the examined frequency of the watering, the values of S_{MSWP} depend as well, on how irrigation was managed, and particularly on the average irrigation depth provided in each watering.

Regarding modelling, the FAO-56 model was able to predict the degree of accumulated stress in citrus orchards with different levels of deficit during the phase II of fruit growth. Consequently, we proposed a model-based water stress integral, $S_{cum,FAO\text{-}56}$. Figure 3-right plot shows how the FAO-56 model predicted the cumulated water stress during the periods of water restriction. The comparison was made between the measured, $S_{cum,MSWP}$, and the simulated, $S_{cum,FAO\text{-}56}$, water stress integral, which was based on a weekly time step. As can be observed, for each treatment (water saving strategy), there is a strong linear correlation between $S_{cum,MSWP}$ and $S_{cum,FAO\text{-}56}$.

This result indicates that under the examined conditions, the model can be successfully used to estimate indirectly the cumulative stress occurring in the field during the phase II of fruit growth, corresponding to any pre-fixed irrigation strategy.

On the basis of the above-mentioned results, we hypothesized that the agrohydrological models, when accurately calibrated, are able to adjust the crop coefficient for the eustress factors, when the target of the irrigation water saving strategy is known (magnitude of the eustressor to be applied and its distribution within the growth cycle). The eustress-adjusting coefficient, $K_{s\ eustress}$, will adjust the crop coefficients (K_c or K_{cb}), which are proposed in FAO56 for the estimation of the crop water requirements (Allen *et al.* 1998). In this way, K_c or K_{cb} will take into account the effect of the water deficit that is needed to reach a prefixed beneficial target (*i.e.*, amount of °Brix, bioactive substance, water use efficiency).

Our proposal to quantify this coefficient applies the inverse modelling approach (Paleari *et al.* 2017). This allows to develop *in-silico* ideo-factors that can be used *a priori* to adjust the crop coefficient, on which farmers should focus to develop profitable irrigation water saving. Moreover, these factors define the $K_{s\ eustress}$, which characterizes a specific crop, in a specific environment, and under a specific water saving strategy.

Development of a technology demonstrator for the determination of the real transpiration and a High-throughput screening system to model the crop response to drought-salinity stress. – The laboratory is developing a technology demonstrator (TD) for the measurement of the real transpiration of a vegetated surface. The TD, named ATMOSMART, is under a national industrial patent and was submitted for an international patent in the PCT (Patent Cooperation Treaty) contest. ATMOSMART is an advanced modification of the atmometer (Livingston 1915) and implements nanotechnologies to reproduce the canopy-atmosphere water vapour exchange when a soil water deficit conditions occur. The laboratory has reviewed the physical principles, developed the hardware, implemented the algorithm and designed the body of the sensors (Fig. 4). The nanotechnology is an electrically-driven smart membrane provided by the laboratory of Integrated Material Systems Laboratory (University of Ohio). The smart membrane reproduces the hydraulic behaviour of the leaves, which depends from the soil and atmosphere water status. In particular, the hydraulic state function of the smart membrane describes the water vapour transfer processes of the leaves (*i.e.*, transpiration). The system implements soil and atmosphere water status sensors to drive the membrane and, therefore, to measure the real conditions of the exchanged water flux.

The laboratory developed in collaboration with the Research Group of Plant Abiotic Stresses of the DiSAAA-a is the *HTS-High-throughput screening (HTS) modular system to model the crop response to drought and salinity stress.* The system integrates the Time Domain Reflectometry (TDR) and the gravimetric (*e.g.*, lysimetry) techniques to asses and modelling the crop response to drought and salinity stress. It measures the soil volumetric water content, the soil bulk electrical conductivity, the real crop transpiration and the growth rate, at growth pot scale in controlled or semi-controlled agro-environments (*e.g.*, greenhouse). The higher spatial (representative volume sensing) and temporal (sub-hour) data acquisition of the water-salinity status at substrate, crop and atmosphere levels, perform combined water-salinity stress models. The fully automated and integrated precision irrigation units supply precise water volume at different salt concentration for drought and/or salinity stress experiments/scenarios. The real-time overview of the water-salinity stress scenarios, can easily be analysed via the AgrHySMo web interface (Fig. 5). Furthermore, this system allows monitoring and managing the fertigation practices. In specialized application fields, such as genetic improvement, the system could calibrate the environmental limiting factors (*e.g.*, salinity and water stress) for the study of the phenotype.

Expert Wireless Sensor Network (WSN) for irrigation feed-back control and drought monitoring. – These sensors systems are studied inside a PhD project (Student: À. Puig-Sirera; Supervisor: G. Rallo; Opponent: D. Intrigliolo) with the objective to develop two wireless sensor networks (WSN) in two Tuscany agro-environment: vineyards in Chianti and pear orchards in Arezzo. In the Chianti terroir the WSN will provide i) farmers with a management tool to support supplemental irrigation and defining the time and amount of watering and ii) a tool for the policy makers to assess objectively the occurrence of drought periods. Vineyards registered under Controlled Designation of Origin (CDO), such as Chianti, are subjected to a certification to verify that the product quality meets the conditions requested from the respective regulations. Dry farming is usually practiced in Chianti region, thus supplemental irrigation (SI) could be necessary after prolonged periods of drought to support the well-functioning of the vineyard. Therefore, monitoring the soil and crop water status in Chianti region can represent an innovative practice to support the audit of drought, which characterizes the wine terroir of Central Italy. In this context, the research project will dispose a smart soil moisture monitoring system, AgriNET, designed and manufactured in USA by Tuctronics (Walla Walla, WA, USA).

With reference to the third mission activities, the laboratory transferred at the *Illuminati Frutta* Farm six-nodes WSN for the feed-back control irrigation scheduling in a pear orchard. In this context, the WSN, provided by Tuctronics, was installed after a zooning analysis, which aimed to design the zones where at least one node of the WSN had to be installed. Fig. 6 illustrates the distribution of the node inside the pilot plot of the farm and an output used for the feed-back control irrigation.

The farmers acquire awareness and are able to perform a feed-back control of the irrigation by looking up to their AgriNET App. In doing this, they will maintain the soil water content within a pre-defined optimal range. This range is delimited from an upper (*i.e.*, above the field capacity) and a lower (*i.e.*, dependent on the adopted water-saving strategy) limit. Referring to a conservative estimate, *Illuminati Frutta* have saved up to about 35% of the water supplied by comparing the new performance with the ordinary irrigation protocol. Further analyses will quantify the water productivity and the energy use efficiency.

FUTURE PROSPECTS. – AgrHySMo fulfills the priorities of the scientific community in agriculture water management and more specifically, it is sensible to the challenges of society. The activities will include actions for the adaptation to climate change, sustainable agriculture, efficient use of resources, as well as interventions for policy support and rural innovation.

We keep in mind that the exploitation of the different levels of interactions between stakeholders and the cybernetic world (*i.e.*, web-based platforms) will contribute to the social awareness of the problem by the rational use of water resources in agriculture.

The laboratory will examine the quality of the water management at both, farm and territorial scale, by the support of the WSN and the evaluation of the indicators of irrigation efficiency. With reference to the Public Administration, which is in charge of water resources protection, they will transfer a tool for the evaluation of the irrigation stakeholders. Therefore, it will be possible to identify and apply strategies connected to good irrigation practices, and induce farmers to install and use these expert systems, which will contribute to the mitigation of drought.

AgrHySMo will continue to support the *Illuminati Frutta* farm by introducing hydraulic smart valves commanded in telemetry to enhance the water-energy use efficiency by introducing regulated deficit irrigation strategies.

In collaboration with an international research group coordinated by Professors Luis Santos Pereira (University of Lisboa) and Ricky Allen (University of Idaho), AgrHySMo is reviewing studies performed in the last decades on crop coefficients for woody perennial crops. This collaboration aims to upgrade the crop coefficient listed in the tables 12 (single crop coefficient, K_c) and 17 (basal crop coefficient, K_{cb}) of the FAO 56 paper.

In conclusion, we take the opportunity to communicate that is open (deadline 2020 May 31) the Special Issue of Water Journal (MDPI) entitled *Applications of Agro-Hydrological Sensors and Models for Sustainable Irrigation* (Editors: Giovanni Rallo, Jaume Puig-Bargués).

REFERENCES

Allen R.G., Pereira S.L., Raes D., Smith M. (1998). Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. FAO Irrigation and drainage paper 56. Food and Agriculture Organization, Rome.

IPCC (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Downloaded from *www.ipcc.ch*.

Livingston B.E. (1915). A modification of the Bellani porous plate atmometer. Science 41: 872-874.

Moratiel R., Snyder R.L., Duran J.M. *et al.* (2011). Trends in climatic variables and future reference evapotranspiration in Duero Valley (Spain). Nat. Hazards Earth Syst. Sci. 11: 1795-1805.

Myers B.J. (1988). Water stress integral - a link between short-term stress and long-term growth. Tree Physiology 4: 315-323.

Paleari L., Movedi E., Confalonieri R. (2017). Trait-based model development to support breeding programs. A case study for salt tolerance and rice. Scientific Reports 7: 1-11.

Puig-Sirera A., Provenzano G., González-Altozano P. *et al.* (2019). Assessing irrigation water saving strategies in Citrus Orchard: analysis of the combined effects of timing and magnitude of soil water deficit. EGU 2019. Vol. 21, EGU2019-460.

Rallo G., González-Altozano P., Manzano-Juárez J. *et al.* (2017). Using field measurements and FAO-56 model to assess the eco-physiological response of citrus orchards under regulated deficit irrigation. Agricultural Water Management 180, Part A: 136-147.

Tabari H., Marofi S., Aeini A. *et al.* (2011). Trend analysis of reference evapotranspiration in the western half of Iran. Agricultural and Forest Meteorology 151: 128-136.

Tanasijevic L., Todorovic M., Pereira L.S. *et al.* (2014). Impacts of climate change on olive crop evapotranspiration and irrigation requirements in the Mediterranean region. Agricultural Water Management 144: 54-68.

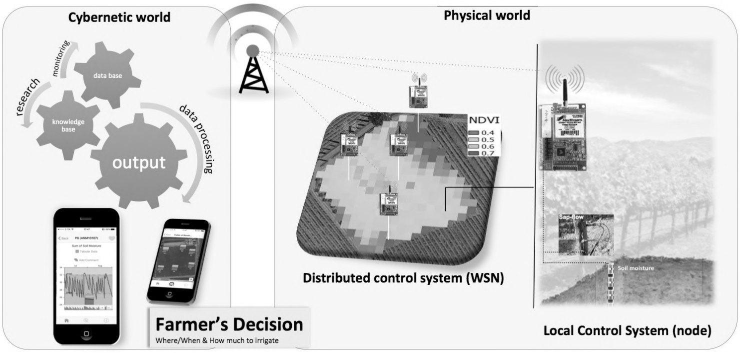


FIG. 1. Conceptualization of an expert system for the feedback control irrigation scheduling in vineyard.

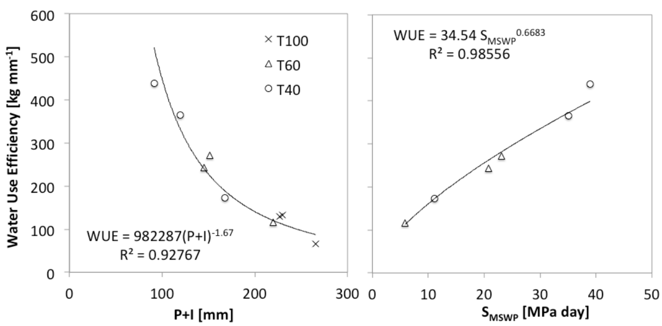


FIG. 2. Relationships among WUE, water supply and stress integral. T100, T60 and T40 are the water saving treatments.

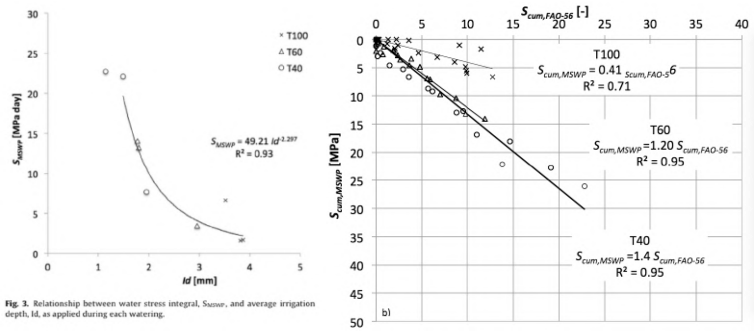


Fig. 3. Relationship (left) between water stress integral, S_{MSWP}, and applied average irrigation depth, Id. In the right plot, S_{MSWP} as a function of simulated water stress (S_{FAO-56}).

FIG. 4. CAD scheme of the technology demonstrator.

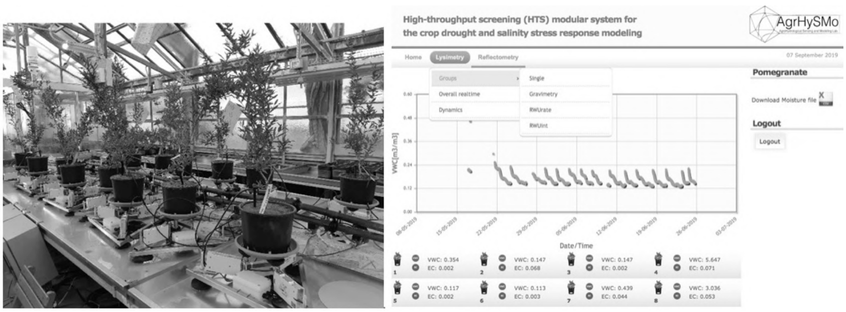


FIG. 5. HTS platform with pomegranate plants and web interface.

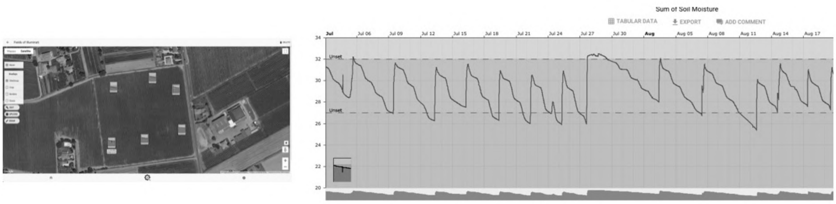


Fig. 6. WSN nodes inside the pilot plot and an output used for the feed-back control irrigation.

TABLE 1. – *International collaborations among the AgrHySMo and Institution/Laboratory/Research groups.*

Institution/Lab/Research group	Lead	Topic
Integrated Material Systems Laboratory. University of Ohio	V. B. Sundaresan	Implementation of nano-technologies in environmental smart sensor
LEAF - Research centre. University of Lisbon	L. S. Pereira T. A. do Paço	Upgrading of the FAO paper num. 56
Riego Deficitario Controlado y programación del riego en base a sensores and Métodos avanzados de estimación de necesidades de agua. Polytechnic University of Valencia	P. González Altozano J. Manzano Juárez	Irrigation water resource management of citrus orchard
Tuctronics Inc. (Walla Walla, WA, USA)	J. Tucker	WSN to feed-back control irrigation scheduling and drought monitoring
Paltin International Inc. (Maryland, USA)	I. C. Paltineanu	Soil moisture sensor calibration protocols
Institute Nationale Agronomique Chott Mariém. University of Sousse, Tunisia	A. Boujelben B. Douh	Sensor based irrigation scheduling

The use of red species for urban "greening" in the age of climate change

MARCO LANDI[1,2*], ERMES LO PICCOLO[1], ELISA PELLEGRINI[1,2], GIOVANNI AGATI[3], CRISTIANA GIORDANO[4], TOMMASO GIORDANI[1], GIACOMO LORENZINI[1,2], FERNANDO MALORGIO[1], ROSSANO MASSAI[1,2], CRISTINA NALI[1,2], GIOVANNI RALLO[1,2], DAMIANO REMORINI[1,2], PAOLO VERNIERI[1,2], LUCIA GUIDI[1,2]

[1] Department of Agriculture, Food and Environment, University of Pisa
[2] CIRSEC, Centre for Climatic Change Impact, University of Pisa
[3] "Nello Carrara" Institute of Applied Physics, CNR, Sesto Fiorentino (FI)
[4] Trees and Timber Institute, CNR, Sesto Fiorentino (FI)

Keywords: anthocyanins, environmental stress, photoinhibition, photoprotection, sunscreen

ABSTRACT. – The red/purple colour of some plant species is due to the presence of anthocyanins, a colourful class of flavonoids widely spread in the *Plantae* kingdom. Beside a doubtless aesthetic value of anthocyanin-rich species, the presence of these pigments confers them peculiar physiological and biochemical properties which make red species usually more tolerant to some environmental stresses, as occur in Mediterranean area. The ability of anthocyanins to partially absorb a proportion of light striking the mesophyll (mainly green and yellow wavebands) represents a useful feature against a condition of excessive light which not only occurs when plants are subjected to high irradiances, but also when other stressors (*e.g.*, high temperature, low water availability) impair the photosynthetic process. The work elucidates as the presence of anthocyanins determines morpho-anatomical, biochemical and physiological effects. In particular, the roles of these pigments are described comparing the leaf ontogenesis of two genotypes of *Prunus cerasifera*, one with red (var. *Pissardii*) and one with green leaves (clone 29C). Red-leafed *Prunus* resulted better protected, especially during the leaf senescence. The presence of anthocyanins also promotes a delayed leaf senescence (4-week-longer leaf lifespan) which is a well-appreciated feature in the context of urban "greening".

INTRODUCTION. – Anthocyanins, one of the most conspicuous classes of flavonoids and, together with proanthocyanidins and flavonols, are important plant pigments responsible for the red, pink, purple, and

*Corresponding author: marco.landi@unipi.it

blue colours in plants (Grotewold 2006). From the Antarctic purple-coloured leafy liverwort *Cephaloziella exiliflora*, to the breathtaking North American woodland trees (painted by intense autumn-red leaves in species such as *Acer rubrum*), the black foliage of *Ophiopogon planiscapus* "Nigrescens" (native to Japan), the intense purple-leafed *Prunus cerasifera* (widely dispersed in the Mediterranean basin and Southwest Asia), and the red-pigmented leaf margin of *Pseudowintera colorata* (from New Zealand), anthocyanic foliage is widespread throughout the plant kingdom and occurs all around the world.

Because anthocyanins also occur so commonly across disparate vegetative organs, there has been concerted research effort to understand their functional significance, particularly in plants that experience abiotic stressors (Chalker-Scott 1999; Landi *et al.* 2015). Among others (*e.g.*, herbivory deterrence, camouflage, antioxidants, metal chelators), the most accepted hypothesis for foliar anthocyanins is that these pigments act as sunscreen, thereby protecting the leaves from adverse situation of excessive light (respect to the capacity of the leaf to use it), namely *photoprotection*.

When the incident radiant flux exceeds the plant's ability to utilize or dissipate that energy, the excess excitation energy within the photosynthetic apparatus can lead to impairment of chloroplast performance and a reduction in carbon fixation. Plants have developed various mechanisms (both morphological and physiological) to avoid or accommodate excessive irradiance, such as leaf or chloroplast movement, reactive oxygen species (ROS) scavenging systems, dissipation of absorbed light energy as heat, activation of cyclic electron flow and photorespiratory pathways (Takahashi & Badger 2011). The biosynthesis of UV- and visible light-absorbing compounds (*e.g.*, phenylpropanoids) may further contribute to attenuate the burden of excessive irradiance (Agati & Tattini 2010). There is substantial empirical evidence that foliar anthocyanins can protect chloroplasts from the adverse effects of excess light (Landi *et al.* 2015). Anthocyanins have the potential to reduce both the incidence and the severity of photo-oxidative damage by intercepting a portion of supernumerary photons that would otherwise strike the chloroplasts, thus increasing ROS production and ROS-triggered damage (Fig. 1). For these reasons, in most cases red genotypes result better protected than greens under a plethora of environmental stressors which impair the photosynthetic process (Landi *et al.* 2015).

Red and green leafed *Prunus*. – As young and senescent leaves are usually more vulnerable to conditions of damage from excessive light, namely photoinhibition (Juvani *et al.* 2013), epidermally-located anthocyanins, photoprotecting the subjacent mesophyll cells may improve the photosynthetic performance of red morphs, making them more competitive in limiting conditions or in condition in which the leaves are more vulnerable (*i.e.*, young and senescent leaves). To test this hypothesis, Lo Piccolo *et al.* (2018) conducted a study in which morpho-metric and photosynthetic parameters as well as pigment content were determined in two morphs of *Prunus cerasifera* with permanent red (var. *Pissardii*; RLP) or green (clone 29C; GLP) leaves from their juvenility (1-week-old leaves) to their (early) senescence (13-week-old leaves).

A low photosynthetic rate in mature leaves of red genotypes was already reported in *Prunus* spp. (Kyparissis *et al.* 2007) and also confirmed by Lo Piccolo *et al.* (2018). Indeed, mature leaves of RLP had a ~30% lower photosynthetic rate compared to GLP. This lower CO_2 photoassimilation in RLP was attributable to the lower irradiance reaching chloroplast due to the anthocyanin presence. The sunscreen effect may appear as a negative feature for the plant, which however becomes very important when the leaves are in excessive light conditions, as in the juvenile and mature phase. Consequently, Lo Piccolo *et al.* (2018) observed that the decline of photosynthetic rate was less pronounced in senescent leaves of red than green *Prunus*, which also showed lower level of oxidative stress (measured in terms of hydrogen peroxide accumulation and super oxide anion production). As a consequence, an increased leaf lifespan of red leaves (4-week-longer than green leaves) and an increased level of recycled nitrogen were detected in RLP (Lo Piccolo *et al.* 2018). The capacity of anthocyanins to retard the leaf senescence, thereby extending the leaf lifespan suggests a "conservative-use strategy" adopted by species with "long-lived organs" (*e.g.*, evergreens) which inhabit nutrient-limiting environments in which a slower turnover of plant organs is advantageous (Valladares *et al.* 2000). On the other hand, green *Prunus* behaves like a fast-growing species that maximizes the biomass yield during favourable conditions and for which the loss of a higher level of N by leaf fall can be easily compensated by enhanced uptake mechanisms from soil in the following growing season.

Conclusion. – Several groups at the Department of Agriculture, Food and Environment of the University of Pisa have a long-running interest in the issue of climate change/plant interactions. Thanks to these experimental activities, physiological, biochemical and molecular responses to climate change-related abiotic stressors of several crop and tree species have been largely elucidated in the last decades. The abovementioned results highlight that the presence of anthocyanins in red *Prunus* represents a useful feature in condition of imbalance of absorbed/utilized light irradiance and also pointed out the possibility to use red-leafed *Prunus* in urban environment due to its capacity to maintain their canopy for longer (about one month longer in autumn) than green *Prunus* genotypes (Fig. 2). This experimental approach represents a good example of physiological research applied to the amelioration of ecosystem services by urban tree, and confirms that the use of red species for urban "greening" is a promising strategy in the age of climate change.

ACKNOWLEDGEMENTS. – This study was performed in the framework of PRA 2017 project "Photo-oxidative stress in juvenile and senescent red *versus* green leaves" financed by the University of Pisa.

REFERENCES

Agati G., Tattini M. (2010). Multiple functional roles of flavonoids in photoprotection. New Phytologist 186: 786-793.

Chalker-Scott L. (1999). Environmental significance of anthocyanins in plant stress responses. Photochemistry and Photobiology 70: 1-9.

Grotewold E. (2006). The genetics and biochemistry of floral pigments. Annual Review in Plant Biology 57: 761-780.

Juvany M., Müller M., Munné-Bosch S. (2013). Photo-oxidative stress in emerging and senescing leaves: A mirror image. Journal of Experimental Botany 64: 3087-3098.

Kyparissis A., Grammatikopoulos G., Manetas Y. (2007). Leaf morphological and physiological adjustments to the spectrally selective shade imposed by anthocyanins in *Prunus cerasifera*. Tree Physiology 27: 849-857.

Landi M., Tattini M., Gould K.S. (2015). Multiple functional roles of anthocyanins in plant-environment interactions. Environmental and Experimental Botany 119: 4-17.

Lo Piccolo E., Landi M., Pellegrini E. *et al.* (2018). Multiple consequences induced by epidermally-located anthocyanins in young, mature and senescent leaves of prunus. Frontiers in Plant Science 9: article number 917.

Takahashi S., Badger M.R. (2011) Photoprotection in plants: a new light on photosystem II damage. Trends in Plant Science 16: 53-60.

Valladares F., Martinez-Ferri E., Balaguer L. *et al.* (2000). Low leaf-level response to light and nutrients in Mediterranean evergreen oaks: A conservative resource-use strategy? New Phytologist 148: 79-91.

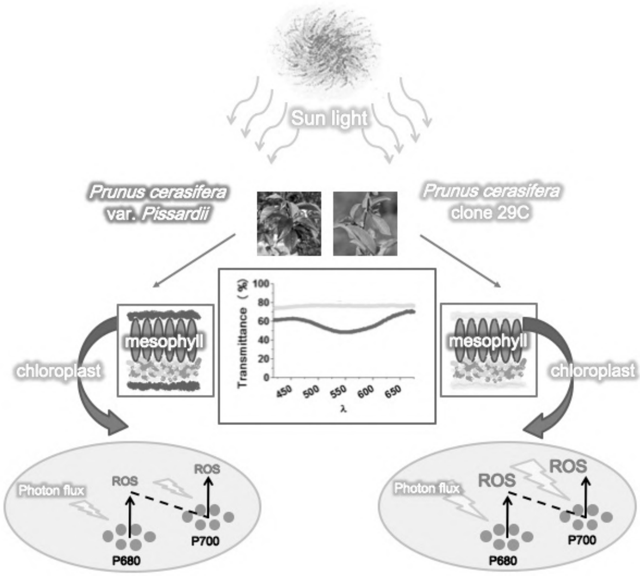


Fig. 1. Sunlight attenuation mechanism proposed for anthocyanins in red pigmented leaves to the green leaves. The abatement by anthocyanins of a proportion of light that would otherwise strike chloroplasts, as illustrated by a lower transmittance through the upper epidermis of red leaves, reduces the amount of reactive oxygen species (ROS) generated from the photosynthetic electron transport chain in photosystem II (PSII) and photosystem I (PSI). Modified from Landi *et al.* (2015).

Fig. 2. Seedlings of *Prunus cerasifera* clone 29C (left) and *P. cerasifera* var. *Pissardii* (right) at the beginning of November 2017, when red leaves were 17-week-old and leaves from clone 29C were completely fallen.

SESSION 4
EFFECTS ON NATURAL BIOSYSTEMS

Sensitivity of wild plants to climate change

GIANNI BEDINI, GIOVANNI ASTUTI, ANGELINO CARTA, DANIELA CICCARELLI, MARCO D'ANTRACCOLI, DAVID DOLCI, LORENZO PERUZZI*
Department of Biology - Systematic and Environmental Botany group, Via Derna, 1 - 56126 Pisa

Keywords: conservation, ecology, evolution, flora, Species Distribution Models

Abstract. – Measuring and modelling the response (sensitivity) of wild plants to current and future climate is crucial to predict future biodiversity and ecological assets. Our research group is using a range of experimental approaches to address this goal. To predict range shifts in plant species under climate change scenarios, we use species distribution models (SDMs). This approach is applied to native species of conservation interest and to alien taxa, in order to check the predictive power of SDM for future invasiveness, when used on early detected alien taxa. Another line of investigation deals with changes in breeding system and seed ecology promoted by climate change. We also evaluate the impact of past natural climatic changes in plant evolution and, finally, our research deals with the study of plant functional traits in relation to climate change.

Application of SDMs to native species of conservation interest. – Species distribution models (SDMs) relate environmental variables to species occurrence records, to gain insights into ecological or evolutionary drivers or to help in predicting habitat suitability across large scales (Elith & Leathwick 2009). We modelled the present and future predicted distribution of the soft-water pools specialist *Hypericum elodes* L. (Carta 2015), in order to facilitate appropriate decision making for its conservation and monitoring. *Hypericum elodes* is confirmed as a climate-sensitive species, with a W-European distribution. The model shows a marked negative influence of climate change, with *ca.* 58% reduction in the number of pre-existing bioclimatically suitable localities by 2050.

In the chasmophytic hypsophilous *Primula apennina* Widmer, an Italian endemic plant of conservation interest occurring on Tuscan-Emilian Apennines, we modelled (Astuti *et al.* 2019) the potential current distribution and projected it in year 2070, under different CO_2 emis-

*Corresponding author: lorenzo.peruzzi@unipi.it

sions scenario projections. We found that the distribution model built under the climate conditions returned a severe decline of cell occurrence coupled with an extremely low occurrence probability of *P. apennina* for all cells, hence predicting a “next-to-the-extinction scenario”. This prediction may be due to an upward range shift in elevation, which has been documented in many mountain plants combined to a “no place left to go” effect, as northern Apennines reach the maximum elevation at little more than 2100 m. Other Italian endemics studied by our research group, which are experiencing a reduction at lower elevations, possibly linked to climate change, are *Athamanta cortiana* Ferrarini (Ansaldi *et al.* 2011) and *Salix crataegifolia* Bertol. (Roma-Marzio *et al.* 2015).

Despite climate change can have significant impacts on the survival of plant species, it is seldom included in the assessment of the extinction risk according to IUCN Red List criteria. In a recent paper (Attorre *et al.* 2018) we addressed the effect of climate change on plant species spatial distribution. 37 Italian policy species (listed in the Habitat Directive and Bern Convention) were used as case study. A stochastic SDM incorporating data on plant dispersal, generation length, and habitat fragmentation was used to predict a range shift due to climate change according to two climatic scenarios. All taxa were potentially affected by climate change through a reduction of their range, albeit only two were characterized by critical decline probabilities. Species with the highest predicted reduction of range were those from lowlands, where fragmentation of natural habitats has occurred since the last decades.

Altogether, SDM can inform conservation spatial planning strategies minimizing the conservation costs, especially if the phylogenetic relationship among species is considered, with consequent reduction of redundant species (Carta *et al.* 2019).

Evaluation of SDMs temporal projection. – SDMs are widely used to forecast climate change impacts. Such temporal extrapolations are a common practice in plant ecology, but their effectiveness is hardly assessed, due to the absence of distribution data at the time when model is projected (*i.e.*, future data). The uncertainty associated with SDMs projections is poorly characterized, despite its potential value to decision makers. To test the reliability of SDM future projections, we performed SDMs on nine Italian endemic species (D’Antraccoli *et al.* 2019), using historical biological data (1910-1930) and historical climatic maps (‘past models’). Then, these models were projected to current climate ('projected models'), and compared with SDMs realized with current biological data (1980-present) and current climatic maps ('present models'). Accordingly, it was possible to test theoretical "future" distributions, with current potential distributions (in this case, corresponding to the "future"). In four out of the nine case studies we observed an overestimation of the projection function, and in five an underestimation. These differences seem correlated to the ecological features of the species: stenoecious species, showing a limited habitat tolerance range, seem prone to overestimation. On the contrary, euryecious species, showing wider habitat tolerance range, seem prone to underestimation. Further research is required to assess the reliability of SDM-based conservation programmes for species with different levels of ecological tolerance.

Application of SDMs to predict invasiveness of alien species. – SDMs have also been extensively applied to invasive species to assess the risks of biological invasions (Jiménez-Valverde *et al.* 2011). Despite this, two core assumptions of SDMs are violated when modelling invasive species. These species are not in equilibrium with their environment and niche quantification in space and time are limited (Gallien *et al.* 2012). To improve our understanding of SDMs applied to biological invasions, we aim to compare the current distribution of selected alien species (either casual, naturalized, or invasive) introduced in Italy near the end of 19th century, to their potential distribution, modelled using past distribution and past climate data. This should allow to get insights into SDMs performance in predicting the "future" degree of invasiveness in alien plants.

Reproductive and regeneration strategies under climate change. – Plant persistence and migration in face of climate change depends on successful reproduction by seed. To assess plant population persistence and survival we primarily observe the disruptive association between reproductive (breeding system) - regenerative (seed ecology) stages and the climatic conditions experienced by wild plant populations. Self-pollinated plants or even mixed breeding systems may be favoured under unpredictable environments (Carta *et al.* 2016a), which may be the case under a climate change scenario. The promotion of a shift toward self-fertilization under climate change, even maladaptive, may favour self-pollination (Casazza *et al.* 2018). Changes in the breeding systems may also result in the development of seeds showing different degrees of seed dormancy (Carta *et al.* 2015). Whilst these strategies may allow acclimatisation of populations, their effects on plant reproduction cannot be reduced to a qualitative interpretation of absolute positives and negatives (Fernández-Pascual *et al.* 2019). In this context, we conducted laboratory experiments to describe the shape of the seed germination niche, discovering associations with the current climate. These studies highlighted species-specific (Carta *et al.* 2014, 2016b) or even population-specific (Carta *et al.* 2016c) climatic cues, triggering seed germination that may negatively impact population survival.

Climate change and plant evolution. – Natural climatic changes that occurred through geological times are one of the drivers of evolution in plants. For instance, we recently evaluated the role played by Plio-Pleistocenic climatic changes in shaping the current genetic structure of black pine (*Pinus nigra* J.F.Arnold) in the Mediterranean (Naydenov *et al.* 2016, 2017). Applying molecular (AFLP and sequences of nuclear ribosomal ITS), karyological (relative genome size estimations and chromosome counts) and morphometric methods to the *Euphorbia verrucosa* alliance (Cresti *et al.* 2019), we underlined the importance of southern European peninsulas as refugial and diversification areas during the Pleistocene, providing additional evidence that Mediterranean high mountain plants are suffering severe range contractions due to climate warming.

Finally, by estimating divergence times under a random molecular clock based on nrITS phylogeny of the genus *Gagea* (Liliaceae), we revealed that this genus most likely originated in southwestern Asia, starting its diversification in the Early Miocene (Peterson *et al.* 2019). In the Middle Miocene, *Gagea* migrated to the Mediterranean and to East Asia, while migration into Euro-Siberia took place in the Late Miocene. During the Pleistocene, the Arctic was colonized and *Gagea serotina,* the most widespread species, reached North America. The Mediterranean basin was colonized multiple times from southwestern Asia or Euro-Siberia. Most of the currently existing species originated during the last 3 Ma. All these migration and diversification rounds paralleled the main climatic changes which shaped the current climate of northern Hemisphere.

Vegetative functional response of plants to climate. – The Mediterranean basin is characterised by increasingly dry summers and the study of the adaptive traits developed by plants living in this stressful environment is of great interest, also in relation to climate projections for this area. Summer drought in which the combined action of water deficit, high air temperatures and excess of light could be very stressful, is generally considered the primary constraint to plant growth in Mediterranean Basin. Considering that climate change is expected to increase temperatures and the intensity and/or frequency of drought in the Mediterranean basin (IPCC 2013), the characterization of plants living in this stressful environment and of their response to constraints related to climate is of great interest.

Mediterranean plants have developed different mechanisms to cope with summer drought involving morphological, biochemical, and physiological changes. Plant functional traits are useful features to study ecological strategies and to determine how plants respond to environmental factors (Perez-Harguindeguy *et al.* 2013). Leaf area, specific leaf area, leaf dry matter content and succulence index were studied in different plants living in different habitats such as coastal sand dunes, sea rocky cliffs, and Mediterranean maquis (Ciccarelli 2015; Ciccarelli *et al.* 2016; D'Antraccoli *et al.* 2018). These studies highlighted how co-occurring species can evolve different responses to the climatic stress factors in the Mediterranean area.

REFERENCES

Ansaldi M., Bacci S., Carta A. *et al.* (2011). *Athamanta cortiana*. The IUCN Red List of Threatened Species 2011: e.T161898A5510657.

Astuti G., Olivieri F., D'Antraccoli M. *et al.* (2019). Species distribution models of the narrow endemic *Primula apennina* Widmer (Primulaceae): a valuable tool for conservation purposes. Book of abstracts [Posters], International Plant Science Conference, 114th Congress of the Italian Botanical Society, September 2019, Padova: 47 .

Attorre F., Abeli F., Bacchetta G. *et al.* (2018). How to include the impact of climate change in the evaluation of extinction risk assessment of policy plant species? Journal of Nature Conservation 44: 43-49.

Carta A. (2015). The impact of climate change on *Hypericum elodes* L. (Hypericaceae) distribution: predicting future trends and identifying priorities. Atti della Società Toscana di Scienze Naturali, Memorie, Serie B 121: 15-24.

Carta A., Probert R., Moretti M. *et al.* (2014). Seed dormancy and germination in three *Crocus* ser. *Verni* species (Iridaceae): implications for evolution of dormancy within the genus. Plant Biology 16: 1065-1074.

Carta A., Bedini G., Giannotti A. *et al.* (2015). Mating system modulates degree of seed dormancy in *Hypericum elodes* L. (Hypericaceae). Seed Science Research 25: 299-305.

Carta A., Savio L., Bedini G. *et al.* (2016a). All in an afternoon: mixed breeding system in one-day lasting flowers of *Hypericum elodes* L. (Hypericaceae). Plant Biosystems 150: 1001-1009.

Carta A., Probert R., Puglia G. *et al.* (2016b). Local climate explains degree of seed dormancy in *Hypericum elodes* L. (Hypericaceae). Plant Biology 18: 76-82.

Carta A., Hanson S., Müller J.V. (2016c). Plant regeneration from seeds responds to phylogenetic relatedness and local adaptation in Mediterranean *Romulea* (Iridaceae) species. Ecology and Evolution 6: 4166-4178.

Carta A., Gargano D., Rossi G. *et al.* (2019). Phylogenetically informed spatial planning as a tool to prioritise areas for threatened plant conservation within a Mediterranean biodiversity hotspot. Science of the Total Environment 665: 1046-1052.

Casazza G., Carta A., Giordani P. *et al.* (2018). Reproductive biology of the threatened *Lilium pomponium* (Liliaceae), a species endemic to Maritime and Ligurian Alps. Journal of Plant Research 131: 633-640.

Ciccarelli D. (2015). Mediterranean coastal dune vegetation: Are disturbance and stress the key selective forces that drive the psammophilous succession? Estuarine, Coastal and Shelf Science 165: 247-253.

Ciccarelli D., Picciarelli P., Bedini G. *et al.* (2016). Mediterranean Sea cliff plants: morphological and physiological responses to environmental conditions. Journal of Plant Ecology 9: 153-164.

Ciccarelli D., Bottega S., Spanò C. (2018). Study of functional and physiological response of co-occurring shrub species to the Mediterranean climate. Saudi Journal of Biological Sciences: *https://www.sciencedirect.com/science/article/pii/S1319562X18301979?via%3Dihub*.

Cresti L., Schönswetter P., Peruzzi L. *et al.* (2019). Pleistocene survival in three Mediterranean refugia: origin and diversification of the Italian endemic *Euphorbia gasparrinii* from the *E. verrucosa* alliance (Euphorbiaceae). Botanical Journal of the Linnean Society 189: 262-280.

D'Antraccoli M., Dolci D., Roma-Marzio F. *et al.* (2019). 'Back to the future': Assessing the effectiveness of Species Distribution Models temporal projection through herbarium data. Book of abstracts [Communications], International Plant Science Conference, 114th Congress of the Italian Botanical Society, September 2019, Padova: xiv.

D'Antraccoli, M., Roma-Marzio, F., Astuti G. *et al.* (2018). Variation of vegetative and reproductive traits in *Cistus laurifolius*: evidences of a response to contrasting habitat conditions. Flora 248: 22-27.

Elith J., Leathwick J.R. (2009). Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution and Systematics 40: 677-697.

Fernández-Pascual E., Mattana E., Pritchard H.W. (2019). Seeds of future past: climate change and the thermal memory of plant reproductive traits. Biological Reviews 94: 439-456.

IPCC - Intergovernmental Panel on Climate Change (2013). The Physical Science Basis Contribution of WG I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Jiménez-Valverde A., Peterson A.T., Soberón J. *et al.* (2011). Use of niche models in invasive species risk assessments. Biological Invasions 13: 2785-2797.

Gallien L., Douzet R., Pratte S. *et al.* (2012). Invasive species distribution models – how violating the equilibrium assumption can create new insights. Global Ecology and Biogeography 21: 1126-1136.

Naydenov K.D., Naydenov M.K., Alexandrov A. *et al.* (2016). Ancient split of major genetic lineages of European black pine: evidence from chloroplast DNA. Tree Genetics and Genomes 12: article number 68.

Naydenov K.D., Naydenov M.K., Alexandrov A. *et al.* (2017). Ancient genetic bottleneck and Plio-Pleistocene climatic changes imprinted the phylobiogeography of European Black Pine populations. European Journal of Forest Research 167: 767-786.

Perez-Harguindeguy N., Díaz S., Garnier E. *et al.* (2013). New handbook for standardised measurement of plant functional traits worldwide. Australian Journal of Botany 61: 167-234.

Peterson A., Harpke D., Peterson J. *et al.* (2019). A pre-Miocene Irano-Turanian cradle: origin and diversification for the species-rich monocot genus *Gagea* (Liliaceae). Ecology and Evolution 9: 5870-5890.

Roma-Marzio F., Carta A., Di Sacco L. *et al.* (2015). Contributo alla conoscenza della flora vascolare endemica di Toscana ed aree contermini. 8. *Salix crataegifolia* (Salicaceae). Informatore Botanico Italiano 47: 205-211.

Ecophysiological research on Mediterranean natural plants in a changing environment

CARLO SORCE[1*], STEFANIA BOTTEGA[1], DANIELA CICCARELLI[1], CARMELINA SPANÒ[1], NICOLETTA MAGRINI[1], ANDREA SCARTAZZA[2]
[1] Dipartimento di Biologia, Università di Pisa, Via Luca Ghini, 13 - 56126 Pisa
[2] Istituto di Ricerca sugli Ecosistemi Terrestri (IRET), CNR, Via Giuseppe Moruzzi, 1 - 56124 Pisa

Keywords: climate change, C fixation, coastal plants, photosynthetic efficiency

ABSTRACT. – The research interest of our group is the impact of climate changes on natural plant species of Mediterranean environments. Global changes potentially expose plants to novel environmental conditions that may be outside of their physiological limits and disrupt evolutionary patterns, while also influencing the interactions between plants and whole ecosystems. Understanding the physiological mechanisms of resistance to stress is fundamental to improve predictions of the effects of climate change, because they may be a key indicator of plant resiliency (or lack thereof) in future environments. Our attention is focused also on invasive plant species, whose competitive ability might be altered by climate changes. Mediterranean coasts are rich of biodiversity, but are intensively exploited for recreational and economic activities. This environment is particularly vulnerable to climate changes, thus urging us to investigate it in depth, in search of clues that may help to foresee and prevent damages to these ecosystems. Markers of plant stress may serve this purpose, therefore our ecophysiological investigations aim at applying basic research in the conservation of natural ecosystems and in the preservation of supply of goods and services for human activities. A few case studies are described to outline the research work of our group.

INTRODUCTION. – Understanding and predicting the response of ecosystems to global climate change is a crucial challenge. Anthropogenic alteration of the environment is occurring at such a rate that the forces driving the evolution of living organisms do not seem to keep pace with it. Higher plants are reliable indicators of the state of the environment and drive important and complex feedbacks on ecosystems. Beyond the physiology, climate changes modify the abundance and distribution of natural species, as well as those of invasive ones. Further complexity

*Corresponding author: carlo.sorce@unipi.it

arises when considering the impact on the whole biotic communities and on the interactions between plants and other living organisms. Extensive research has led to a rapid progression in our knowledge of the responses to individual elements of climate change (Ort & Ainsworth 2012). Nevertheless, further efforts are needed, to take into account the complexity of the processes occurring at ecosystem level: several authors (Albert *et al.* 2011 and references therein) have drawn attention to the importance of studying the response to multiple climatic factors. In this respect, natural ecosystems are excellent experimental systems and more attention should be focused on them. Clearly, to address the remarkable complexity of this work it is required the collection of large bodies of data and a multidisciplinary approach. For this reason, our group gathers the expertise of researchers working on plant ecophysiology, biochemistry, ecology and botany. The ecophysiological approach may be considered central to gain insight into the processes of plant adaptation to changing environments (Ainsworth *et al.* 2016). Such knowledge is essential for attempting to mitigate global climate change and for maintaining humankind's supply of goods and services as climate change intensifies (Foley *et al.* 2011).

Climate change in the Mediterranean area. – Despite its limited surface (only 1.6% of the global land area), the Mediterranean basin is a global hotspot of biological diversity, with nearly 10% of all known plants on earth. This region is characterized by seasonal water shortage, high photon flux density (PFD) and the occurrence of extreme weather phenomena such as heavy rainstorms and hail. The synergy of three ecological factors – water deficit, high air temperatures and excess light – puts plants under strain. Also winter cold stress, induced by low temperatures and clear days with elevated PFD impairs physiology and strongly influences the development and distribution of Mediterranean plants. Global changes in the Mediterranean basin are expected to produce a general warming with drier conditions and an increase of erratic (unpredictable) precipitation (Ciccarelli *et al.* 2016), thus exacerbating the existing environmental issues. Coastal areas are predicted to increasingly experience flooding and erosion in the next future, as well as a rising human pressure, therefore these habitats will probably undergo modification, fragmentation and further reduction. Our attempts to amend this situation will be unsuccessful, unless we strengthen the scientific knowledge on the dynamics of coastal environments, to designate potential indices of perturbation that may be useful in forecasting changes and setting up management strategies for protecting or restoring these areas, that are invaluable for their multiple ecological roles as well as for their relevance to economic activities (Cramer *et al.* 2018).

MEDITERRANEAN PLANTS IN A CHANGING ENVIRONMENT. – Mediterranean coastal species have the ability to cope with a series of extreme environmental factors such as shallow and nutrient poor soils, water deficit, intense sunlight, salt spray and strong winds. Plants of coastal dune habitats must withstand also recurrent sea swash, sandblast, burial by sand and a marked shortage of water and nutrients, owing to the incoherence of the sand. Mediterranean coastal plants must face further threats due to pollution, erosion, global warming, urban development, intense touristic exploitation and the diffusion of alien species (Ciccarelli 2014). Notably, the degradation of coastal dunes has raised serious concern in Europe and particularly in Italy, where up to 80% of the dune systems have been lost during the past century (Feola *et al.* 2011). The problem affects also northern Tuscany (Fig. 1), which is partly undergoing erosion, with dramatic changes in local ecological conditions (Anfuso *et al.* 2011). Given the central role played by native plant species in landscape conservation and coastal protection (Van der Meulen & Salman 1996), understanding the interactions between coastal flora and its habitat is of basic importance.

ECOPHYSIOLOGICAL STUDY OF THE MEDITERRANEAN FLORA. – Markers of plant stress may represent early signals of change before strong ecological impacts take place. Physiological responses of plants to the environment may involve photosynthesis, redox status and water balance and can be accurately measured, thus making them good candidates as early indices of environmental changes. Accordingly, in our work we acquire, both in the field and in the laboratory, parameters indicative of the physiological status of plants, like water potential (WP), relative water content (RWC), photosystem II (PSII) functioning and biochemical markers of oxidative stress (Sorce *et al.* 2019). Our ecophysiological investigations rely also on the evaluation of leaf gas exchanges through the measurement of stomatal conductance and on the analysis of photosynthetic water use efficiency and carbon metabolism by the determination of carbon isotope composition in structural and non-structural carbohydrates (Scartazza *et al.* 2014) and of the daily oscillation of mesophyll cell pH (the latter parameter helps to detect CAM-like photosynthetic activity). Increased stress on the most representative species may thus be highlighted through the ecophysiological data, collected over several years. Our approach to the scientific problems is widened by recording floristic and morpho-functional data. The main goal of our work is to gain more insight into the mechanisms and strategies of response to stress of the most representative native species, that must face environmental challenges that vary seasonally, over very short distances and also at a whole-ecosystem level. We also investigate the physiology of invasive species, with the aim to evaluate possible relations between their diffusion and environmental changes. Information achieved through our work may be helpful for the identification of trustworthy and cost-efficient indicators of early changes in coastal habitats.

The following paragraphs provide a concise overview of our research activities.

MEDITERRANEAN SEA CLIFF PLANTS. – Six species typical of the coastal rocky cliffs were analyzed to evaluate their diverse physiological and morphological responses to the environment across the seasons, and to examine the strategy of the ecological group to which each species belongs (Ciccarelli *et al.* 2016). The selected species are characteristic of the sea cliffs of Elba island (Tyrrhenian Sea, Italy): the halophyte *Crithmum maritimum*, the semideciduous *Helichrysum italicum* and *Lavandula stoechas* and the sclerophylls *Myrtus communis*, *Quercus ilex* and *Rhamnus alaternus*. *Crithmum maritimum* showed high resistance to the recurrent dry periods, because of the high water storage capacity of its leaves and its photochemical efficienct (PE) declined markedly only in July (Fig. 2), under the harshest climatic conditions. Semideciduous taxa utilize primarily an avoidance strategy, which aims at reducing the overall leaf surface, while sclerophylls mostly show a tolerance strategy towards the prevailing stressors, possibly due to osmoregulation and photoinhibition. The sclerophyllous taxa underwent a slight loss of PE also in winter, likely owing to the combined action of low temperature and high PFD. *Myrtus communis* appeared to be the least resistant species, with a physiological performance that was lower than that of the other sclerophylls studied and its spread is potentially jeopardized by winter chill and, mostly, summer drought. This makes *M. communis* a good candidate as a bioindicator for tracking the changes in Mediterranean ecosystems.

COASTAL DUNE PLANTS. – Mediterranean coastal dunes, due to the complex coast-to-inland gradient of environmental conditions, contribute greatly to plant biodiversity and display a peculiar vegetation profile which may be affected by the natural and artificial degradation of the coast. Given that disturbances are likely to increase in the future, we were interested in advancing our knowledge on the mechanisms of resistance allowing plants to colonize this stressful environment (Sorce *et al.* 2019). Three representative species of the different dune zones, *Achillea maritima*, *Ammophila arenaria* and *Helichrysum stoechas* were studied during the four seasons. These species are found from the embryonic shifting dunes (close to the shore) to the fixed dunes (more inland). Physiological performances of the studied species changed across the seasons and the occupied niches, in accordance with the respective strategies of resistance. Winter and summer were the most critical seasons with different levels of stress depending on the coast profile where plants grew. The shoreline-inland gradient of stress conditions was evident only for *A. arenaria*, which experienced a physiological crisis in foredune during summer (see, for example, the central panel of Fig. 3, displaying the marked decrease of PE of foredune-growing *A. arenaria* occurring in summer). For this reason, this species could be a good candidate as effective clue of climate changes, that are expected to lead to increasingly harsh environmental conditions. The markers of stress that we analyzed are promising indicators of early changes in coastal sand dunes habitats.

ECOPHYSIOLOGY OF THE INVASIVE SPECIES *YUCCA GLORIOSA* IN MEDITERRANEAN COASTAL DUNES. – *Yucca gloriosa* is an invasive alien species that causes serious ecological problems in the dune environment of Migliarino Regional Park (Northern Tuscany). We studied the ecophysiology of *Y. gloriosa* to provide information for explaining its high competitiveness and its response to environmental factors, as well as for assessing if segregation of CAM or C3 metabolism-related traits occurs in this environment. *Yucca gloriosa* exhibited great physiological plasticity: as a C3-CAM intermediate species (Heyduk *et al.* 2016), it is able to perform two distinct types of photosynthetic metabolism, as well as a third one (CAM cycling), which may be considered intermediate between the aforesaid two. The latter consists in assimilating C as a C3, but during the night, when stomata are closed, part of the CO_2 released by respiration is fixed again, thus enhancing the synthesis of organic

C. We observed that *Y. gloriosa* may shift the photosynthetic pathway depending on the season: CAM photosynthesis in summer, C3 in winter and CAM cycling in the other seasons, thus fixing C with high efficiency throughout the year (Fig. 4). These changes were coordinated with stomatal functioning (day/night cycle) and morpho-anatomical features of the leaf. None of the individuals that we analyzed exhibited segregation for C3 and CAM photosynthesis traits. Temperature proved to be the main climatic factor controlling photosynthesis shifting. The high capacity of C acquisition also allows the plant to maintain a high water use efficiency. These, along with the plasticity of photosynthesis, are ecophysiological features that may contribute to the rapid growth of *Y. gloriosa*. The foreseen climate changes in the Mediterranean area should lead to environmental conditions that could be even more favorable for *Y. gloriosa*: tracking the ecophysiology of this species, particularly the shift between C3, CAM cycling and CAM photosynthesis over the year, may provide information for anticipating ecological changes.

GEOTHERMAL FIELDS: AN ENVIRONMENT MIMICKING EXTREME CLIMATE CHANGES. – The vegetation profile and the ecophysiology of the evergreen dwarf shrub *Calluna vulgaris* was analyzed in a Mediterranean ecosystem in the presence of intense geothermal activity (Bartoli *et al.* 2013; Pippucci *et al.* 2015). The geothermal fields of Southern Tuscany may be an example of the aftermath of extreme climate changes, since this environment is characterized by high air and soil temperatures, low water and nutrient availability and high atmospheric CO_2 concentration. Therefore, one of the main goals of our research was to gain more insight into the response to long-term exposure to the extreme conditions of this environment and, consequently, into the mechanisms of adaptation to multiple stress factors. Among the higher plants present in the area, *C. vulgaris* appears to be the sole to possess the ability to grow near the geothermal sources. The hot fluid springs strongly alter the environment in their proximity due to their partial precipitation to the soil, thus leading to its extreme acidification and nutrient depletion. Furthermore, the temperature starts to rise sharply just a few centimeters below soil surface. Under this multiple stress, the individuals of *C. vulgaris* growing within a few meters from the springs showed lower PE, higher oxidative damage to the biomembranes and lower stomatal conductance than the individuals growing farther away. Drought and high air temperatures occurring in summer exacerbate these harsh conditions, but only the plants closer to the springs did undergo an acute, yet transient crisis, as shown by the analyzed parameters. The ecophysiological traits of *C. vulgaris* are suitable for surviving even at highly unfavorable spots, close to the geothermal sources. Leaf anatomical traits contribute to the achievement of the high degree of tolerance. The air around the geothermal springs is enriched with CO_2 and other gaseous compounds, some of which might be toxic to plants: under these conditions, stomatal conductance may be significantly lowered. Our data (Tab. 1) confirm this hypothesis, because stomatal conductance was lower in As (plants growing close to the geothermal springs) than in Ac (control group) plants, even shortly after a rainfall. Such restriction of leaf gas exchanges enhances water use efficiency and might be crucial for increasing the ability of *C. vulgaris* to overcome the driest period in summer, although the drawback would be a down-regulation of photosynthesis, as suggested by Albert *et al.* (2011). Thus, *C. vulgaris* growing in geothermal fields may represent a valid model to establish a base of ecological and ecophysiological data which may help to scale up to a higher level our current knowledge of the response of plants to multiple stresses.

REFERENCES

Ainsworth E.A., Bernacchi C.J., Dohleman F.G. (2016). Focus on ecophysiology. Plant Physiology 172: 619-621.

Albert K.R., Mikkelsen T.N., Michelsen A. *et al.* (2011). Interactive effects of drought, elevated CO_2 and warming on photosynthetic capacity and photosystem performance in temperate heath plants. Journal of Plant Physiology 168: 1560-1561.

Anfuso G., Pranzini E., Vitale G. (2011). An integrated approach to coastal erosion problems in Northern Tuscany (Italy): Littoral morphological evolution and cell distribution. Geomorphology 129: 204-214.

Bartoli G., Bottega S., Forino L.M.C. *et al.* (2013). Morpho-physiological plasticity contributes to tolerance of *Calluna vulgaris* in an active geothermal field. Australian Journal of Botany 61: 107-118.

Ciccarelli D. (2014). Mediterranean coastal sand dune vegetation: influence of natural and anthropogenic factors. Environmental Management 54: 194-204.

Ciccarelli D., Picciarelli P., Bedini G. *et al.* (2016). Mediterranean sea cliff plants: morphological and physiological responses to environmental conditions. Journal of Plant Ecology 9: 153-164.

Cramer W., Guiot J., Fader M. *et al.* (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. Nature Climate Change 8: 972-980.

Feola S., Carranza M.L., Schaminée J.H.J. *et al.* (2011). EU habitat of interest: an insight into Atlantic and Mediterranean beach and foredunes. Biodiversity and Conservation 20: 1457-1468.

Foley J.A., Ramankutty N., Brauman K.A. *et al.* (2011). Solutions for a cultivated planet. Nature 478: 337-342.

Heyduk K., Burrell N., Lalani F. *et al.* (2016). Gas exchange and leaf anatomy of a C3-CAM hybrid, *Yucca gloriosa* (Asparagaceae). Journal of Experimental Botany 67: 1369-1379.

Ort D.R., Ainsworth E.A. (2012). Focus on climate change. Plant Physiology 160: 1675-1676.

Pippucci A., Lorenzi R., Spanò C. *et al.* (2015). Stress-induced changes to the flora in a geothermal field in Central Italy. Acta Physiologiae Plantarum 37: 198, doi 10.1007/s11738-015-1953-1.

Scartazza A., Vaccari F.P., Bertolini T. *et al.* (2014). Comparing integrated stable isotope and eddy covariance estimates of water-use efficiency on a Mediterranean successional sequence. Oecologia 176: 581-594.

Sorce C., Bottega S., Spanò C. (2019). Seasonal and microclimatic influences on the ecophysiology of Mediterranean coastal dune plants. Estuarine, Coastal and Shelf Science 219: 317-327.

Van der Meulen F., Salman A.H.P.F. (1996). Management of Mediterranean coastal dunes. Ocean & Coastal Management 30: 177-195.

TABLE 1. — *Mean stomatal conductance (mmol H_2O m^{-2} s^{-1} ± SD) of the selected plants of* Calluna vulgaris *(Ac = control and As = plants directly exposed to geothermal spring effluents;* n *= 20 per group). Different letters indicate significant differences between treatments and times (P ≤ 0.05).*

Date	Ac	As
Jul 29	195.02 ± 8.047^a	68.05 ± 2.417^c
Aug 26	92.67 ± 1.825^b	27.95 ± 3.491^d
Sep 23	113.10 ± 6.085^a	51.92 ± 3.155^c

Fig. 1. Ongoing erosion of the coast between the estuaries of river Arno and river Serchio, approximately 43°44’03”N, 10°16’30”E.

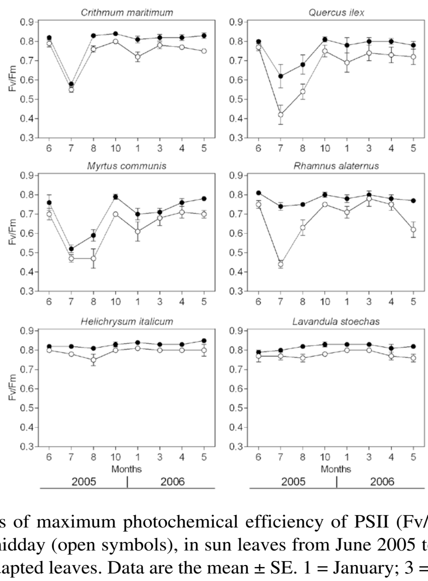


FIG. 2. Seasonal changes of maximum photochemical efficiency of PSII (Fv/Fm) measured before dawn (filled symbols) and at midday (open symbols), in sun leaves from June 2005 to May 2006. Midday values were recorded on dark adapted leaves. Data are the mean ± SE. 1 = January; 3 = March; 4 = April; 5 = May; 6 = June; 7 = July; 8 = August; 10 = October (from Ciccarelli *et al.* 2016).

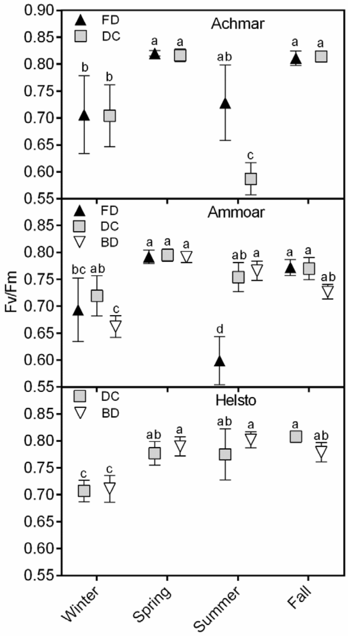


FIG. 3. Seasonal changes of maximum photochemical efficiency of PSII (Fv/Fm) of the three species studied (*Achillea maritima*, Achmar; *Ammophila arenaria*, Ammoar and *Helichrysum stoechas*, Helsto), over three coast profiles (foredune, FD; dune crest, DC and backdune, BD). Each value represents the mean of 60 measurements ± SD. Different letters indicate significant differences between seasons and profiles (P ≤ 0.05) (from Sorce *et al.* 2019).

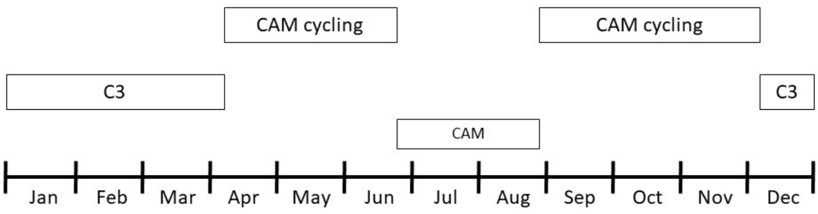


FIG. 4. Diagram showing the shifting of photosynthetic metabolism observed during one year in *Yucca gloriosa* plants growing in the coastal dune environment of Migliarino Regional Park.

Climate change, ozone and plant life

LORENZO COTROZZI[1], ELISA PELLEGRINI[1,2], CRISTINA NALI[1,2],
GIACOMO LORENZINI[1,2,*]
[1]Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto, 80 - 56124 Pisa
[2]CIRSEC, Centre for Climate Change Impact, University of Pisa, Via del Borghetto, 80 - 56124 Pisa

Keywords: air pollution, ecosystem services, global models, heat-waves, oxidative stress

ABSTRACT. – Tropospheric ozone (O_3) is a global air pollution issue and a pivotal greenhouse gas. Even if the emissions of O_3-precursors are reduced, it is expected that there will be an increase in the frequency of high polluted days globally due to the changes in weather (*e.g.*, high temperature, reduced precipitation) expected under future climate change (CC), especially in hot-spot areas such as the Mediterranean basin. Although it is now certain that understanding of the role of O_3 pollution on natural and urban ecosystems is crucial to any effort to mitigate CC by stabilizing atmospheric carbon dioxide concentrations, a full comprehension of the prediction of the overall continual impact of O_3 under different realistic environmental scenarios is so far missing. The phytopathology group at the Department of Agriculture, Food and Environment of the University of Pisa has a long-running interest in the issue of plant/O_3 interactions, and its activities are aimed to cover the gaps and uncertainties on the complex network among CC, O_3 pollution and vegetation.

INTRODUCTION. – *TROPOSPHERIC OZONE.* – Tropospheric ozone (O_3, *i.e.*, the one occurring in the lowest part of the Earth's atmosphere which extends from the ground up to a variable height of approximately 14 km) is a global air pollution issue and a pivotal greenhouse gas. Unlike many other air pollutants, O_3 is not directly emitted; it is a secondary pollutant since it is formed, under solar radiation and high temperature, by chemical reactions among precursors such as carbon monoxide (CO), volatile organic compounds (VOC), methane (CH_4) and nitrogen oxides (NO_x). These precursors arise from both natural/biogenic sources and a broad range of human activities. Motor vehicle exhausts, industrial emissions, and chemical solvents are the major anthropogenic sources of these

[*]Corresponding author: giacomo.lorenzini@unipi.it

chemicals. Although the O_3 precursors often originate in urban areas, they can be carried round the globe, making it a transboundary pollution problem, spatially non-uniform and time-variant. Another source of O_3 in the troposphere is transport from the stratosphere (Ainsworth *et al.* 2019).

Together with human population and activity, concentrations of tropospheric O_3 have been increasing over the last century and, despite significant efforts and legislation to control emissions of O_3 precursors, tropospheric O_3 is still a major air quality issue over large regions worldwide. The Mediterranean basin is considered a hot-spot region in terms of O_3 pollution (Sicard *et al.* 2013). Where they have implemented, policy measures have had demonstrable success at reducing emissions of O_3 precursors with substantial reductions of NO_x and VOC and consequent declines in short-term peak O_3 concentrations which however, continue to exceed the WHO guideline values of 50 ppb (1 ppb O_3 = 1.96 µg m^{-3} at 25°C and 101.325 kPa) in many countries, including Latin America, North America, Europe and Africa. For example, peaks of O_3 over 90 ppb were registered in Tuscany (Central Italy) in Summer 2019 (*http://www.arpat.toscana.it/*). At the same time, however, measurements in many regions show that the hemispheric background has been increasing in the mid-latitude Northern hemisphere, a phenomenon that is not yet fully understood. Other uncertainties come from many developing regions with higher O_3 concentrations which, unlike North America, Europe and Japan where O_3 is being well monitored, have limited and no continuous O_3 monitoring networks. A certainty, instead, is that the current tropospheric O_3 levels (35-50 ppb in the Northern hemisphere) are high enough to damage human health [in the EU28, tropospheric O_3 is associated with at least 16 thousand excess deaths each year (EEA 2018)] and vegetation due to the high oxidation potential (+ 2.07 V) of the pollutant (Mills *et al.* 2018).

Ozone and climate change. – The production of O_3 is controlled by temperature, sunlight and humidity (higher temperatures and elevated radiation accelerate O_3 production, whereas humidity has a negative climate feedback on O_3), and by the long-range transport of pollutants all of which are sensitive to changes in climate. Many of the processes creating or destroying O_3 or delivering it to the ground level are influenced by sinoptic and local weather patterns, which also provide the pathways for the long range transport and for the ventilation of O_3 and its precursors from the boundary layer to the free troposphere. Thus, climate variability on inter-annual to inter-decadal timescales may have a substantial influence on background O_3 levels. In this context, following the extreme heat and high O_3 concentrations of 2003 and 2012 observed in the Mediterranean area, where climate change (CC) is expected to be more pronounced than in most other regions of the world (stronger temperature increases and precipitation reductions), the scientific community has been alerted to the possibility that CC may increase the risk of such extreme events in the future (The Royal Society 2008).

On the other hand, O_3 increases also contribute to CC through both direct and indirect routes. Ozone is a greenhouse gas, and it has been estimated that tropospheric O_3 increases since pre-industrial times have contributed somewhere between 0.25 and 0.65 W m^{-2} to global radiative forcing. On the basis of this directing forcing, O_3 is ranked as the third most important anthropogenic greenhouse gas after carbon dioxide (CO_2, 1.49-1.83 W m^{-2}) and CH_4 (0.43-0.53 W m^{-2}). Increases in O_3 will also have an indirect effect on global warming by suppressing plant growth, reducing the land carbon sink for CO_2 and therefore increasing the rate at which CO_2 increases in the atmosphere. Thus, future impacts on climate of changing O_3 concentrations should be considered alongside those of rising CO_2 concentrations (Matyseek *et al.* 2012).

What about future ozone scenarios? – Modeling works to predict future O_3 scenarios emphasize the important role of emission controls for determining future O_3 concentrations. They also show that by 2050, CC may have significant impacts on ground-level O_3 at the local and regional scale. When changes in both emissions and CC are considered, the largest increases in O_3 concentrations are projected for regions where there are major sources of emissions and where emissions controls are currently weakest, such as Asia and Africa. In industrialized countries such as United States, Europe and Japan, where emissions controls are relatively strong and emissions are projected to decline over forthcoming decades, O_3 concentrations are expected to be reduced although CC will likely tend to reduce the effectiveness of emission reductions. Even if emissions are reduced, it is expected that there will be an increase in the frequency of high polluted days globally due to the changes in weather expected under future CC, especially in hot-spot areas such as the Mediterranean basin (The Royal Society 2008; Wang *et al.* 2016).

However, there is currently no consensus among modelers about what the dominant climate feedback on surface O_3 globally might be, in part because different effects are likely at different spatial scale. Furthermore, there are significant uncertainties in the representation of many of the processes and feedbacks included in coupled chemistry-climate models, as well as gaps in basic understanding.

One key aspect that is not properly included in prediction models is the role(s) that vegetation has in the context of air pollution due to O_3 and CC. Although it is known that plants are essential players in this context, there are, as yet, big gaps and uncertainties in the few global modelling studies coupling climate, vegetation and atmospheric chemistry in a fully interactive way. The suggested sensitivity of future O_3 to ecosystems is indicative of an important interaction that needs to be fully integrated into climate-chemistry models.

THE ROLES OF VEGETATION IN THE AIR POLLUTION SCENARIO AND THEIR INTERACTION WITH CLIMATE CHANGE. – *PLANTS AS VICTIMS.* – Plants are primary targets of O_3 toxicity, and O_3 represents the most phytotoxic air pollutant. The most important direct effects of O_3 on plants are those on leaf physiology (*i.e.*, decreased photosynthesis and stomatal conductance) and plant growth, and the main factors involved are the control of the flux of the pollutant by stomata into the leaf and the capacity for redox detoxification/repair processes within the cells. Once O_3 is inside the leaf, it dissolves in the apoplastic fluid forming reactive oxygen species (ROS) which primarily target the lipid and protein components of cell membranes. Thus, depending on the O_3 dose ("*concentration × exposure time*") and the species, O_3-induced oxidative stress may overwhelm the plant detoxification capacity and cause a range of direct effects, such as cell dehydration, excessive excitation energy and accelerated leaf senescence, even in the absence of visible symptoms. Overall, these effects result in reduction of crop and forest productions and huge economic loss (Ainsworth *et al.* 2019).

As a consequence, high O_3 concentrations lead to the loss of plant-related ecosystem services. No surprise that O_3 may influence both vegetation community structure and functions, also declining diversity. Furthermore, increases in O_3 will also have a further indirect effect on global warming, representing a driver for an increase in CO_2 concentrations in the atmosphere. As stated above, sequestration of atmospheric CO_2 by forest system is a major control of CO_2 abundance and its growth rate. Thus, reductions of plant growth induced by O_3 will compromise the role of vegetation in carbon sink for CO_2 (Wang *et al.* 2016).

Plants as sink. – As well as CO_2, plants are also an important sink for many gaseous air pollutants (mainly during their physiological gas exchange activity), so doing protecting human health (Nowak 2006). In the terrestrial environment, dry deposition of O_3 occurs as a result of reactions with the external surfaces of vegetation and soil and uptake by plant stomata. Dry deposition rates range from 2 to 15 mm s^{-1} and are mainly regulated by opening and closing of stomata, wind speed and turbulence and the presence of surface water on vegetation.

The aperture of the stomatal pores on the leaf surface is governed by plants in response to sunlight, temperature, humidity, soil moisture and CO_2 concentration. In drought conditions, for example, the closure of stomata to protect plants against desiccation reduces stomatal conductance and dry deposition of O_3. This aspect further highlights the complexity of the network among CC, O_3 pollution and vegetation.

Plants as source. – Plants are also a source of air pollution. Plants themselves, in particular trees, emit a considerable amount of VOC: different compounds known as Biogenic Volatile Organic Compounds (BVOC), involved in a wide class of ecological functions, emitted as a consequence of the interactions of plants with biotic and abiotic factors. The BVOC emission at planetary level has been estimated of 1150 Tg C $year^{-1}$ (Calfapietra *et al.* 2013). These compounds, identically to VOC of anthropogenic nature enter the troposphere to take part to the whirlwind of reactions which bring to photochemical smog and O_3 formation.

As well as for pollutants absorption, quality of BVOC emitted depends on species and environmental conditions. One of the most important feedbacks with climate is through temperature induced increased emissions fluxes of O_3 precursors, including BVOC from vegetation. It is thus expected that CC will lead to increases in BVOC emissions that will bring to reductions of air quality in terms of both pollution and climate.

Plants as bio-indicators. – Plants that show conservative, unquestionable and easily measured reactions are also excellent bio-indicators of air pollution. Since the knowledge of O_3 distribution at ground level is a priority in the environmental monitoring activities in order to prevent risks to human health, and the establishment and management of chemophysical automatic analyzers are very costly, several bio-monitoring campaigns have been performed using vascular plants. For example, *Nicotiana tabacum* cv. "Bel W3" has been largely used for bio-monitoring O_3 in Europe and North America since it is very O_3-sensitive and shows characteristic and easily quantified O_3-induced necroses on the leaves (Pellegrini *et al.* 2014).

Gaps, uncertainties and research needs. – A synthesis of the abovementioned major interactions among climate, O_3 pollution and ecosystems is reported in Figure 1. According to The Royal Society (2008), feedback reactions between climate and O_3 concentrations are well understood and represented in chemistry-climate models, although the importance of regional and local meteorology, inter-annual and-decadal variation in climate and extreme events such as heat waves has not been properly considered. Conversely, the interactions concerning ecosystems are either partially understood and represented in models or emerging as important but not generally included in model predictions. Major gaps and uncertainties are especially for the effects of O_3 toxicity on ecosystems, as well as for the interactions between vegetation and CO_2 abundance in the atmosphere.

Therefore, the major science and research needs concern (together with increasing of inventory data for O_3 concentrations, better understanding on natural emissions of O_3-precursors and improving modelling techniques) the evaluation of the impacts of long-term O_3 exposure at baseline concentrations to vegetation health. It is now certain that understanding of the role of O_3 pollution on vegetation ecosystems is crucial to any effort to mitigate CC by stabilizing atmospheric CO_2 concentrations.

The study of more species growing in different realistic environmental scenarios, the assessment of critical levels (CLs) for protecting vegetation from dose-response investigations, the elucidation of the interactive effects on plants among O_3 and other CC-related abiotic stressors, the understanding of how processes operating at the level of individuals translate into population and community dynamics or the finding of a mechanistic explanation of the O_3-effects on plants (it seems a "mission impossible"!) are only some of the several research needs in this context. A full comprehension of the prediction of the overall continual impact of O_3 on vegetation ecosystems under different realistic environmental scenarios is so far missing (Lorenzini *et al.* 2018).

RESEARCH ACTIVITIES OF THE PHYTOPATHOLOGY GROUP AT THE DEPARTMENT OF AGRICULTURE, FOOD AND ENVIRONMENT OF THE UNIVERSITY OF PISA. – The phytopathology group at the Department of Agriculture, Food and Environment (DAFE) of the University of Pisa has a long-running interest in the issue of plant/O_3 interactions. In order to cover the gaps and uncertainties reported above, the DAFE phytopathology group have been largely focused on the effects of the pollutant on vegetation, mainly using the fumigation facilities at the field-station of San Piero a Grado (PI), but also being involved in experiments performed in other semi-controlled and uncontrolled environments worldwide. Thanks to these activities, physiological, biochemical and molecular responses to O_3 of several crop and tree species have been largely elucidated in the last decades (*e.g.,* Francini *et al.* 2008; Pellegrini *et al.* 2018a), with attention also to aromatic plants (Pellegrini *et al.* 2018b; Marchica *et al.* 2019a); and a number of works have been focused on the interactive effects among O_3 and other CC-related abiotic stressors (*e.g.,* Calzone *et al.* 2019; Cotrozzi *et al.* 2016; Podda *et al.* 2019). The group has been also interested is the advancements in phenotyping techniques (*i.e.*, vegetation spectroscopy) able to early detect and monitor the effects of O_3 on plants (Cotrozzi *et al.* 2018; Marchica *et al.* 2019b). Last but not least, several bio-monitoring O_3 campaigns using vascular plants have been also conducted throughout the whole country, also highlighting the educational benefit potentially related to this activity (Pellegrini *et al.* 2014).

REFERENCES

Ainsworth E.A., Lemonnier P., Medow J.M. (2019). The influence of rising tropospheric carbon dioxide and ozone on plant productivity. Plant Biology, doi:10.1111/plb.12973.

Calfapietra C., Fares S., Manes F. *et al.* (2013). Role of Biogenic Volatile Organic Compounds (BVOC) emitted by urban trees on ozone concentration in cities: A review. Environmental Pollution 183: 71-80.

Calzone A., Podda A., Lorenzini G. *et al.* (2019). Cross-talk between physiological and biochemical adjustments by *Punica granatum* cv. Dente di cavallo mitigates the effects of salinity and ozone stress. Science of the Total Environment 656: 589-597.

Cotrozzi L., Remorini D., Pellegrini E. *et al.* (2016). Variations in physiological and biochemical traits of oak seedlings grown under drought and ozone stress. Physiologia Plantarum 157: 69-84.

Cotrozzi L., Townsend P.A., Pellegrini E. *et al.* (2018). Reflectance spectroscopy: a novel approach to better understand and monitor the impact of air pollution on Mediterranean plants. Environmental Science and Pollution Research 25: 8249-8267.

European Environment Agency (EEA) (2018). Air quality in Europe. EEA report 12/2018.

Francini A., Nali C., Pellegrini E. *et al.* (2008). Characterization and isolation of some genes of the shikimate pathway in sensitive and resistant *Centaurea jacea* plants after ozone exposure. Environmental Pollution 151: 272-279.

Lorenzini G., Pellegrini E., Nali C. (2018). A new "*Mission Impossible*": A mechanistic understanding of ozone impact and risk assessment on forest ecosystems? Agrochimica 62: 273-300.

Marchica A., Lorenzini G., Papini R. *et al*. (2019a). Signalling molecules responsive to ozone-induced oxidative stress in *Salvia officinalis*. Science of the Total Environment 657: 568-576.

Marchica A., Loré S., Cotrozzi L. *et al.* (2019b). Early detection of sage (*Salvia officinalis* L.) responses to ozone using reflectance spectroscopy. Plants 8: 346; doi:10.3390/plants8090346.

Mills G., Pleijel H., Malley C.S. *et al.* (2018). Tropospheric ozone assessment report: present-day tropospheric ozone distribution and trends relevant to vegetation. Elementa Science of the Anthropocene 6: 47.

Nowak D.J. (2006). Institutionalizing urban forestry as a "biotechnology" to improve environmental quality. Urban Forestry & Urban Greening 5: 93-100.

Pellegrini E., Campanella A., Lorenzini G. *et al.* (2014). Biomonitoring of ozone: A tool to initiate the young people into the scientific method and environmental issues. A case study in Central Italy. Urban Forestry & Urban Greening 13: 800-805.

Pellegrini E., Campanella A., Cotrozzi L. *et al.* (2018a). What about the detoxification mechanisms underlying ozone-sensitivity in *Liriodendron tulipifera*? Environmental Science and Pollution Research 25: 8148-8160.

Pellegrini E., Campanella A., Cotrozzi L. *et al.* (2018b). Ozone primes changes in phytochemical parameters in the medicinal herb *Hypericum perforatum* (St. John's wort). Industrial Crops and Products 126: 119-128.

Podda A., Pisuttu C., Hoshika Y. *et al.* (2019). Can nutrient fertilization mitigate the effects of ozone exposure on an ozone-sensitive poplar clone? Science of the Total Environment 657: 340-350.

Sicard P., De Marco A., Troussier F. *et al.* (2013). Decreases in surface ozone concentrations at Mediterranean remote sites and increase in the cities. Atmospheric Pollution 79: 705-715.

The Royal Society (2008). Ground-level ozone in the 21st century: future trends, impacts and policy implications. The Royal Society, London. Science Policy Report 15/08.

Wang B., Shugart H.H., Shuman J.K. *et al.* (2016). Forests and ozone: productivity, carbon storage, and feedbacks. Scientific Reports 6: 22133.

http://www.arpat.toscana.it/temi-ambientali/aria/qualita-aria/grafici_bollettino/index/O3, retrieval date: 12 September 2019.

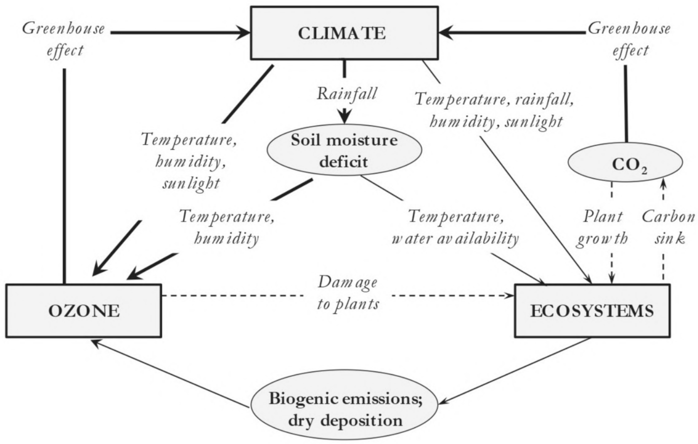


Fig. 1. A synthesis of the major interactions among climate, ecosystems and tropospheric ozone (Lorenzini *et al.* 2018). Thick solid lines represent processes that are generally well understood and represented in coupled chemistry-climate models; thin solid lines represent processes that are understood but for which uncertainties exist and are only partially represented in models; dashed lines represent links that are emerging as important but not generally included in model predictions.

Dune habitats vulnerability to the climate change

ANDREA BERTACCHI[1*], MAURIZIO CUTINI[2], BRUNO PAURA[3]
[1]Department of Agriculture, Food and Environment, University of Pisa
[2]Department of Sciences, University of Rome3, Rome
[3]Department of Agriculture, Environment and Food, University of Molise, Campobasso

Keywords: dune habitats, coastal erosion, climate changes, psammophilous vegetation

ABSTRACT. – Italy sandy coasts are characterized by a great diversity of habitats and, at the same time, many of these coastal stretches are in erosive condition. The causes of erosion are represented by multiple factors essentially geomorphological but to which today others of a climatic change can be added. These are linked to the intensification of extreme climatic events and/or sea level rise. Therefore, it is important to understand, in areas where marine erosion is particularly strong, which are the most vulnerable and most threatened habitats. This paper sets out a summary of the results obtained up to now from the survey of dune habitats (*sensu* Directive 92/43/EEC) along the northern Tyrrhenian coast. This investigations, aim to point out the arrangement of these habitats in relation to extreme weather events and dune erosion and the different resilience in the face of important changes in the beach/dune system.

INTRODUCTION. – The scenarios envisaged in the context of climate change for the Mediterranean basin highlight strong critical issues related to coastal environments (EEA 1999; Castellari *et al.* 2014; NOAA 2018; Blunden *et al.* 2018). These are mainly determined by an increase in sea level and wind, changing in wave power and shoreline stream (Lionello *et al.* 2014; Marisco *et al.* 2017; Vecchio *et al.* 2019). In addition to this, the rise in temperatures can be decisive in changes in the floristic component of dune vegetation with ingression of alien species (Janssen *et al.* 2016).

Italy has a coastline of about 7,500 km, of which approximately 37% is represented by rocky coasts and 63% by sandy coasts, characterised by a great diversity of habitats of high natural and environmental interest (Biondi *et al.* 2012). In this context, over the 45% of sandy coasts (Valpreda & Simeoni 2003) is affected by erosion, in part linked to

*Corresponding author: andrea.bertacchi@unipi.it

some changed coastal geomorphogenesis aspects (lower river sediments transport, changes in marine drift currents, etc.) and partly to causes that are still little known and analyzed but unquestionably linked to climate change (Masselink & Russel 2013).

The strong transformation of the biotic characteristics of the plant communities is strong correlated with the geomorphological traits of the dune ecosystems. Consequently, it is important that the monitoring of significant case studies can be the key to understanding possible changes ongoing and provide future scenarios. These habitats, just because linked to a geomorphologically dynamic environment, are subject to strong transformations and are intrinsically characterized both by extreme fragility and vulnerability and, at the same time, by a great resilience (Feagin *et al.* 2005; Janssen *et al.* 2016).

DUNE HABITATS AND CONSERVATION. – Sandy coastal ecosystems, occupying the transition zone between marine and sedimentary terrestrial environments, are susceptible to constant changes in their morphological structure and vegetation landscape (Brown & McLaghan 2002; Maun 2009). At the same time, they show a great biodiversity, in terms of plant species and communities (Prisco *et al.* 2012). The dune environment and the dune habitats that occur there are consequently very sensitive and vulnerable to environmental changes of even less intensity. This makes them particularly worthy of monitoring and protection for their specific ecosystem functions (Doody 2013).

The dune habitats are characterized by specific flora and specific plant associations (Biondi 1999) and, in an undisturbed environmental state, would be placed according to a precise spatial zonation (Acosta & Ercole 2015) Whenever in dunal environments there is a natural or artificial disturbance, we are witnessing the alteration of the natural distribution pattern of the plant communities (fragmentation and a reversal and in the worst cases, the disappearance of a community) (Fig. 1).

The identified and monitored dune habitats, in accordance with Habitat Directive, along the Italian coasts are: 1210 Annual vegetation of drift lines; 2110 Embryonic dunes; 2120 White dunes; 2210, 2230, 2240 *Crucianellion* fixed dunes and *Malcolmietalia* and *Brachypodetalia* dune grasslands; 2250 Coastal dunes with *Juniperus* spp.; 9340 *Quercus ilex* and *Quercus rotundifolia* forests and 2270 Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*. For a more detailed floristic-vegetational characterization of the coded dune habitats, see *http://vnr.unipg.it/habitat/*.

From a conservationist point of view Council Directive 92/43/ECC (commonly called “Habitats”) is a European Community legislative instrument in the field of nature conservation that establishes a common framework for the conservation of wild animal and plant species and natural habitats of Community importance. Annex I is based on the hierarchical classification of European habitats developed by the CORINE Biotopes project, because it was the only existing classification at the European level, while phytosociology affords the main reference for detecting the diagnostic species that have a lead role in defining the habitats (European Commission DG Environment 2007).

WHICH METHODS... – Monitoring in dune environments is usually carried out in the following ways:

1. field surveys by phytosociological approach (Gehu 1992). These are aimed at identifying the flora and vegetation and the diagnostic and characteristics plants/associations of the habitats, whose presence absence and frequency is evidence of the integrity and/or alteration of the same habitat. Normally the initial samplings are followed by subsequent periodic surveys on the same points to identify possible transformations (Sperandii *et al.* 2018).
2. with photo-interpretation of the images from remote sensing (aircraft, UAV, satellite) and, where possible, their diachronic comparison (Bertacchi *et al.* 2009; Malavasi *et al.* 2013).

...AND WHICH AREAS. – An example of great interest is represented by the coast of San Rossore Estate of Migliarino-San Rossore-Massaciuccoli Park (Tuscany, Italy). This stretch of coastline, about 11 km long, is under erosion from about a century but with a strong acceleration from the last 50 years (Fig. 2). In this sector, several investigation, conducted in recent years have shown, together with the presence of the most representative dune habitats, also their vulnerability (Bertacchi *et al.* 2016; Bertacchi 2017). As part of the study of the degradation dynamics of coastal environments, the comparison of historical aerial photos with the current ones was very useful in the survey. In this sector, due to erosion, around 200 ha of sandy shore have been lost since 1954, leaving today only a thin strip of dune of about 55 ha.

However, as a result of the aforementioned marine erosion, to this “richness” of habitat corresponds to a serious state of degradation of the same, in terms of alteration, fragmentation and disappearance, in over two thirds of the coast examined. In fact the marine erosion, determines the submersion of the first stretch of sandy shore, the salification of the same, the collapse of the dune structure and, finally, with the wave and tide motion, the removal of the sand (Fig. 3).

In our study area, this high erosion has determined the substantial disappearance of some habitats (H2110 embryonic dune with *Elymus farctus* and H2250, fixed dune with *Juniperus* spp.) and the significant degradation of others (H2120, white dune with *Ammophila arenaria*), with the almost disappearance of characteristic species (*e.g*., *Echinophora spinosa* and, partially, of *Juniperus oxycedrus*) and the dominance of other (*e.g*., *Euphorbia paralias*). Habitat 1210 (characterized by *Cakile maritima* and *Salsola kali*), shows an important subversion of normal zoning with a fragmentation of the habitat. The different vulnerability of habitats to coastal erosion is clearly related to the different ways in which this is expressed and where it occurs. Those species and plant communities that are not able or not fast enough to running inwards, are destined to disappear. Thus, the first degradation time is the destruction of the normal dune zonation, with habitat fragmentation and, sometimes, inversion. The next moment is the rarefaction and/or disappearance of characteristic species. The final moment is the disappearance of all species.

In this mainland consumption, the species of natural habitats closest to the coastline often fail to follow the erosion process and "move" inwards, especially when this phenomena is sudden and fast. In this dynamic, the annual species (*e.g*., *Cakile maritima*), the most halophilous species (*e.g*., *Salsola kali*), or those of habitats constantly in formations (*e.g*., *Elymus farctus* and/or *Euphorbia paralias*) show greater resilience, even if the habitats that are often used are no longer identifiable. Other species, although dune edifiers (such as *Ammophila arenaria*) show a high vulnerability and, often, disappear definitively in the dune belts particularly subject to erosion (Bertacchi *et al.* 2016; Sperandii *et al.* 2019).

CONCLUSIONS. – The constant monitoring and the constantly updated projections of the government agencies as NOAA or IPCC, together other specific investigations, on the average rise of the level of the oceans and the increase of storms on the planet coasts show the high risk in place for the coastal oceanic environments (Sweet *et al.* 2017; Rahmstorf 2017). Similarly, recent scientific papers on the Mediterranean environment, seem to confirm this trend. Also for our closed basin and a potential drowning of the Italian coastal plains (Marisco *et al.* 2017; Vecchio *et al.* 2019).

Consequently, the marine erosion of a large part of the coasts of the Italian peninsula can be certainly increased by sea level rise and may become a "marine trasgression". To this, large storm surges, flooding, strong wave action, and, sometime, human activities, thet "wear away" the beaches, can be added. In this scenario the constant monitoring of the plant communities of the dunes and of the habitats that go to characterize becomes of fundamental importance, with the dual purpose of early identifying the symptoms of erosive processes, and of identifying the possible actions to protect habitats.

This trend of dune habitats seem to be the same observed in other coastal areas of the central and southern Italian peninsula, as showned in the recent different investigations (Sperandii *et al.* 2018, 2019).

REFERENCES

Acosta A.T.R., Ercole S. (Eds) (2015). Italian coastal dune habitats: ecology and conservation issues [Gli habitat delle coste sabbiose italiane: ecologia e problematiche di conservazione]. ISPRA, Serie Rapporti, 215/2015, 101 pp.

Bertacchi A. (2017). Dune habitats of the Migliarino-San Rossore-Massaciuccoli Regional Park (Tuscany, Italy). Journal of Maps 13: 322-331.

Bertacchi A., Lombardi T., Bocci G. (2009). Il paesaggio vegetale dell'ambiente dunale di Calambrone nel litorale pisano (Toscana settentrionale). Informatore Botanico Italiano 41: 281-292.

Bertacchi A., Zuffi M., Lombardi T. (2016). Foredune psammophilous communities and coastal erosion in a stretch of the Ligurian Sea (Tuscany, Italy). Rendiconti Scienze Fisiche Accademia Lincei 4: 639-651.

Biondi E. (1999). Diversità fitocenotica degli ambienti costieri italiani. In: Bon M., Sburlino G., Zuccarello V. (a cura di), Aspetti ecologici e naturalistici dei sistemi lagunari e costieri. Arsenale Ed., Venezia, 89 pp.

Biondi E., Burrascano S., Casavecchia S. *et al.* (2012). Diagnosis and syntaxonomic interpretation of Annex I Habitats (Dir. 92/43/EEC) in Italy at the alliance level. Plant Sociology 49: 5-37.

Blunden J., Arndt D.S., Hartfield G. (Eds) (2018). State of the Climate in 2017. Bull. Amer. Meteor. Soc. 99: 310.

Brown A.C., McLachlan A. (2002). Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. Environmental Conservation 29: 62-77.

Castellari S., Venturini S., Ballarin A. *et al.* (2014). Rapporto sullo stato delle conoscenze scientifiche su impatti, vulnerabilità ed adattamento ai cambiamenti climatici in Italia. Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma, 816 pp.

Doody J.P. (2013). Sand dune conservation, management and restoration. Springer, Heidelberg, 306 pp.

Feagin R.A., Sherman D.J., Grant W.E. (2005) Coastal erosion, global sea-level rise, and the loss of sand dune plant habitats. Frontiers in Ecology and the Environment 3: 359-364.

European Commission, DG Environment (2007). Interpretation Manual of European Union Habitats. Version EUR27, 142 pp.

EEA (1999). State and pressures of the marine and coastal Mediterranean Environment. Environmental Issues Series No. 5, European Environment Agency, Copenhagen. *https://www.eea.europa.eu/publications/ENVSERIES*. Last accessed: 10.01.2019

Janssen J.A.M., Rodwell J.S., García Criado M. *et al.* (2016). European Red List of Habitats. Part. 2. Terrestrial and freshwater habitats. Publications Office of the European Union. doi: 10.2779/091372.

Géhu J.M. (1992). Végétation et qualité de l'environnement cotier en mediterranée. Colloques Phytosociologiques, Vol. 19. Cramer Ed., Berlin-Stuttgart, 760 pp.

Lionello P., Abrantes F., Gacic M. *et al.* (2014). The climate of the Mediterranean region: research progress and climate change impacts. Regional Environmental Change 14: 1679-1684.

Malavasi M., Santoro R., Cutini M. *et al.* (2013). What has happened to coastal dunes in the last half century? A multitemporal coastal landscape analysis in Central Italy. Landscape and Urban Planning 119: 54-63.

Marsico A., Lisco S., Lo Presti V. *et al.* (2017). Flooding scenario for four Italian coastal plainsusing three relative sea level rise models. Journal of Maps 13: 961-967.

Masselink G., Russell P. (2013) Impacts of climate change on coastal erosion. MCCIP Science Review 71-86.

Maun M.A. (2009). The biology of coastal sand dunes. Oxford University Press, Oxford, 288 pp.
NOOA (2018). Climate Change: Global Sea Level. *https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level*. Last accessed 30.07.2019.
Prisco I., Acosta A.T.R., Ercole S. (2012). An overview of the Italian coastal dune EU habitats. Annali di Botanica 2: 39-48.
Rahmstorf S. (2017). Rising hazard of storm-surge flooding. Proceedings of the National Academy of Sciences 114: 11806-11808.
Sperandii M.G., Prisco I., Stanisci A. *et al.* (2017). RanVegDunes - A random plot database of Italian coastal dunes. Phytocoenologia 47: 231-232.
Sperandii M.G., Prisco I., Acosta A.R.T. (2018). Hard times for Italian coastal dunes: insight for a diachronic analysis based on random plot. Biodiversity & Conservation 27: 633-646.
Sperandii M.G., Bazzichetto M., Acosta A.R.T. *et al.* (2019). Multiple drivers of the plant diversity in coastal dunes: a Mediterranean experience. Science of the Total Environment 652: 1435-1444.
Sweet W., Horton R., Kopp R. *et al.* (2017). Sea level rise. In: Climate Science Special Report: A Sustained Assessment Activity of the U.S. Global Change Research Program. Wuebbles D.J. *et al.* Eds. U.S. Global Change Research Program, Washington, DC, 493-539.
Valpreda E., Simeoni U. (2003). Assessment of coastal erosion susceptibility at the national scale: the Italian case. Journal of Coastal Conservation 9: 43-48.
Vecchio A., Anzidei M., Serpelloni E. *et al.* (2019). Natural Variability and Vertical Land Motion Contributions in the Mediterranean Sea-Level Records over the Last Two Centuries and Projections for 2100. Water 11: 1480.

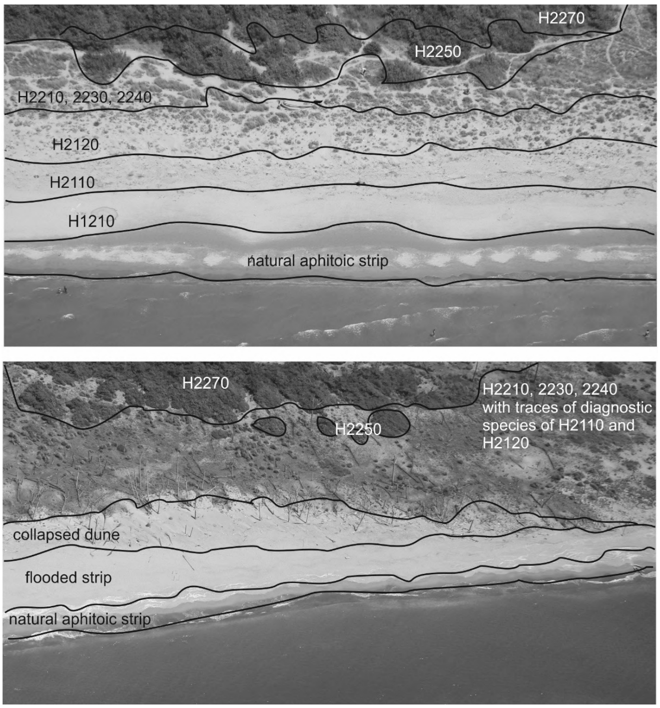


FIG. 1. Natural and undisturbed zonation on dune habitats in sedimentary Tuscany coasts (Calambrone) (*up*); Destruction of dune morphology and degradation of vegetation zonation (San Rossore) (*below*) (Aerial photos from Regione Toscana/Provincia Livorno, modified).

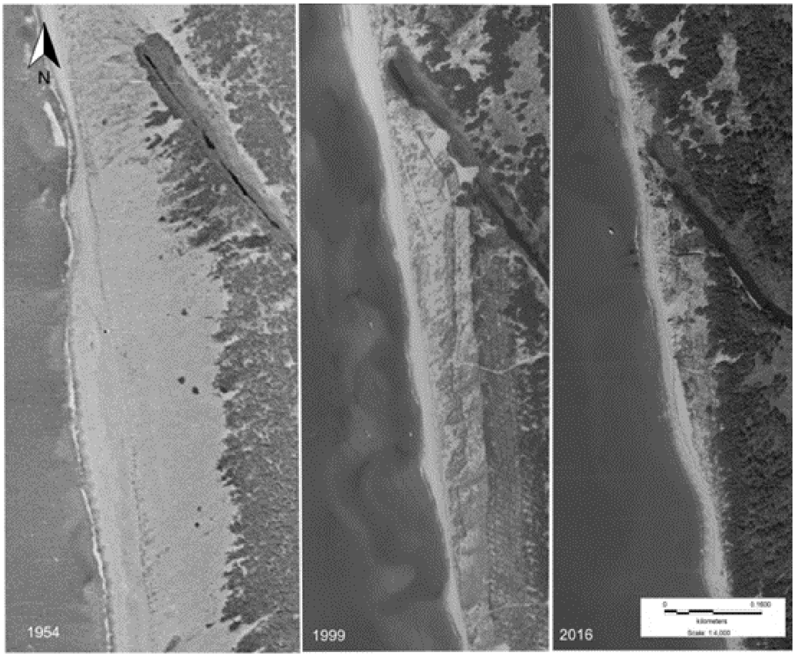


Fig. 2. Dune erosion and progressive reduction of dune habitats between 1954 and 2016 (San Rossore, Fiume Morto Vecchio) (from *http://www.regione.toscana.it/-/geoscopio* and licensed under Creative Commons Attribution CC-BY3.0 IT, modified)

Fig. 3. The collapse of the dune and the complete disappearance of dune habitats (San Rossore).

Biological responses to aridity in Mediterranean ecosystems: stress and adaptation in mosses and lichens

LUCA PAOLI*, ERIKA BELLINI, LUIGI SANITÀ DI TOPPI
Dipartimento di Biologia, Università di Pisa, Via Luca Ghini 13 - 56126 Pisa

Keywords: biological soil crusts, chlorophyll a fluorescence, desiccation-tolerance, forest management, habitat fragmentation

ABSTRACT. – This work summarizes a selection of researches carried out with the contribution of the University of Pisa and related to the early responses of mosses and lichens to arid conditions in Mediterranean ecosystems. The following topics have been highlighted, with their implications for environmental management: 1) effects of aridity on the ecophysiology of biological soil crusts (mosses and lichens); 2) effects of habitat fragmentation and aridity on sensitive forest macrolichens; 3) combined effects of eutrophication and dry conditions in sensitive and tolerant lichens in Mediterranean ecosystems.

INTRODUCTION. – Predictions for 2100 suggest that climate change will cause an increase in air temperature and a decrease in precipitation in the Mediterranean Basin region (Christensen *et al.* 2007; Sanità di Toppi 2018), exposing Mediterranean ecosystems to longer and abrupt periods of high temperatures and drought. It is therefore crucial for environmental protection and management to understand how relevant biological components of the ecosystems in Mediterranean environments will respond to climate change, including longer periods of drought. Lichens and mosses are relevant components of Mediterranean ecosystems, highly susceptible to the variations of environmental water availability. Therefore, they can provide early warnings on the processes ongoing in Mediterranean ecosystems due to the increase of aridity and their implications for environmental management. This paper introduces to selected researches that involved the University of Pisa and related to the ecophysiological responses of mosses and lichens to arid conditions in Mediterranean ecosystems. Aridity as a stressing factor has been considered alone or in combination with other stressors, such as habitat fragmentation due to forest management and habitat eutrophication

*Corresponding author: luca.paoli@unipi.it

due to nitrogen excess. The following topics have been highlighted: 1) effects of aridity on the ecophysiology of biological soil crusts (mosses and lichens); 2) effects of habitat fragmentation and aridity on sensitive forest macrolichens; 3) combined effects of eutrophication and dry conditions on sensitive and tolerant lichens in Mediterranean ecosystems.

Effects of aridity on the ecophysiology of Biological Soil Crusts. – In drylands, especially in Mediterranean ecosystems, where desertification and soil erosion are among the main environmental threats, biological soil crusts (biocrusts) are important for soil protection and soil-water-atmosphere dynamics (*e.g.*, Morillas *et al.* 2016). In drylands, lichens and mosses represent the macroscopic components of biocrusts (Belnap *et al.* 2016). These poikilohydric organisms, unable to avoid desiccation, depend for their water content directly on environmental water availability. Consequently, lichens and mosses spend their lives switching between hydrated and desiccated status. Their ability to exploit short periods of water availability and reversibly deactivate metabolism is crucial for their growth and survival. This suggests that prolonged dry conditions in lichens and mosses may eventually cause progressive damages that can be repaired only when there is sufficient time in the hydrated status. In addition, species-specific characteristics and differences in growth conditions may also affect the rate of recovery after rehydration (Harel *et al.* 2004). Thus, when such organisms are subjected to different drought stress (duration and intensity), photosynthesis reactivation may take different times.

Thanks to the cooperation between researchers of the universities of Lisbon (Portugal), Santiago de Compostela (Spain) and Pisa (Italy), an interesting study was carried out to investigate how photosynthesis reactivation in terricolous lichens and mosses responds to drought periods of different duration. Our working hypotheses were that: (i) prolonged drought periods negatively affect the reactivation of photosynthesis in terricolous lichens and mosses in a Mediterranean environment, and that (ii) invasive moss species are less sensitive than native species to differences in drought duration (Munzi *et al.* 2019). At this purpose, photosynthesis reactivation, respectively after long (65-66 days) and short (15 days) dry periods, in lichen and moss species widespread in two Mediterranean environments (Portugal and Italy) was assessed. Chlorophyll *a* fluorescence emission of the samples (the parameter

F_V/F_M, an indicator of vitality of photosynthetic organisms), was used as a proxy for photosynthesis reactivation.

The results indicated that widespread fruticose lichens (*Cladonia convoluta* and *C. rangiformis*), and mosses (*Pleurochaete squarrosa*), typical of Mediterranean environments, had a significantly slower reactivation of photosynthetic activity when subjected to a longer period of drought. Conversely, alien invasive mosses (*Campylopus introflexus*) were not affected by prolonged dry conditions (Munzi *et al.* 2019). These results suggest the likelihood of a reduction in biocrust productivity as a consequence of climate change in Mediterranean drylands and stimulate insights for further researches. In fact, according to future climate change scenarios, the ecological consequence of increasing duration of dry periods will lead to reduced productivity of biocrusts, with the consequent reduction in the ecosystem services they provide. Extended droughts will mean longer periods of inactivity of poikilohydric organisms, and also slower resumption of photosynthetic activity (Munzi *et al.* 2019). In sensitive ecosystems like drylands, where biomass production in slow-growing communities is restricted, a net cumulative loss of carbon over repeated cycles of dehydration/rehydration could lead to an impairment of ecosystem functioning. In these conditions, shifts in community composition and biodiversity loss can also be hypothesized, *i.e.*, more tolerant invasive species will replace sensitive ones (Sanità di Toppi 2018). Hence, the predicted increase in air temperature and the decrease in rain events in Mediterranean environments will have important consequences: net cumulative loss of carbon over repeated cycles of dehydration/rehydration; increased likelihood of invasion by species with a more efficient recovery rate, overall leading to a loss of biodiversity. The relationship between temperature, duration of the dry period and photosynthesis reactivation in protective biocrusts must be further explored to maximize their role in drylands, threatened by desertification and soil erosion (Munzi *et al.* 2019).

EFFECTS OF HABITAT FRAGMENTATION AND ARIDITY ON SENSITIVE FOREST MACROLICHENS. – Forest management affects biodiversity (Kraus & Krumm 2013) and alters forest structure and dynamics, as well as environmental parameters important to the dispersal, establishment and maintenance of epiphytic organisms (Aragón *et al.* 2010; Nascimbene *et al.* 2013). Forest management is associated with forest fragmentation and trees exploitation that cause a complete break in the availability of the primary habitat for epiphytic lichens (Otálora *et al.* 2011), causing habitat degradation and loss, that impact local populations structure, size and dynamics (Scheidegger & Werth 2009; Benesperi *et al.* 2018). Under these conditions, lichens may adapt to drought and high-light stress through a variety of mechanisms, such as energy dissipation, melanisation of the thalli, reduction of photosynthetic activity (Mafole *et al.* 2017). However, adaptation mechanisms do not always balance rapid environmental changes and the consequences are relevant especially for sensitive forest lichens, such as the macrolichen *Lobaria pulmonaria*, often used as a model species and considered as a "flag" indicator species (Scheidegger & Werth 2009) of forest ecosystems with long ecological continuity worthy of conservation. Modelling of different climate change scenarios suggests that *L. pulmonaria* could face a high extinction risk associated with a possible reduction of its distribution range (Nascimbene *et al.* 2016). *Lobaria pulmonaria* has been recognized as sensitive to the effects of logging and the consequent increase in habitat dryness. Nevertheless, any habitat modification that implies an increase of dry conditions would likely affect this sensitive species (and other associated organisms) much more than in the past.

This study was carried out thanks to the cooperation between researchers of the Slovak Academy of Sciences (Slovakia) and the universities of Siena, Firenze and Pisa (Italy). To this purpose, 18 months after logging within a mixed oak forest selected as experimental site (Murlo, Tuscany), photosynthetic performances, thallus anatomy and water holding capacity (WHC) of *L. pulmonaria* thalli were investigated, comparing thalli from retained-forest patches and retained-isolated trees (Fačkovcová *et al.* 2019). Forest logging reduced the density of stems from ~ 1100 to 165 per ha, with a consequent strong increase of sun irradiance on retained-isolated trees (from 130-1100 to 900-1550 $\mu mol\ m^{-2}\ s^{-1}$ PAR at noon), in parallel with a decrease of the overall water availability to the thalli growing on such trunks. The results indicated that thalli on the trunks of retained-isolated trees (*i.e.*, under dryer conditions) were thinner and showed a decreased vitality (as indicated by the potential quantum yield of primary photochemistry – F_V/F_M and the index of overall photosynthetic performance – PI_{ABS}), as well as lower water holding capacity. In contrast, thalli from forest patches had performances comparable to those of healthy samples from unlogged forests (Fačkovcová *et al.* 2019). Furthermore, it was estimated that after logging, 46% of retained-isolated trees were colonized by thalli with visible symptoms of damage, consisting in bronzing (melanisation), or in the worst case (14%) discoloration, up to bleaching (Paoli *et al.* 2019), which were not present within forest patches.

Our data provide an early warning on the processes ongoing after logging, and more extensive analyses divided by multiple years and growing seasons would be useful to delineate a long-term overview on the survival of the species (Fačkovcová *et al.* 2019).

COMBINED EFFECTS OF EXCESS NITROGEN AND ARIDITY IN LICHENS: ECOPHYSIOLOGICAL RESPONSES AND LICHEN-ASSOCIATED MICROBIAL COMMUNITIES. – The main goal of this activity is to disclose whether ammonia excess influences microbial communities associated to lichen thalli and whether such responses change along aridity gradients. This topic is going to be developed thanks to the cooperation between colleagues of the universities of Lisbon (Portugal), Florence and Pisa (Italy). The lichen microbiome interpreted as a potential functional trait in relation to nitrogen (N) excess represents a new topic, which can help to disclose the mechanisms of lichen tolerance and sensitivity to N pollution. Our collaboration is expected to produce one of the first papers on this topic. To this purpose, a N tolerant lichen (*Xanthoria parietina*) has been selected as a model species, being suitable for investigations on N excess on the ecosystems. In a first step, *Xanthoria parietina* has been sampled from sites impacted by ammonia (selected livestock farming) and remote control areas in Portugal and Italy. The diversity of lichen-associated microbial communities will be investigated in the light of the potential role of bacterial communities in mediating the response of lichens to N excess. A series of ecophysiological parameters (photosynthetic activity and total chlorophylls, membrane lipids peroxidation, glutathione, dehydrogenase, enzymatic activities, secondary compounds production) will be investigated in the lichen as proxy of the influence of ammonia pollution. In fact, such selected physiological parameters are associated with the vitality of both the lichen photobiont and mycobiont and can be profitably used to detect the effects of excess N under controlled conditions and in the environment, as shown by previous studies (*e.g.*, Munzi *et al.* 2012; Paoli *et al.* 2010, 2014). In this context, also the photosynthetic activity of lichens exposed to ecologically relevant NH^{4+}/NH_3 concentrations has been shown as clearly susceptible to the presence, intensity and duration of the exposure to such pollutants (Paoli *et al.* 2010; Munzi *et al.* 2012). In a second step, the influence of aridity gradients will be explored. As a background, during a previous investigation we assessed whether growth form and substrate in lichens influence their physiological responses along aridity gradients (Paoli *et al.* 2017). Thalli of foliose (*Parmotrema perlatum*) and fruticose (*Ramalina canariensis*) lichens were transplanted in selected rural/forested sites of Southern Portugal characterized by a different aridity index. Physiological parameters, such as photosynthetic performances, content of chlorophylls and ergosterol and vitality of the samples were measured prior to the exposure (in winter) and after 6 months of exposure (in summer). Photosynthetic performances were also investigated in common native foliose and fruticose epiphytic lichens and in fruticose terricolous species. Both transplanted and native lichens reported lower photosynthetic performances in summer and in sites classified as drier, while higher performances corresponded to humid forested sites (Paoli *et al.* 2017). Based on such differences in ecophysiological responses along aridity gradients, we will verify whether also the diversity of lichen-associated microbial communities undergoes differences related to aridity and finally, in a third step, we will combine nitrogen and aridity gradients.

REFERENCES

Aragón G., Martínez I., Izquierdo P. *et al.* (2010). Effects of forest management on epiphytic lichen diversity in Mediterranean forests. Applied Vegetation Science 13: 183-194.

Belnap J., Weber B., Büdel B. (2016). Biological soil crusts as an organizing principle in drylands. In: "Biological soil crusts as an organizing principle in drylands" (Weber B., Büdel B., Belnap J., Eds), Springer, pp. 3-13.

Benesperi R., Nascimbene J., Lazzaro L. *et al.* (2018). Successful conservation of the endangered forest lichen *Lobaria pulmonaria* requires knowledge of fine-scale population structure. Fungal Ecology 33: 65-71.

Christensen J.H., Hewitson B., Busuioc A. *et al.* (2007). Regional climate projections. In: "Climate Change 2007: The physical science basis. Contribution of WG I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change" (Solomon S., Qin D., Manning M., *et al.* Eds). Cambridge University Press, pp. 848-940.

Fačkovcová Z., Guttová A., Benesperi R. *et al.* (2019). Retaining unlogged patches in Mediterranean oak forests may preserve threatened forest macrolichens. *I*Forest 12: 187-192.

Harel Y., Ohad I., Kaplan A. (2004). Activation of photosynthesis and resistance to photoinhibition in cyanobacteria within biological desert crust. Plant Physiology 136: 3070-3079.

Kraus D., Krumm F. (Eds) (2013). Integrative approaches as an opportunity for the conservation of forest biodiversity. European Forest Institute, 284 pp.

Mafole T.C., Chiang C., Solhaug K.A. *et al.* (2017). Melanisation in the old forest lichen *Lobaria pulmonaria* reduces the efficiency of photosynthesis. Fungal Ecology 29: 103-110.

Morillas L., Bellucco V., Lo Cascio M. *et al.* (2016). Contribution of biological crust to soil CO_2 efflux in a Mediterranean shrubland ecosystem. Geoderma 289: 11-19.

Munzi S., Paoli L., Fiorini E. *et al.* (2012). Physiological response of the epiphytic lichen *Evernia prunastri* (L.) Ach. to ecologically relevant nitrogen concentrations. Environmental Pollution 171: 25-29.

Munzi S., Varela Z., Paoli L. (2019). Is the length of the drying period critical for photosynthesis reactivation in lichen and moss components of biological soil crusts? Journal of Arid Environments 166: 86-90.

Nascimbene J., Thor G., Nimis P.L. (2013). Effects of forest management on epiphytic lichens in temperate deciduous forests of Europe - A review. Forest Ecology and Management 298: 27-38.

Nascimbene J., Casazza G., Benesperi R. *et al.* (2016). Climate change fosters the decline of epiphytic *Lobaria* species in Italy. Biological Conservation 201: 377-384.

Otálora M.G., Martínez I., Belinchón R. *et al.* (2011). Remnants fragments preserve genetic diversity of the old forest lichen *Lobaria pulmonaria* in a fragmented Mediterranean mountain forest. Biodiversity and Conservation 20: 1239-1254.

Paoli L., Benesperi R., Fačkovcová Z. *et al.* (2019). Impact of forest management on threatened epiphytic macrolichens: evidence from a Mediterranean mixed oak forest (Italy). *I*Forest 12: 383-388.

Paoli L., Benesperi R., Proietti Pannunzi D. *et al.* (2014). Biological effects of ammonia released from a composting plant assessed with lichens. Environmental Science and Pollution Research 21: 5861-5872.

Paoli L., Pinho P., Branquinho C. *et al.* (2017). The influence of growth form and substrate on lichen ecophysiological responses along an aridity gradient. Environmental Science and Pollution Research 24: 26206-26212.

Paoli L., Pirintsos S.A., Kotzabasis K. *et al.* (2010). Effects of ammonia from livestock farming on lichen photosynthesis. Environmental Pollution 158: 2258-2265.

Sanità di Toppi L. (2018). Interazioni piante-ambiente. Piccin, Padova, pp. 1-335. ISBN: 978-88-299-2870-5.

Scheidegger C., Werth S. (2009). Conservation strategies for lichens: insights from population biology. Fungal Biology Reviews 23: 55-66.

An integrated study for paleoclimate reconstructions in a threatened habitat: the Malagasy littoral humid forest

SERGIO TOFANELLI[1*], STEFANIA BERTONCINI[1], JACOPO D'ERCOLE[1,2],
CRISTIAN CAPELLI[3], GIUSEPPE DONATI[4]
[1] Dipartimento di Biologia, Università di Pisa, Pisa
[2] Centre for Biodiversity Genomics, University of Guelph, Guelph, Ontario, Canada
[3] Department of Zoology, University of Oxford, Oxford, UK
[4] Department of Social Sciences, Oxford Brookes University, Oxford, UK

Keywords: Madagascar, Eulemur collaris, fragmentation

ABSTRACT. – The case study of the collared brown lemurs from the littoral and lowland humid forests of Southeastern Madagascar is presented to stress the potential of integrated approaches involving genetics for paleo-climatic reconstructions. Both, the apportionment of genetic diversity based on autosomal STRs and the molecular clock based on mitochondrial DNA, support a scenario of demographic contractions largely coinciding with the Late-Holocene shifts from woodland forest to grassland sustained by the paleo-ecological evidence.

THE CASE STUDY. – The littoral humid forest (hereafter LIT) of Southeastern Madagascar is a type of lowland humid forest growing on a sandy soil. Today, only small pockets of forest surrounded by grassland remain (Fig. 1) and the area is severely threatened by intensive human exploitation that converted to non-forested habitat almost 90% of its original extension (Bollen & Donati 2006; Consiglio *et al.* 2006; Ingram & Dawson 2006). Recent paleo-ecological analyses from sedimentary sequences suggest that fluctuations in sea level and rainfalls triggered several ecological switches of the LIT from forest to grassland and vice-versa during the late Holocene (Virah-Sawmy *et al.* 2009a). If confirmed, it would make this habitat a highly sensitive detector of climatic changes.

The LIT hosts an exceptional level of biodiversity (Dumetz 1999; Ganzhorn *et al.* 2001; Rabenantoandro *et al.* 2007) with several lemur species playing a fundamental role for the conservation of the ecosystem because of their efficiency as seed disperser (Bollen *et al.* 2005; Donati *et al.* 2007a). The collared brown lemur (*Eulemur collaris*) is the largest lemur species living in the Southeastern littoral forest. These animals

*Corresponding author: sergio.tofanelli@unipi.it

live in multi-male/multi-female groups of 2-20 individuals and have a good ecological tolerance to fragmented habitats (Donati *et al.* 2007b; Ganzhorn *et al.* 2007).

Since 2011 the Laboratory of Molecular Anthropology of the University of Pisa, the University of Oxford Brookes (UK) and the University of Oxford (UK) pursue an integrated study in the Fort-Dauphin district exploring the correlates between ecological, ethological and genetic aspects of collared brown lemur groups for conservation purposes. What we soon realized by estimating the apportionment of genetic variance between forests and fragments were the potential repercussions of our results on the reconstructions of historical climatic changes in the area (Bertoncini *et al.* 2017).

We investigated genetic diversity at eight autosomal short tandem repeats (STRs) and the mitochondrial D-loop region in DNA extracted from fecal samples in three populations living in LIT fragments (Mandena – MND, Ste Luce - S9, Ste Luce - S17) and two populations from the nearby lowland humid forest (hereafter LOW) of the Tsitongambarika Protected Area (TGK1, TGK3) (Fig. 1).

A highly structured pattern and very low diversity within sub-populations were observed. As expected, diversity drop appeared more significant in LIT fragments than in the continuous block of the LOW. A long-term limitation to gene flow among LIT patches was inferred, other than by the high genetic distance among sub-populations (mean Fst: 0.236±0.068), by the high rate of private alleles and its apportionment within single groups (35.9%), from which a uniform low number of migrants per generation under a migration-drift model was inferred (0.229 ± 0.098 SD, range 0.13-0.50). The boundary formed by combining the three main barriers to gene flow crossed the savannah-like ecotone that separates littoral from lowland forests (Fig. 2).

Despite the current heterogeneous distribution of diversity, other genetic estimators suggested a common demographic history for lowland and littoral humid forests. In fact, the parameter theta, which is a mutation-scaled measure of effective population size, inversely proportional to the amount of drift experienced by the population, showed low and very similar values across LIT and LOW groups. This makes it plausible to speculate either a single ancestral population with few breeding animals or synchronous size contractions in multiple groups, both followed by independent evolution. Both the above scenarios were also supported by the M-ratio approach (Garza & Williamson 2001) which tests size declines by calculating the discrepancy between the number of alleles and the range in allele size. For all the LIT and LOW groups absolute values were always below 0.68, commonly considered as critical in bottlenecked vertebrate species.

In order to date tentatively the origin of present day genetic differentiation, which is a proxy of fragmentation origin, we estimated the Time since the Most Recent Common Ancestor (TMRCA) of mitochondrial lineages by the Walsh's formula (Walsh 2001). As expected, mitochondrial variability was remarkably low: all groups were monomorphic with the exception of TGK3, where half of the sampled animals showed a second haplotype differing from the former by seven mutations. This difference provided a minimal divergence time between mitochondrial lineages of 704 yBP and a median of 1352 yBP. Such estimate supports the analysis of paleo-soils that indicated peaks of aridity in the interval from 950 to 600 yBP in the area, coinciding with large-scale faunal extinctions (between 1400 and 500 cal. yBP) and drought/marine surges (between 1200 and 700 cal. yBP) over the whole island (Virah-Sawmy *et al.* 2009a,b, 2010).

To differentiate between natural and anthropogenic drivers of change remains a problematic task since archaeological evidence indicates the presence of human settlements in the Southeast since around 1150 yBP (Rakotoarisoa 1997; Burney *et al.* 2004). However, the collared brown lemur case is consistent with genetic studies on non-Lemur genera (Microcebus, Yoder *et al.* 2016; Propithecus, Quéméré *et al.* 2010) supporting an island-wide scenario with some areas of grassland that have existed for a few millennia and other areas rapidly shifting between grassland, dry forest, and humid forest due to severe climatic desiccations (Virah-Sawmy *et al.* 2009a,b, 2010).

CONCLUDING REMARKS. – Our study demonstrated that pieces of paleo-climatic evidence are intrinsic to the genetic variability of living species and may be figured out by multidisciplinary approaches. The apportionment of genetic diversity in a large lemur species suggests that the grassland laying between littoral fragments and between them and the inland continuous humid forest in southeastern Madagascar has been for long an obstacle to migration. Thus, the quote of diversity accumulated within and between sub-populations may also reflect the effect of habitat shifts in the region. A scenario of a common demographic contraction for LIT and LOW groups recalls an original condition of mixed woodland forest and a rapid transition to an open habitat dominated by ericoid grassland and Myrica bushland (Virah-Sawmy *et al.* 2009b; 2010) by 700-1500 yBP, when the LIT fragments came to play as refugia for the local fauna and flora.

REFERENCES

Bertoncini S., D'Ercole J., Brisighelli F. *et al.* (2017). Stuck in Fragments: Population Genetics of the Endangered Collared Brown Lemur *Eulemur Collaris* in the Malagasy Littoral Forest. American Journal of Physical Anthropology 163: 542-552.

Bollen A., Donati G. (2006). Conservation status of the littoral forest of South-eastern Madagascar: a review. Oryx 40: 57-66.

Bollen A., Donati G., Fietz J. *et al.* (2005). Fruit Characteristics in a Dry Deciduous and a Humid Littoral Forest of Madagascar: Evidence for Selection Pressure through Abiotic Constraints rather than Seed Dispersers. In: "Tropical Fruits and Frugivores. The Search for Strong Interactors" (Dew L., Boubli J.P. Eds). Springer, Netherlands, pp. 92-118.

Burney D.A., Burney L.P., Godfrey L.R. *et al.* (2004). A chronology for late prehistoric Madagascar. Journal of Human Evolution 47: 25-63.

Consiglio T., Schatz G.E., McPherson G. *et al.* (2006). Deforestation and plant diversity of Madagascar's littoral forests. Conservation Biology 20: 1799-1803.

Dewar R.E. (2014). Early human settlers and their impact on Madagascar's landscapes. In: "Conservation and Environmental Management in Madagascar" (Scales I.R. Ed.). Abingdon, Oxford, Routledge, pp. 44-64.

Donati G., Bollen A., Borgognini Tarli S.M. *et al.* (2007a). Feeding over the 24-h cycle: dietary flexibility of cathemeral collared lemurs (*Eulemur collaris*). Behavioral Ecology and Sociobiology 61: 1237-1251.

Donati G., Ramanamanjato J.B., Ravoahangy A.M. *et al.* (2007b). Translocation as a conservation measure for a threatened species: the case of *Eulemur collaris* in the Mandena littoral forest, Southeastern Madagascar. In: "Biodiversity, Ecology and Conservation of the Littoral Ecosystems of Southeastern Madagascar" (Ganzhorn J.U., Goodman S.M., Vincelette M. Eds). Washington, Smithsonian Institution Press, pp. 237-246.

Dumetz N. (1999). High plant diversity of lowland rainforest vestiges in Eastern Madagascar. Biological Conservation 8: 273-315.

Ganzhorn J.U., Lowry P.P. II, Schatz G. *et al.* (2001). The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. Oryx 35: 346-348.

Ganzhorn J.U., Andrianasolo T., Andrianjazalahatra T. *et al.* (2007). Lemurs in evergreen littoral forest fragments of different size and degrees of degradation. In: "Biodiversity, Ecology and Conservation of the Littoral Ecosystems of South-eastern Madagascar" (Ganzhorn J.U., Goodman S.M., Vincelette M. Eds). Washington, Smithsonian Institution Press, pp. 223-236.

Garza J.C., Williamson E.G. (2001). Detection of reduction in population size using data from microsatellite loci. Molecular Ecology 10: 305-318

Ingram J.C., Dawson T.P. (2006). Forest cover, condition, and ecology in human-impacted forests, South-eastern Madagascar. Conservation and Society 4: 194-230.

Quéméré E., Amelot X., Pierson J., Crouau-Roy B., Chikhi L. (2012). Genetic data suggest a natural prehuman origin of open habitats in Northern Madagascar and question the deforestation narrative in this region. Proceedings of the National Academy of Science 109: 13028-13033.

Rabenantoandro J., Randriatafika F., Lowry P.P. II (2007). Floristic and structural characteristics of remnant littoral forest sites in the Tolagnaro area. In: "Biodiversity, Ecology and Conservation of the Littoral Ecosystems of South-eastern Madagascar" (Ganzhorn J.U., Goodman S.M., Vincelette M. Eds). Washington, Smithsonian Institution Press, pp. 65-77.

Rakotoarisoa J. (1997). A cultural history of Madagascar. Evolution and interpretation of the archeological record. In: "Natural Change and Human Impact in Madagascar" (Goodman S.K., Patterson B.D. Eds). Washington DC, Smithsonian Institution Press, pp. 331-341.

Virah-Sawmy M., Gillson L., Willis K.J. (2009a.) How does spatial heterogeneity influence resilience to climatic changes? Ecological dynamics in Southeast Madagascar. Ecological Monographs 79: 557-574.

Virah-Sawmy M., Katherine J., Gillson W. *et al.* (2009b). Threshold response of Madagascar's littoral forest to sea-level rise. Global Ecology and Biogeography 18: 98-110.

Virah-Sawmy M., Willis K.J., Gillson L. (2010). Evidence for drought and forest declines during the recent megafaunal extinctions in Madagascar. Journal of Biogeography 37: 506-519.

Walsh B. (2001). Estimating the time to the most recent common ancestor for the Y chromosome or mitochondrial DNA for a pair of individuals. Genetics 158: 897-912.

Yoder A.D., Campbell C.R., Blanco M.B. *et al.* (2016). Geogenetic patterns in mouse lemurs (genus *Microcebus*) reveal the ghosts of Madagascar's forests past. Proceedings of the National Academy of Sciences 113: 8049-56.

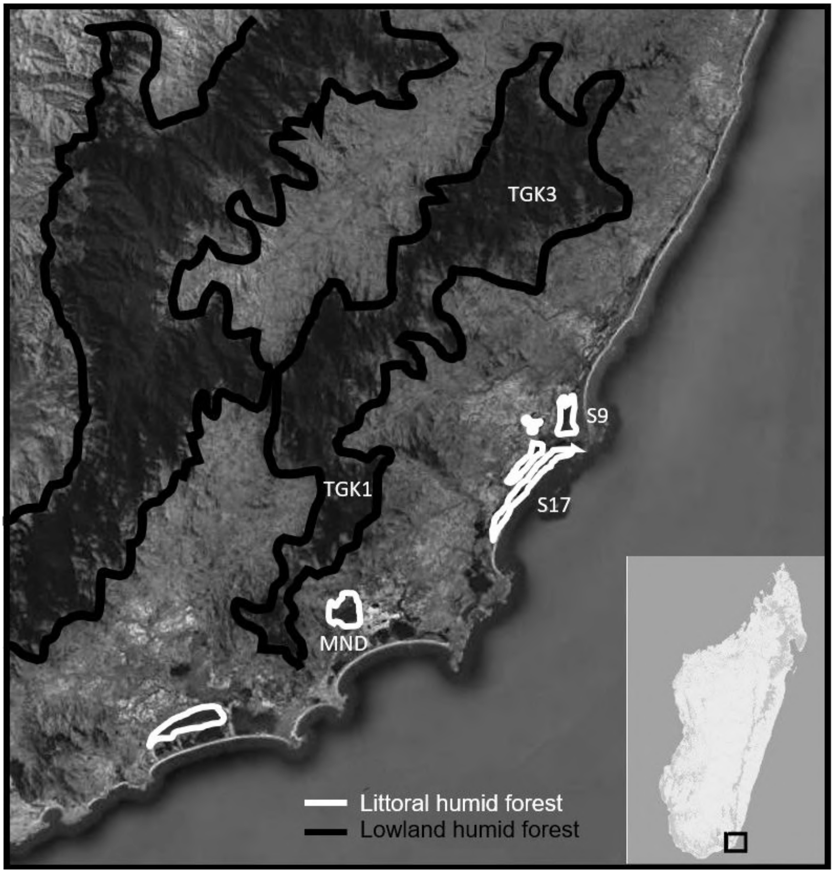


Fig. 1. Map of the study sites. MND indicates Mandena, S indicates Saint Luce, TGK indicates Tsitongambarika.

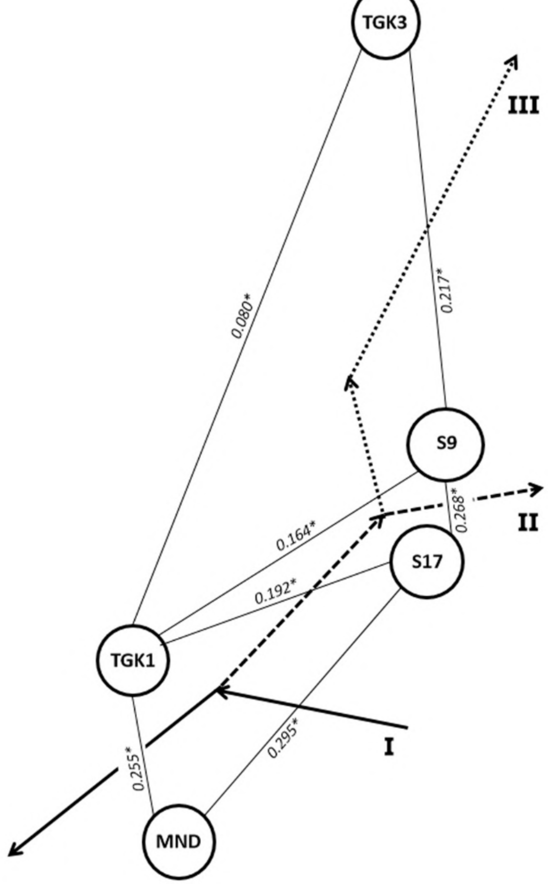


FIG. 2. An analysis of genetic barriers using Monmonier's maximum difference algorithm employing Delaunay's triangulation. Edges are associated with Fst pairwise distance measures. I, II, III: respectively first, second and third rank genetic barriers.

SESSION 5
GEOLOGICAL ISSUES

Italian glaciers, sensitive sentinels of climate change

CARLO BARONI[1,2*], MARIA CRISTINA SALVATORE[1,2], LINDA ALDERIGHI[3], SIMONA GENNARO[3]
[1] Dipartimento di Scienze della Terra, Università di Pisa
[2] Consiglio Nazionale delle Ricerche - Istituto di Geoscienze e Georisorse (CNR–IGG), Pisa
[3] Dottorato Regionale in Scienze della Terra, Università di Pisa

Keywords: glacier retreat, monitoring, Little Ice Age, Holocene, Italian Alps

ABSTRACT. – Glaciers are relevant proxies for reconstructing climate change in the past because they react to climatic parameters variation by modifying their mass balance that, in turn, drives changes of Equilibrium Line Altitude, frontal fluctuations, and variation in shape and size. Therefore, glaciers are very sensitive sentinels of climate changes. These relevant natural archives of the climate history are also strategic as “water tower” retaining a precious resource of fresh water available for agricultural, civil, and industrial purposes. As documented in other mountain chains of the world, Alpine glacier experienced several fluctuations since the Last Glacial Maximum, thus recording key events of climate history relevant both at regional and global scale. Glaciological parameters reconstructed for past and present Italian glaciers furnish powerful tools for investigating and modelling environmental and climate changes occurred in the past and acting at present, being also suitable for predicting future scenarios.

INTRODUCTION. – It is well known that glaciers retain a precious resource of fresh water available for agricultural, civil and industrial employments. It is also widely recognized that glaciers are environmental indicators very sensitive to climatic variations. In fact, glacier length, areal and volumetric variations induced by external stresses reflect changes in the energy balance and are overall relevant indicators of climate change. The relationships between climate and glacier behaviour are quite complex but the final response of glaciers to climatic variations translates into changes in the mass balance (ratio between accumulations and losses) and fluctuation of Equilibrium Line Altitude (ELA). In particular, Alpine glaciers are very sensitive to temperature variations (especially to high temperature during summer season) as the ice temperature is almost exclusively close to the melting point (temperate

[*]Corresponding author: carlo.baroni@unipi.it

glaciers). Moreover, an important role is played by the amount of snowfall (especially during the winter season) and by the components of the glacier's energy balance, which control the energy available for melting snow and ice. The small Alpine glaciers respond quickly to temperature variations, while the "response time" of the valley glaciers varies from a few years to a few decades (complex valley glaciers). Glaciers' frontal variation and mass balance monitoring are conducted in the Alpine region since more then a century supplying quantitative data for defining recent glaciers variations (WGMS 1989, 2015, 2018). Monitoring of Italian glaciers (Fig. 1) has been performed by the Italian Glaciological Committee (CGI) since 1895 (CGI 1928-1977, 1978-2018; Baroni *et al.* 2017, 2018). Multitemporal analysis of glaciers' outlines detected by new generation of high resolution orthophotos allows to depict in detail the state of the Italian glaciers since the '50s of the last century (Salvatore *et al.* 2015) up to the date of the most recent orthophotos. The management of glaciers' outline in GIS environment allows to extract quickly valuable quantitative data on recent areal changes of glacial bodies as well as variation of the glaciological parameters (area, maximum length, width, slope, max and min elevation, aspect, latitude and longitude of the glacier centroid) and to reconstruct mass loss. Reconstruction of past maximum and minimum relative glacier extension reached since the Last Glacial Maximum (*i.e.*, Late Glacial stages, early and mid Holocene, Little Ice Age - LIA) further contribute to detect the mechanisms that drive climate change on a regional and global scale, being glaciers sensitive proxies of past climatic conditions.

RECENT VARIATIONS OF ITALIAN GLACIERS. – The Italian glaciers reached their maximum Holocene extension between the early 17th and mid-19th centuries during the Little Ice Age (LIA), well known as the most recent cold climatic phase recorded at global scale between the early 14th and mid-19th centuries. After the end of the LIA, Italian glaciers experienced a phase of general withdrawal, accentuated in the 1950s, which was followed by a brief phase of advance culminating between the end of the 70s and early 80s. Since the 1990s a generalized withdrawal affected almost all Italian glaciers as also recorded by many other glaciers in the entire Alpine chain (Haeberli *et al.* 2007; Zemp *et al.* 2015). From the mid 19th century, Italian glaciers shrank more than 40%, while the ELA lifted over 100 m in average. Many small glaciers disappeared, while many others split into smaller individuals, retreating their fronts even more than 2 km. Today, almost 100% of Italian monitored glaciers are in retreat and most frontal margins thinned and widely debris covered. This situation is in agreement with WGMS data, which underline that centennial glacial retreat is a global phenomenon documenting "an historically unprecedented global glacier decline" (Zemp *et al.* 2015). Considering the most recent data (2014-2015 hydrological years), the Italian Alps host more then 850 glacial bodies covering a surface of ca. 344 km^2 (also including two glacierets on the Gran Sasso d'Italia in the Central Apennines). Southern Rhaetian Alps host the most glaciated mountain group of the Italian Alpine chain. Ortles Cevedale and Adamello groups, which hold more then 120 and 70 glaciers, respectively including the Forni Glacier (10.7 km^2; Figs. 2, 3) and the Adamello ice plateau (15.7 km^2), which are the two widest glaciers of the Italian Alps. The Pennine and the Graie Alps are followed by Mount Rosa and Mount Bianco in terms of glacial coverage. Glacier size spans from <0.1 km^2 to 15.7 km^2 (Adamello Glacier). Smaller size classes retain most of the Italian glaciers, representing *ca.* 55% of the total number but covering less than 6% of the total area. The southernmost glacier in the Italian Peninsula, the Calderone Glacier in the Gran Sasso d'Italia, recently generated two small debris-covered glacierets extending about 0.04 km^2. In the last decade, numerous Alpine glaciers repeatedly experienced imbalance condition being often entirely below the snowline. Analysis of mass balance time series underlines a negative trend induced not only by increased ablation but also by lengthening of the ablation season and by contraction of snow precipitation due to warmer temperature. Recent data suggest that the smaller and thinner Italian glaciers are reacting faster than other Alpine glaciers to climatic changes (Carturan *et al.* 2016). Finally, hemispheric circulation pattern (*e.g.*, NAO index) have opposite effects in the Northern and Southern sectors of the Alps, and this relationship is worthy to be better investigated (Carturan *et al.* 2016). Only the inertia of the glacial masses allow them to overcome the most critical phases: the strong imbalance that characterize the glaciers with respect to the current climatic conditions suggests that, if this situation will persist, we must wait for further, dramatic areal and volumetric reductions of Alpine glaciers (Zemp *et al.* 2006) as quantitatively recorded by the Careser Glacier that is very close to its extinction (Carturan *et al.* 2013).

CONCLUSION. – What are the consequences on the use of water resources stored in glaciers? What scenarios should we expect in the coming decades? There is no certain and unambiguous answer to these questions; it would therefore be desirable for a greater scientific awareness of the Alpine glacial world, which can only derive from a deep knowledge of glaciers, their dynamics, the archives of environmental information that are kept in them and their ancient and recent history. Climate warming is particularly significant in the Alps since the Little Ice Age, but has dramatically accelerated in the last two decades (IPCC 2013, 2018; Zemp *et al.* 2015). The glacier retreat scenario gives opportunity for better understanding glaciers dynamics and their behaviour in responding to ongoing climate changes. The enduring glacier retreat makes available new deglaciated-areas, which are affected by active geomorphic agents clearly increasing instability processes and enhancing the exposure to natural hazards (Zanoner *et al.* 2017). On the other hand, increasing ice-free areas produced by deglaciation enlarge habitat opportunities for Alpine and nival species at high elevation, supplying new unpredicted landscape opportunities to biodiversity, worthy to be further investigated (Gentili *et al.* 2015a,b). Finally, Alpine glaciers should be considered as the "water tower" of Europe, feeding many important rivers and furnishing water for both agricultural and industrial purposes. Researches on glaciers variations and their future expected behaviour are needed for better defining the effect of climate change on the natural environment, for modelling future availability of melt-water, and for better planning the correct management of water as natural resource (not only in the Alpine region but also in a wider European sector extending to the Black Sea).

ACKNOWLEDGEMENTS. – This research was funded by the MIUR Project (PRIN 2010-11): "Response of morphoclimatic system dynamics to global changes and related geomorphological hazards" – and by the project of strategic interest NEXTDATA.

REFERENCES

Baroni C., Bondesan A., Chiarle M. (Eds) (2017). Report of the Glaciological Survey 2016. Geografia Fisica e Dinamica Quaternaria 40: 233-320.

Baroni C., Bondesan A., Carturan L., Chiarle M. (Eds) (2018). Report of the Glaciological Survey 2017. Relazioni della Campagna Glaciologica 2017. Geografia Fisica e Dinamica Quaternaria 41: 115-193.

Carturan L., Baroni C., Becker M. *et al.* (2013). Decay of a long-term monitored glacier: the Careser Glacier (Ortles-Cevedale, European Alps). The Cryosphere 7: 1819-1838.

Carturan L., Baroni C., Brunetti M. *et al.* (2016). Analysis of the mass balance time series of glaciers in the Italian Alps. The Cryosphere 10: 695-712.

CGI - Comitato Glaciologico Italiano (1928-1977). Relazioni delle campagne glaciologiche. Boll. CGI, Series I and II: 1-25.

CGI - Comitato Glaciologico Italiano (1978-2016). Relazioni delle campagne glaciologiche. Geografia Fisica e Dinamica Quaternaria 1-39.

Gentili R., Bacchetta G., Fenu G. *et al.* (2015a). From cold to warm-stage refugia for boreo-Alpine plants in Southern European and Mediterranean mountains: the last chance to survive or an opportunity for speciation? Biodiversity 16: 247-261.

Gentili R., Baroni C., Caccianiga M. (2015b). Potential warm-stage microrefugia for Alpine plants: Feedback between geomorphological and biological processes. Ecological Complexity 21: 87-99.

Haeberli W., Hoelzle M., Paul F. *et al.* (2007). Integrated monitoring of mountain glaciers as key indicators of global climate change: The European Alps. Annals of Glaciology 46: 150-160.

IPCC (2013). Summary for policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of WG I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (T.F. Stocker, D. Qin, G.-K. Plattner *et al.* Eds). Cambridge University Press, Cambridge.

IPCC (2018). Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, (V. Masson-Delmotte, P. Zhai, H.O. Pörtner *et al*. Eds). WMO, Geneva.

Salvatore M.C., Zanoner T., Baroni C. *et al.* (2015). The state of Italian glaciers: A snapshot of the 2006-2007 hydrological period. Geografia Fisica e Dinamica Quaternaria 38: 175-198.

WGMS (1989). World Glacier Inventory. Status 1988. In: World Glacier Monitoring Service (Haeberli W., Bosch H., Scherler K., *et al.* Eds). IAHS-UNEP-UNESCO, Zurich, 288 pp.

WGMS (2015). Global Glacier Change Bulletin No. 1 (2012-2013). In: World Glacier Monitoring Service (Zemp M, Gärtner-Roer I, Nussbaumer SU, *et al.* Eds). ICSU(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, Zurich, pp. 230.

WGMS (2018). Fluctuations of Glaciers Database. World Glacier Monitoring Service, Zurich. Online access: *http://dx.doi.org/10.5904/wgms-fog-2018-11*.

Zanoner T., Carton A., Seppi R. *et al.* (2017). Little Ice Age mapping as a tool for identifying hazard in the paraglacial environment: The case study of Trentino (Eastern Italian Alps). Geomorphology 295: 551-562.

Zemp M., Haeberli W., Hoelzle M. *et al.* (2006). Alpine glaciers to disappear within decades? Geophysical Research Letters 33: L13504.

Zemp M., Zumbühl H.J., Nussbaumer S.U. *et al.* (2011). Extending glacier monitoring into the Little Ice Age and beyond. PAGES News 19: 67-69.

Zemp M., Frey H., Gärtner-Roer I. *et al.* (2015). Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology 61(228): 745-762.

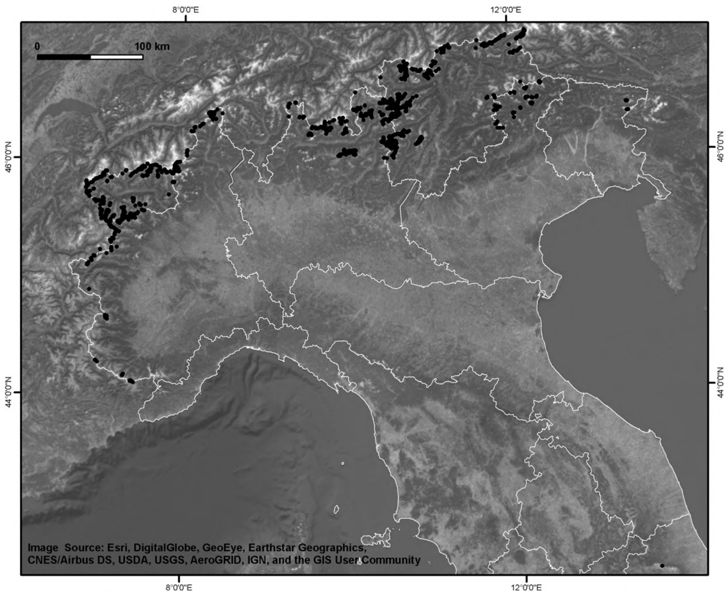


FIG. 1. Distribution of the Italian glaciers (black dots) in 1957-1958 (after CGI - Italian Glaciological Committee; *http://www.glaciologia.it/en/i-ghiacciai-italiani/*).

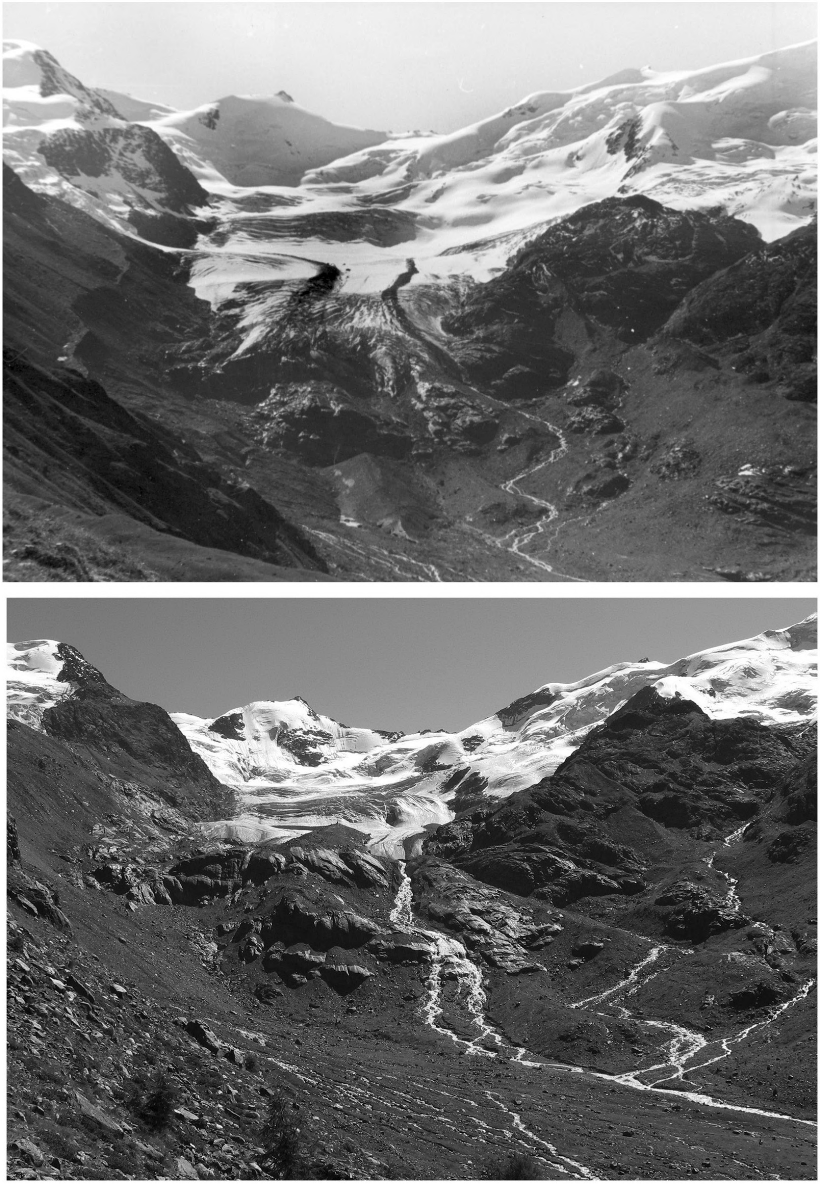


Fig. 2. Forni Glacier (Ortles Cevedale Group) in September 1966 (above, photo by A. Giorcelli, CGI) and in September 2006 (below, photo by G. Casartelli, CGI). Note the vigorous frontal retreat and the contraction of glacier boundary also in the accumulation basin.

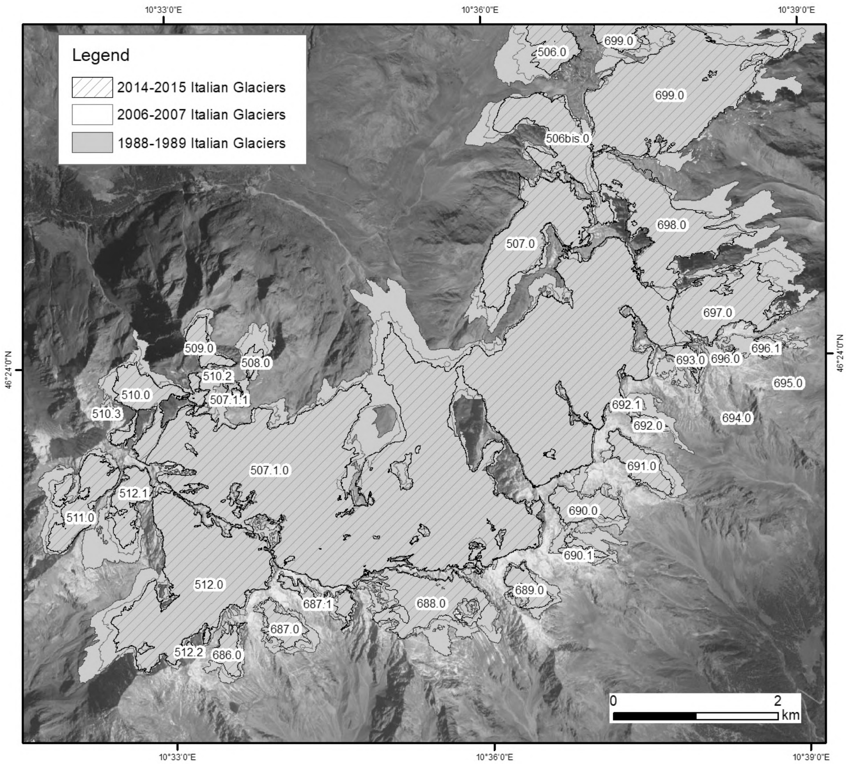


FIG. 3. Forni Glacier (n. 507.1.0) and other glaciers of the Ortles Cevedale Group in different time steps (after Nextdata Project).

Dendrochronological studies to reconstruct last millennium climatic variations in the Central Italian Alps

RICCARDO CERRATO[1,*], MARIA CRISTINA SALVATORE[1,2], CARLO BARONI[1,2]
[1] Dipartimento di Scienze della Terra, Università di Pisa
[2] Consiglio Nazionale delle Ricerche - Istituto di Geoscienze e Georisorse (CNR-IGG), Pisa

Keywords: mean summer temperature, dendroclimatic reconstruction, Larix decidua, Pinus cembra

ABSTRACT. – The ongoing increase in the global mean temperature at an unprecedented recorded rate is well documented. High-elevation landscapes are among the most strongly affected environment by ongoing climate change. In fact, in the European Alps, as well as in other mountain chains, the cryosphere is experimenting a widespread withdrawal of glaciers and the biosphere suffers fast changes in biomes. Albeit the anthropic origin of the actual climate changes is undeniable, the knowledge of past climate variations is fundamental to better understand the amplitude of this phenomena. Nevertheless, high-elevation areas often lack climatic instrumental series longer than one hundred years, and global datasets cannot represent local variations accurately. Thus, proxy data, such as tree-ring chronologies, can be powerful tools and source of information to better understand the past environmental dynamics and climatic variations that have occurred in remote and sensitive sites. Since 2000s the University of Pisa laboratory for dendrochronology conducts analysis on samples coming from high-elevation landscape in the Italian Alps. This approach, by means of dendroclimatic reconstruction based on wood physical parameters, allows to define and better understand the temperature history of remote areas in climatic and glaciological key sectors of the Alps.

INTRODUCTION. – Recently some politics are arguing on the existence of the climate change and if the anthropic activity had or has a key role on it. Nevertheless, from a scientific point of view the increasing temperature over the last decades is not an open issue, instead, is a well-established process being the “scientific evidence for warming of the climate system unequivocal” (IPCC 2013). Many studies were per-

*Corresponding author: riccardo.cerrato@dst.unipi.it

formed to better understand the current climate variability and the role that humans have on the accelerated rise in temperature (IPCC 2013, IPCC 2018). Due to the changing climate, among the most affected features by the increase of the temperatures in the Northern Hemisphere there are Greenland Ice Sheet an other glaciers, the Arctic Sea-Ice, and the widely documented Alpine glaciers shrinkage (Haeberli *et al.* 2007; Paul *et al.* 2011; Salvatore *et al.* 2015). As a consequence of the Alpine glaciers retreat, recently deglaciated areas are affected by mass wasting induced by different geomorphologic processes in a newly formed paraglacial environment (Ballantine 2002; Baroni *et al.* 2007, 2014; Zanoner *et al.* 2017). In this situation, contextualize the ongoing climate change in a long-term scenario is fundamental to better understand the recent warming. In fact, climatic information deriving from instrumental measurements are relative only to the 20th century (Harris *et al.* 2014) or to the last two centuries in the best cases (Auer *et al.* 2007). Even in this last case, gridded data are reliable for the low altitude, but they lack in accuracy increasing the topographic factor. Thus, climate information deriving from high altitude sites that extend our climate knowledge beyond the industrial era, are needed. By means of dendrochronology, datasets of inferred climatic factors at annual scale and with a monthly or seasonal precision can be obtained (Fritts 1976; Schweingruber 1988). Moreover, dendrochronology can be used to infer climatic parameters at many scales, from the hemispheric to the regional and the local.

DENDROCLIMATIC SERIES OF THE RHAETIAN ALPS. – The interest of the Pisa University laboratory for dendrochronology for the dendroclimatology and the possibility to reconstruct climatic parameters at annual or seasonal scales start at the beginning of the 2000s. Dendroclimatological studies were designed to reconstruct temperature pattern at high elevation stands to understand how the climate change affects one of the main glacial body of the Alps, the Adamello Glacier. In fact, since 1990s this glacier has been target of many dendrochronological studies aimed to reconstruct and understand its evolution (Baroni & Carton 1990a,b). Since then, many field activities were performed to collect samples from trees that live at the upper tree line, the environmental area where trees are more stressed by the temperature. These sampling activities permitted to create a dendrochronological dataset of the Adamello-Presanella and Ortles-Cevedale Group that nowadays count of 650 individual series circa (Fig. 1).

At the early stages, the Pisa University laboratory for dendrochronology activities were focused on the European larch (*Larix decidua* Mill.) being this species widely used in dendroclimatology, especially in the Alps. These studies permitted to create several chronologies relative to different valleys of the Adamello-Presanella Group, demonstrating that temperature, rather than precipitation, and in particular June temperature, is the main climatic factor that control the European larch radial growth at the upper treeline (Coppola *et al.* 2012). The study also shows how the relationship between the tree-ring growth and the temperature is influenced by the mean site elevation, revealing, at a smaller scale, a temporal instability in climate/growth relationship with a significant unstable responses and substantial variability over time since 1960s. In fact, whereas the correlation with June temperature show a decreasing trend, a synchronous increasing trend was observed in the correlation values between larch chronologies and the August temperatures, allowing to hypothesize a prolongation of the growing season that could have influenced positively the tree growth (Coppola *et al.* 2012). The knowledge of the European larch response to climate in the Adamello-Presanella Group, permitted to create one of the few dendroclimatic temperature reconstruction of the Alps and the first for this key area from a climatic and glaciological point of view. Using the HISTALP gridded dataset as calibration data, a reconstruction of the June-August (JJA) mean temperature of the Adamello-Presanella Group spanning from 1610 to 2008 CE was proposed (Coppola *et al.* 2013). The study reported relatively cool temperature in the pre-instrumental period (1610-1780), with few fluctuations. Relatively low temperature are visible until 1650 whereas an increase in summer temperature occurred until 1680. A temperature recrudescence is observable until about 1700 when a regular increase starts. Since the half of the 18th century progressive cooling occurs and continues until 1821. The 1813-1821 period is characterized by the lowest temperatures of the reconstruction and it is coherent with the previous knowledge dating to those years one of the lasts and coldest phases of the Little Ice Age (LIA) also characterized by the maximum Holocene extension of the Alpine glaciers (Fig. 2).

Among other alpine studied area, Bosco Antico represents the most ancient living wood in the Val di Sole area and is among the oldest living stands in the Italian Alps (Cerrato *et al.* 2018). The chronology covers 596 years, from 1420 to 2015 CE, and the longest reliable portion for dendroclimatic reconstruction spans from 1520 to 2015 CE, for a total of 496 years. The mean summer temperature acts as the main limiting factor for tree growth in this stand and the chronology was used to reconstruct the June-July mean temperature (Fig. 3). The reconstructed series shows the most negative minimum in 1816, during the 1800s cold phases of the LIA. Another relevant minimum occurred in approximately 1699 and presumably represents the period when the temperature in this area drops at the highest rate, probably driven by the sun stasis known as the Maunder minimum. In fact, this minimum concludes a century characterized by cool and cold temperature during which the maximum Holocene glacial extent of the nearer La Mare Glacier occurred (Carturan *et al.* 2014). Analyzing the reconstructed temperature, a strong but non-homogeneous increasing trend is detected since 1816, interrupted by two major phases of negative anomalies: i) around 1900 and ii) during the 1970s. The former phase can be attributed to the Damon minimum, another sun activity stasis whereas the second phase perfectly matches with the last re-advancement of the glacier fronts registered and described in the area (Salvatore *et al.* 2015). Before 1699, the reconstructed trend shows anomalies oscillating around zero, underlying cooler periods during the 1580s and in the first half of the 17th century. The reconstruction based on Bosco Antico chronology is consistent with the others already proposed for the area (Coppola *et al.* 2013) but it slightly underestimates the negative anomalies that occurred before the 18th century in comparison to the alpine temperature reconstructions. An explanation for this positive bias, was found in the indirect anthropic impact. In fact, as a consequence of the intense harvesting that happened during the 15th century, only the youngest trees survived. This scenario may have caused a decrease in intraspecific competition, resulting in synchronous tree growth release. The successive land uses (pasture and grazing) could have contributed to the maintenance of the area as a competition-free site.

The Bosco Antico based reconstruction of the JJ temperature, highlighted two other significant minima: 1753 and 1888 that appear to be synchronous with larch budmoth (LBM; *Zeiraphera diniana* Gn.) outbreaks that cyclically affected the larches. A study performed on the occurrence of outbreaks of this lepidoptera in the Adamello-Presanella and Ortles-Cevedale Massifs (Cerrato *et al.* 2019a) shows that a clear cyclicity is lacking also due to the elevation of the stand, located beyond the optimum elevation belt for LBM sited between 1700 and 2000 m a.s.l. Nevertheless, the analysis highlight a shift from a cycle characterized by a return period around 20-years in the early 19th century, to a cycle with a return period of 9-years circa at the end of the 20th century. The appearance of a return period ascribable to an LBM regular cycle since 1950s can be related to the climatic changes affecting the area. In fact, during period characterized by low temperature the insect probably had is optimum belt at lower elevations, and thus only massive LBM outbreaks could have influenced the high-elevation stands. Due to the climate warming, the optimum belt of the LBM shifted upward explaining why in the last fifty years of the 20th century a regular cycle of this insect appear at high-elevation stands at least until 1990s (Cerrato *et al.* 2019a). Since this date, in fact, the continuous rising temperature contribute to destroy the LBM regular cycle in the Alps. Recently, the interest of the Pisa University laboratory for dendrochronology spread on new techniques and promising species. Specifically, the correlation analyses show the high sensitivity of the maximum latewood density (MXD) of the Swiss stone pine (*Pinus cembra* L.) to the temperature. We demonstrated that the mean temperature of July, August and September influences positively the MXD. Considering the seasonal aggregated temperature the correlation became more stable and stronger. Contextually, an increase of the positive influence of the May and September mean temperature on the MXD in the 20th century is obvious and also in this case led to thinking about an elongation of the growing season induced by higher temperature due to the climate change (Cerrato *et al.* 2019b).

CONCLUSION. – Dendrochronology represents a powerful proxy for reconstructing past temperature in absence of instrumental record and allows to improve the knowledge on the climatic and glaciological variations that occurred in the Alps in the last millennium. Beside two dendroclimatic temperature reconstructions spanning from 1520 to 2015 CE that help to understand the climatic variability at high-elevation sites in the last six hundred years at the annual scale, the studies improve our knowledge of the insect population cycles, useful for interpreting and correcting dendroclimatic reconstructions and for understanding how the insect population dynamic is influenced by the climate change. Moreover, recent studies on highly neglected species offer new evidences on the capability of Swiss stone pine to be used as a proxy for climatic reconstructions in the Alps. This last outcome is particularly relevant for further applications in dendroglaciological studies aimed to estimate the past mass balance of glaciers in the Italian Central Alps.

ACKNOWLEDGEMENTS. – The studies were funded by the Italian MIUR Project (PRIN 2010-11): “Response of morphoclimatic system dynamics to global changes and related geomorphological hazards” and by the project of strategic interest NEXTDATA (PNR National Research Programme 2011-2013).

REFERENCES

Auer I., Böhm R., Jurkovic A. *et al.* (2007). HISTALP - historical instrumental climatological surface time series of the Greater Alpine Region. International Journal of Climatology 27: 17-46.

Baroni C., Carton A. (1990a). Variazioni glaciali oloceniche nel Gruppo del Monte Adamello (Alpi Centrali). Memorie Società Geologica Italiana 45: 877-882.

Baroni C., Carton A. (1990b). Variazioni oloceniche della Vedretta della Lobbia (Gruppo dell'Adamello, Alpi Centrali). Geografia Fisica e Dinamica Quaternaria 13: 105-119.

Baroni C., Armiraglio S., Gentili R. *et al.* (2007). Landform-vegetation units for investigating the dynamics and geomorphologic evolution of alpine composite debris cones (Valle dell'Avio, Adamello Group, Italy). Geomorphology 84: 59-79.

Baroni C., Martino S., Salvatore M.C. *et al.* (2014). Thermomechanical stress-strain numerical modelling of deglaciation since the Last Glacial Maximum in the Adamello Group (Rhaetian Alps, Italy). Geomorphology 226: 278-299.

Carturan L., Baroni C., Carton A. *et al.* (2014). Reconstructing fluctuations of La Mare glacier (Eastern Italian Alps) in the late Holocene: new evidence for a Little Ice Age maximum around 1600 AD. Geografiska Annaler: Series A, Physical Geography 96: 287-306.

Cerrato R., Salvatore M.C., Brunetti M. *et al.* (2018). Dendroclimatic relevance of "Bosco Antico", the most ancient living European larch wood in the Southern Rhaetian Alps (Italy). Geografia Fisica e Dinamica Quaternaria 41: 35-49.

Cerrato R., Cherubini P., Büntgen U. *et al.* (2019a). Tree-ring-based reconstruction of larch budmoth outbreaks in the Central Italian Alps since 1774 CE. IForest - Biogeosciences and Forestry 12: 289-296.

Cerrato R., Salvatore M.C., Gunnarson B.E. *et al.* (2019b). A *Pinus cembra* L. tree-ring record for late spring to late summer temperature in the Rhaetian Alps, Italy. Dendrochronologia 53: 22-31.

Coppola A., Leonelli G., Salvatore M.C. *et al.* (2012). Weakening climatic signal since mid-20th century in European larch tree-ring chronologies at different altitudes from the Adamello-Presanella Massif (Italian Alps). Quaternary Research 77: 344-354.

Coppola A., Leonelli G., Salvatore M.C. *et al.* (2013). Tree-ring-based summer mean temperature variations in the Adamello-Presanella Group (Italian Central Alps), 1610-2008 AD. Climate of the Past 9: 211-221.

Fritts H.C. (Ed.) (1976). Tree Rings and Climate. Elsevier, London, 582 pp.

Haeberli W., Hoelzle M., Paul F. *et al.* (2007). Integrated monitoring of mountain glaciers as key indicators of global climate change: The European Alps. Annals of Glaciology 46: 150-160.

Harris I.C., Jones P.D., Osborn T.J. *et al.* (2014). Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. International Journal of Climatology 34: 623-642.

IPCC (2013). Summary for policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of WG I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (T.F. Stocker, D. Qin, G.-K. Plattner, *et al.* eds). Cambridge University Press, Cambridge.

IPCC (2018). Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change. (V. Masson-Delmotte, P. Zhai, H.O. Pörtner *et al.* Eds). World Meteorological Organization, Geneva.

Paul F., Frey H., Le Bris R. (2011). A new glacier inventory for the European Alps from Landsat TM scenes of 2003: challenges and results. Annals of Glaciology 52: 144-152.

Salvatore M.C., Zanoner T., Baroni C. *et al.* (2015). The state of Italian glaciers: A snapshot of the 2006-2007 hydrological period. Geografia Fisica e Dinamica Quaternaria 38: 175-198.

Schweingruber F.H. (1988). Tree Rings Basic and Applications of Dendrochronology. Kluwer Academic Publishers, Dordrecht, 276 pp.

Zanoner T., Carton A., Seppi R. *et al.* (2017). Little Ice Age mapping as a tool for identifying hazard in the paraglacial environment: The case study of Trentino (Eastern Italian Alps). Geomorphology 295: 551-562.

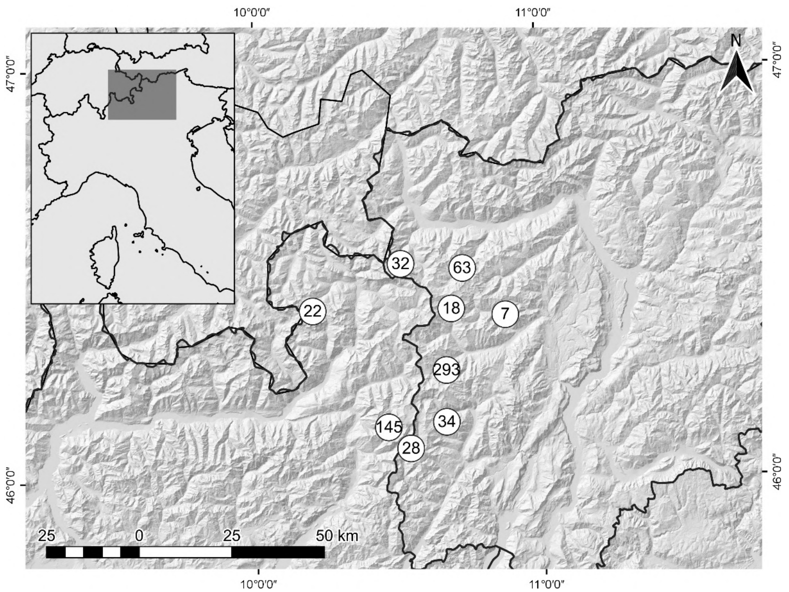


FIG. 1. Scratch map of the working area. Number inside the dots identifies the trees collected at each location.

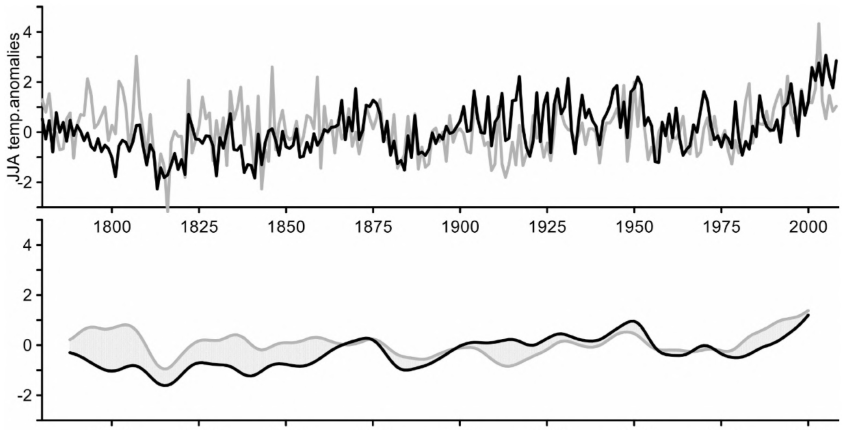


FIG. 2. Comparison of the Adamello-Presanella reconstruction of June to August (JJA) temperature (black) with the HISTALP JJA mean temperature (1780-2008, grey) for unfiltered series (top) and after filtering with a 20-yr low-pass filter (bottom) (modified after Coppola *et al.* 2013).

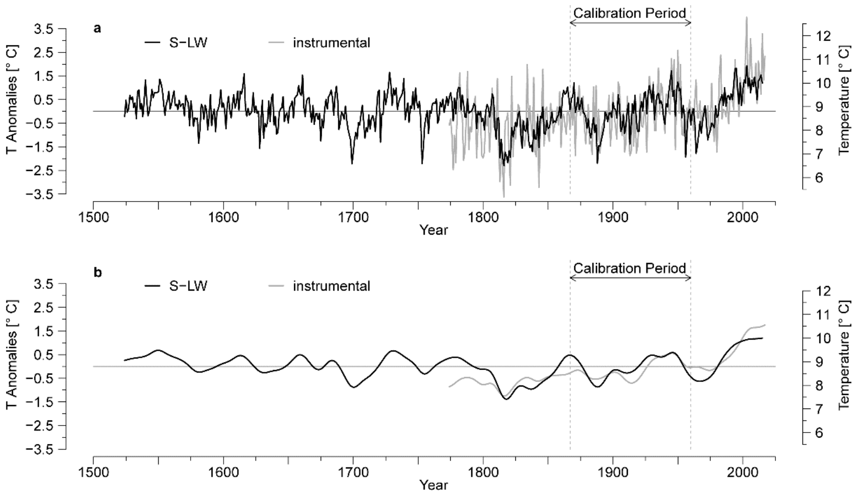


FIG. 3. Yearly Bosco Antico standard latewood (S-LW) based reconstructed June-July temperature anomalies using the 1867-1960 calibration period (a) and the 31-years Gaussian filtered series (b) (Cerrato *et al.* 2018).

Permafrost and climate change: the South-Western Alps perspective

ADRIANO RIBOLINI*
Dipartimento di Scienze della Terra, Università di Pisa, Via S. Maria, 53 - 56126 Pisa

Keywords: Alpine cryosphere, rock glacier, geophysical methods

ABSTRACT. – Permafrost is a subsurface and invisible phenomenon because of its purely thermal definition (*i.e.*, ground remaining at or below 0°C for at least two consecutive years). However, permafrost is an important component of the Earth's cryosphere, and an essential element of the global climate system. Permafrost interacts with climate by reacting with the aggradation or degradation processes, ultimately causing the increase/decrease of its thickness. The transformations of the state of permafrost affecting alpine slopes are critical to people and to ecosystems. They induce slope instability and changes in geomorphic processes (*e.g.*, floods) and related hazard scenarios. Moreover, the long-term reservoirs of frozen water represented by permafrost-affected terrains are likely to become increasingly important water reservoir under ongoing global-warming. The methods and the main results collected in the South-Western Alps are briefly reported, underlining the relevance to climate change. In this alpine region the permafrost investigations are relative to rock glaciers, the most widespread landforms due to permafrost existence in detritical accumulations. Although near its climatic limit of existence, permafrost is still present and very sensitive also to slight interannual climatic variations.

PERMAFROST: BASIC CONCEPTS AND RELEVANCE TO CLIMATE CHANGE. – Permafrost is defined as ground (soil and/or rock, including ice and organic material, plus air/gas in unsaturated ground) that remains at or below 0°C for at least two consecutive years (Williams & Smith 1989; French 2010) (Fig. 1a). Accordingly, permafrost can, but does not need to, contain water or ice. Most permafrost areas experience seasonal thaw, during which ground surface temperatures rise above 0°C. The ground layer that thaws on a seasonal basis is called "active layer" (Fig. 1a). Given its influence on ground surface energy exchange, hydrological processes, carbon budgets and natural hazards, permafrost has been

*adriano.ribolini@unipi.it

identified as one of the key components of the global climate system (Harris *et al.* 2009). Specifically, permafrost is one of the components of the Earth's cryosphere, an all-encompassing term for those portions of the Earth surface where water is in solid form (*i.e.*, sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets and frozen ground, which includes permafrost). The exposed Earth surface below which some permafrost can be expected (*i.e.,* the global permafrost region) is estimated to be $22\pm3 \times 10^6$ km^2, approximately 17 % of the global land area (Gruber 2012).

Permafrost interacts with climate, ecosystems and human systems (Nelson *et al.* 2002; Harris *et al.* 2009; Schuur *et al.* 2015; Vonk *et al.* 2015). The aggradation (*i.e.*, formation) and degradation (*i.e.*, melting) of permafrost usually occur in association with a change in mean ground temperature due to microclimatic and climatic changes (Williams & Smith 1989). Among these causative changes the main air temperature is the most important, but also the regime of precipitations (solid and liquid) and snow cover depth and duration play an important role. The degradation of permafrost is seen as a major challenge in the current discussion of globally rising air temperatures (IPCC 2013).

In this regard, the Alpine cryosphere has demonstrated to be highly sensitive to climatic and environmental changes, because evidence from around the globe underlined that the rate of warming increases with elevation, to such an extent that high mountain environments would experience more rapid changes in temperature than the global average at lower elevations. The climate-forced transformations in the state of alpine permafrost are critical to people and ecosystems. They induce a general destabilization of mountain slopes and changes in geomorphic processes and related hazard scenarios. There are many evidences that the degradation of permafrost leads to an increase in magnitude, distribution and frequency of mass wasting processes, and even of rapid kinematics. These phenomena may affect populated areas and high-altitude infrastructures (ski resorts, mountain huts, roads, etc.), representing a serious geomorphological hazard and a challenge for local authorities, that need new tools for improved adaptation and resilience.

Permafrost-affected terrains are long-term reservoirs of frozen water and are likely to become increasingly important water sources under global-warming conditions (Haeberli & Beniston 1998; Brenning 2005; Rangecroft *et al.* 2015; Jones *et al.* 2019).

For all these reasons, the understanding of existence, spatial extent and thickness of permafrost in mountain environments has become crucial.

GEOPHYSICAL AND THERMAL METHODS FOR DETECTING PERMAFROST EXISTENCE. – Among the methods adopted to detect permafrost along mountain detritical slopes and rock-walls, the most common are geophysical investigations and the thermal monitoring of ground/rock surface. The recent availability of borehole data has demonstrated the reliability of both methods in detecting/predicting the existence of internal ice formed under permafrost condition, as well as the potentiality of monitoring its annual/seasonal behavior.

Electrical Resistivity Tomography (ERT), Ground-Penetrating Radar (GPR) and Refraction Seismic (RS) are the most frequently used geophysical methods. The monitoring of Surface Ground Temperature (SGT) of detritical accumulations and of rock-wall surface temperature are commonly employed across the Alps.

Continuous updating of device technologies enables to increase performances in field data capture (by also designing new types of surveys) and more efficient data processing steps generates better results in terms of quality, resolution and depth of investigation. By applying various methods to a same site, it is possible to identify the potentialities and limits of strategies of data acquisition and processing. However, these techniques are indirect investigations, and they provide data from which the existence of permafrost can be only hypothesized. In other words, the data must be interpreted in terms of subsurface stratigraphic, cryologic and hydrogeologic characteristics. So far, by combining ERT and RS data, it has been possible to disentangle the four phases composing the permafrost-affected terrains (ice, rocks, air, water), and to figure out their relative percentages (Hauck 2013). In addition, the long-term series of SGT now available figure out the behaviour of permafrost-affected detrical slopes and rock walls, showing climate warming-driven phenomena (*i.e.*, slope instability) and processes acceleration (*i.e.*, increase in the speed of permafrost creep).

ROCK GLACIER AS A PERMAFROST-RELATED LANDFORM. – The methods described above are normally applied to earth surface features (landforms) which indicate a potential existence of permafrost beneath. Rock glaciers (*i.e.*, slow flowing mixtures of debris and ice in variable proportion) are the clearest, most abundant and studied permafrost-related landforms in mountain regions (Barsch 1988) (Fig. 1b). They are characterised by a distinctive surface topography of transversal and longitudinal detritical ridges and furrows, expression of long-term creep of ice-rock mixtures under permafrost conditions (Berthling 2011) (Fig. 1c). Rock glaciers can take several thousand years to develop; their distribution can provide information about current as well as past occurrence of permafrost and related climatic characteristics (Oliva *et al.* 2018). Compared to glaciers, rock glaciers are believed to be less sensitive to rising temperature due to insulation of debris mantles (*i.e.*, active layer). However, there are also emerging observations suggesting that rock glaciers in the European Alps have increased flow rates in response to climate change (Kääb *et al.* 2007; Bodin *et al.* 2009).

THE SOUTH-WESTERN ALPS PERSPECTIVE. – Several geophysical and thermal investigations have been undertaken during the last two decades in the South-Western Alps, specifically in the Maritime and Cothian Alps. These were essentially ERT and GPR prospections as well as GST monitoring of rock glaciers selected according to a previous geomorphological analysis (Ribolini & Fabre 2006; Ribolini *et al.* 2007, 2010) (Fig. 2). The results in terms of potential permafrost existence were then exported to all the other rock glaciers, with the aim of delineating the altitudinal limit above which permafrost is possible/probable in this alpine region.

All these methods converge in delineating a highly probable permafrost existence at elevation above 2,500 m a.s.l. inside the rock glaciers and debris accumulations of different geneses (glacial deposits, slope debris) (Ribolini & Fabre 2006). Sporadic permafrost layers could be present also at lower elevations along slopes and channels insulated by solar radiation and/or with prevalent aspects toward norther quadrants. Below 2,300 m a.s.l. permafrost existence can be considered improbable/absent. It is worth noting that very small and near-to-the extinction glaciers are still present in this alpine region (Federici *et al.* 2018). This is why interactions between glacier-related phenomena (*i.e.*, fragments of buried glacier ice abandoned during the glacier retreat) and an ongoing permafrost creep (at the rock glacier root) are possible in the recently deglaciated areas (Ribolini *et al.* 2010).

The thermal analyses of rock glacier ground surface up to 1 m in depth highlight that, beside the mean annual air temperature, phenomena such as warm water percolation during the summer season, thickness and timing of snow cover impact on the thermal regime. These phenomena seem to have experienced an increase during the last 10-15 years, superimposing their effects onto that caused by the progressively increasing air temperature and hence exacerbating permafrost degradation (Ribolini & Fabre 2006).

The results so far obtained in the South-Western Alps, and specifically in the Maritime Alps, point out that this is the southernmost region where permafrost is present, although near its climatic limit for existence. Likewise, the glaciers still surviving in this area are the southernmost of the entire alpine arch. Being near the limit of climatic existence, make these components of alpine cryosphere very sensitive also to slight interannual climatic variations, so a sort of sentinels of the effects of ongoing climatic tendency.

ONGOING STUDIES AND FUTURE DEVELOPMENTS. – Ongoing projects in the South-Western Alps deal with the detection of permafrost by adopting modern and effective geophysical systems, along with constant thermal monitorings on some sites. All these investigations are undertaken on selected rock glaciers. The aim of these activities is the detailed exploration of rock glacier interior for ice volume estimation. This value can then be converted into water content by imposing an ice density. In addition to climatic and paleo-climatic significance of permafrost, the hydrological value of permafrost inside debris accumulation (*e.g.*, rock glacier) has become a relevant and challenging issue in this mountain region. Owing to the insulation of debris mantles, the frozen water storage represented by rock glacier permafrost is believed to have become comparable to (or higher than) that represented by glaciers. In this regard, rock glaciers can be considered high-mountain porous aquifers, deserving a deep comprehension of circuits of water circulation in the light of seasonal and climate change-forced ice thawing.

ACKNOWLEDGMENTS. – These projects are supported by national (University of Pisa, University of Insubria) and regional funds (ARPA), and benefit from the cooperation of foreign research institutes (University of Aberdeen, University of Madrid, University of Athens).

REFERENCES

Barsch D. (1988). Rockglaciers. In: “Advances in Periglacial Geomorphology” (Clark M.J. Ed.), Wiley, New York, pp. 69-90.

Berthling I. (2011). Beyond confusion: Rock glaciers as cryo-conditioned landforms. Geomorphology 131: 98-106.

Bodin X., Thibert E., Fabre D. *et al.* (2009). Two decades of responses (1986-2006) to climate by the Laurichard rock glacier, French Alps. Permafrost and Periglacial Processes 20: 331-344.

Brenning A. (2005). Geomorphological, hydrological, and climatic significance of rock glaciers in the Andes of Central Chile (33-35 S). Permafrost and Periglacial Processes 16: 231-240.

Federici P.R., Ribolini A., Spagnolo M. (2018). Glacial history of the Maritime Alps from the Last Glacial Maximum to the Little Ice Age. Geological Society of London, Special Publication 433: 137-159.

French H.M. (2010). The Periglacial Environment. Third edition, John Wiley, Chichester, 480 pp.

Gruber S. (2012). Derivation and analysis of a high-resolution estimate of global permafrost zonation. The Cryosphere 6: 221-233.

Jones D.B., Harrison S., Anderson K. *et al.* (2019). Rock glaciers and mountain hydrology: A review. Earth-Science Reviews 193: 66-90.

Haeberli W., Beniston M. (1998). Climate Change and Its Impacts on Glaciers and Permafrost in the Alps. Ambio 27: 258-265.

Harris H., Arenson L.U., Christiansen H.H. *et al.* (2009). Permafrost and climate in Europe: Monitoring and modelling thermal, geomorphological and geotechnical responses. Earth-Science Reviews 92: 117-171.

Hauck C. (2013). New Concepts in Geophysical Surveying and Data Interpretation for Permafrost Terrain. Permafrost and Periglacial Processes 24: 131-137.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of WG I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Kääb A., Frauenfelder R., Roer I. (2007). On the response of rockglacier creep to surface temperature increase. Global and Planetary Change 56: 172-187.

Nelson F.E., Anisimov O.A., Shiklomanov N.I. (2002). Climate change and hazard zonation in the circum-Arctic permafrost regions. Natural Hazards 26: 203-225.

Oliva M., Žebre M., Guglielmin M. *et al*. (2018). Permafrost conditions in the Mediterranean region since the Last Glaciation. Earth-Science Reviews 185: 397-436.

Rangecroft S., Harrison S., Anderson K. (2015). Rock glaciers as water stores in the Bolivian Andes: an assessment of their hydrological importance. Arctic, Antarctic, and Alpine Research 47: 89-98.

Ribolini A., Fabre D. 2006. Permafrost existence in the rock glaciers of the Argentera Massif (Maritime Alps, Italy). Permafrost and Periglacial Processes 17: 49-63.

Ribolini A., Chelli A., Guglielmin M. *et al.* (2007). Relationships between glacier and rock glacier in the Maritime Alps, Schiantala Valley, Italy. Quaternary Research 68: 353-363.

Ribolini A., Guglielmin M., Fabre D. *et al.* (2010). The internal structure of rock glaciers and recently deglaciated slopes as revealed by geoelectrical tomography: insights on permafrost and recent glacial evolution in the Central and Western Alps (Italy-France). Quaternary Science Reviews 29: 507-521.

Schuur E.A.G., McGuire A.D., Schädel C. *et al.* (2015). Climate change and the permafrost carbon feedback. Nature 520: 171-179.

Vonk J.E., Tank S.E., Bowden W.B. *et al.* (2015). Reviews and syntheses: Effects of permafrost thaw on Arctic aquatic ecosystems. Biogeosciences 12: 7129-7167.

Williams P.J., Smith M.W. (1989). The frozen earth. Fundamentals of geocryology. Cambridge University Press, Cambridge.

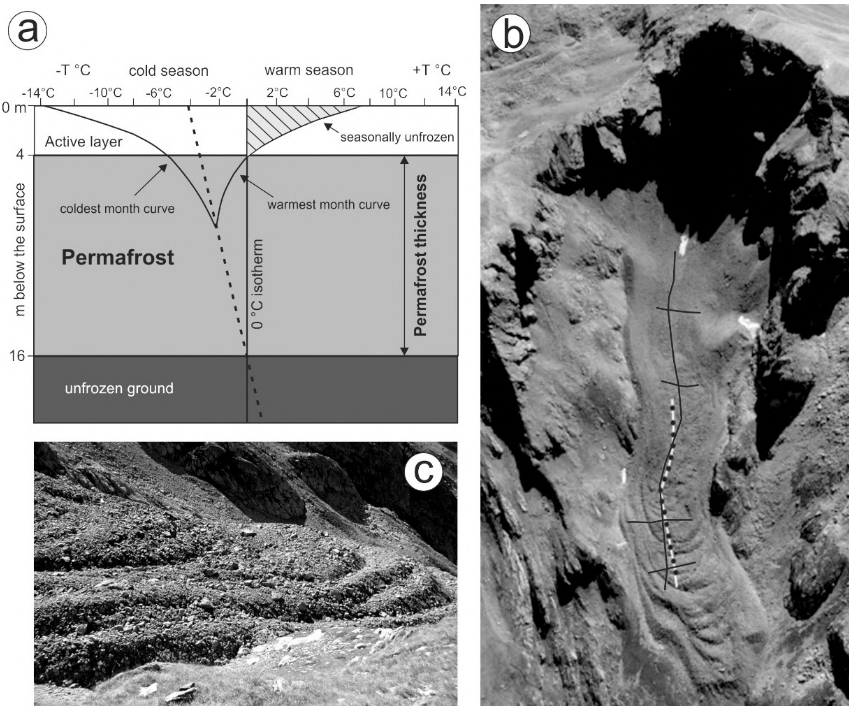


Fig. 1. Permafrost model (ground temperature *vs* depth) (a). Oblique aerial view of a rock glacier in the Maritime Alps (source: Google Earth) (b). Continuous lines are the locations of Ground-Penetrating Radar profiles; the continuous-dotted line is the location of the Electrical Resistivity Tomography profile. For scale: the continuous-dotted line is 260 m long. Transversal and longitudinal ridges and furrows of a rock glacier (Maritime Alps) (c). A long-term creep of ice-rock mixtures under permafrost conditions causes them.

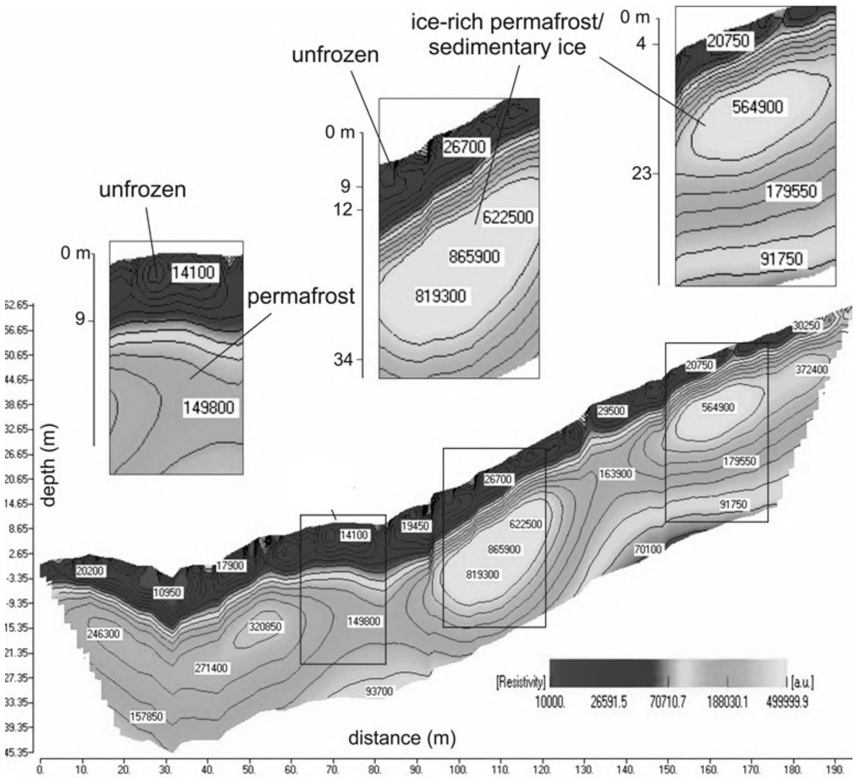


FIG. 2. Electrical Resistivity Tomography (ERT) on a rock glacier in the Cothian Alps (Mt Viso area). The higher the resistivity (colours from light to very light) the higher is the ice content. The dark-coloured surface layer is the unfrozen active layer. Resistivity values are expressed in Ohm x m.

Ancient interglacials as analogues of the present: reconstructing the past variability for understanding and modelling the future climate

ELEONORA REGATTIERI[1*], GIOVANNI ZANCHETTA[1], RUSSELL N. DRYSDALE[2], BIAGIO GIACCIO[3]
[1]Dipartimento di Scienze della Terra, University of Pisa, Via S. Maria, 53 - 56126 Pisa
[2]School of Geography, University of Melbourne, Victoria 3010, Australia
[3]Istituto di Geologia Ambientale e Geoingegneria, IGAG-CNR, Via Salaria, km 29.400 - 00010 Monterotondo, Rome

Keywords: continental carbonates, stable isotope geochemistry

ABSTRACT. – Past interglacials can be seen as analogues for the present interglacial and its future evolution. Here we present some results regarding the climate and dynamics of two past interglacial periods, the MIS5 (*ca.* 130 ka) and the MIS19 (*ca.* 790 ka), as reconstructed from well-dated oxygen stable isotopes composition ($\delta^{18}O$) records from sedimentary carbonates from central Italy. Carbonates $\delta^{18}O$ is used to infer past hydrological changes (mostly rainfall amount variability), that can be tracked at regional and extra-regional scale, allowing to shed light on mechanisms of abrupt climate variability and on the sensitivity of the climate systems to different combinations of boundary conditions.

INTRODUCTION AND BACKGROUND. – Glacial and interglacial are the two extreme operation modes of the Quaternary Earth' climate history. Their cyclicity is ultimately driven by variations in the Earth's orbit parameters causing periodic changes in the magnitude and in the seasonal and latitudinal distribution of the incoming solar radiation. These subtle changes are amplified, transmitted and sustained by a complex network of climate feedbacks involving all the components of the Earth System. Due to the high non-linearity of these feedbacks, the pacing of the glacial ages changed through time, and between 1.2 and 0.6 Ma ago, weaker cycles with a period of ~40 ka gave way to stronger cycles with a recurrence period closer to 100 ka. By 800 ka ago, this transition was almost complete and long, cold and high global ice volume glacial periods started to alternate with short, warm, low ice extent interglacials, like the one in which we live today, the Holocene (PAGES 2016).

*Corresponding author: eleonora.regattieri@unipi.it

Past interglacials, and especially those of the last 800 ka, have a particularly useful role in climate studies because they provide a basis for comparison with the present interglacial and its future evolution (Tzedakis *et al.* 2009). A wide range of continuous climate records from terrestrial sites, marine sediment cores and the oldest Antarctic ice cores, shows that each past interglacial was characterized by a different combination of boundary conditions (insolation patterns, atmospheric greenhouse gases concentration, ice volume, temperatures, Fig. 1), which led to a great diversity among them: timing, intensity of the peak warmth, evolution and internal variability are indeed different in each case. Thus, the study of past interglacials allows to disentangle the sensitivity of the Earth System to different forcing and can provide insights into climate processes and feedbacks operating under globally warm conditions, a key issue in the context of future climate change. Their study also may help to clarify our position in the natural progression of events and to assess potential deviations arising from anthropogenic processes (Tzedakis *et al.* 2009). Particularly crucial is the recognition of short-term (*i.e.*, multi-decadal to sub-millennial), climate oscillations, because it provides the context of natural variability in which human induced changes operate, and may help to shed light on the mechanisms of abrupt climatic changes during warm interval, whose probability is likely increased by the ongoing human activity (Alley *et al.* 2003).

In this contribute, we present some results produced by our research group in the last years regarding the climate evolution, the internal dynamics and the environmental expression of past interglacial periods, as reconstructed from terrestrial climate archives from the central Mediterranean. The Mediterranean climate is very sensitive to modifications in North Atlantic atmospheric and oceanic patterns and in the tropical circulation (Ulbrich *et al.* 2012) Particularly, the hydrology of the basin (*i.e.*, amount and seasonality of the precipitation) shows strong teleconnections with the extra-regional climate, so the Mediterranean represents a key area in which investigate the mechanisms and the environmental impact of past climatic changes occurring at global and hemispheric scale. We will focus particularly on two past interglacials, those corresponding to the Marine Isotope Stages (MIS) 5 and 19 (Fig. 1).

THE RECORDS AND THEIR PALEOENVIRONMENTAL SIGNIFICANCE. – The natural archives used in our climatic reconstructions are continental carbonates sequences. These deposits form within the hydrological cycle and their geochemical, stratigraphic and sedimentological properties can be related to the climatic and environmental conditions in which they form. Because their deposition spans long time intervals (up to hundred thousands years), they can be used to reconstruct the time evolution of those conditions. Particularly, in the Mediterranean, the stable oxygen isotopes composition ($\delta^{18}O$) of continental carbonates is a key proxy to trace hydrology at different time-scale, and its variability is primarily considered as reflecting fluctuations in the amount of rainfall recharging the lake or the cave system (*e.g.*, Bard *et al.* 2002). The records discussed here are from the sedimentary lacustrine succession from the Sulmona Basin (Abruzzo) and from cave speleothems from Corchia and Tana che Urla caves (Apuan Alps, Tuscany) (Fig. 1).

A crucial feature of our records is that they are all anchored to high-quality chronologies produced by radiometric methods (U-Th method for the speleothem and $^{40}Ar/^{39}Ar$ method on interbedded volcanic ash layers, tephra, for the lacustrine sediment; *e.g.*, Hellstrom 2003; Lowe 2011). This provides independent time-scales for the observed changes, and allows the proper understanding of triggering, propagation and sustaining mechanisms of climatic changes.

CLIMATE INSTABILITY OVER THE LAST INTERGLACIAL. – The Last Interglacial (LIG), or Eemian, occurred between *ca.* 130 and 110 ka and is the interglacial period closer to the present one (PAGES 2016). Orbital parameters were different from that of the Holocene, with higher eccentricity leading to a stronger Northern Hemisphere (NH) summer insolation (Fig. 1) for the early LIG. Globally distributed records show that it was, on average, 2°C warmer than the pre-industrial Holocene, with temperature anomalies up to +6°C at the high-latitudes of the NH. Due to a reduced ice volume, sea-level is estimated to have been ~6-9 m above present (PAGES, 2016). Despite the differences in boundary conditions, it can be seen as an analogue for the projected global warming, and is a good context in which study the interactions occurring in the Earth System during warmer-than-present conditions.

A pervasive, centennial-scale climate instability during the LIG is a common feature of many marine records from the mid to high-latitudes North Atlantic. Terrestrial records from the Mediterranean as well report the occurrence of secular events of reduced precipitation. However, the relationship between marine cooling events, changes in deep-water oceanic circulation and precipitation patterns were not fully resolved, mostly due to the lack of a common and independent time scale. The $\delta^{18}O$ records obtained from Corchia (Drysdale *et al.* 2005; Tzedakis *et al.* 2018), Tana che Urla (Regattieri *et al.* 2014) and Sulmona (Regattieri *et al.* 2015, 2017), each possessing its own chronology, provides a well-dated, robust framework of hydrological variability for the central Mediterranean. In all the three records, the timing and the evolution of the LIG appear very similar, and several common drier intervals can be identified (Fig. 3). These events can be tracked at the extra-regional scale. Particularly interesting is the comparison with the record from the marine sediment core MD01-2444, from the western Iberian Margin (Figs. 2, 3). The Iberian Margin is considered a prime location for palaeoclimatic research. It combines a narrow continental shelf with major rivers which deliver terrestrial material to the sea floor. It is also deep enough to generate high quality isotopic records from planktonic and benthonic foraminifera, which are representative of the state of the Atlantic Meridional Overturning Circulation (AMOC) (*e.g.*, Margari *et al.* 2010).

The similarity observed between the percentage of temperate forest pollen and the Italian $\delta^{18}O$ (Fig. 3) allows to transfer the Corchia chronology to the marine record, basing on the assumption that rainfall amount exerts a dominant control on both the composition of southern European vegetation and on the $\delta^{18}O$ of Mediterranean carbonates (Tzedakis *et al.* 2018). The alignment shows that the dry events can be associated with changes in marine proxies and particularly to perturbation of surface hydrography (expressed by the $\delta^{18}O$ of the planktonic) and deep-water ventilation (expressed by the $\delta^{13}C$ of the benthonic). These changes in marine conditions can be tracked in others marine records from the high-latitude North Atlantic and testify the presence of multi-centennial significant reductions in the AMOC strength (Tzedakis *et al.* 2018). These perturbations affected evaporation and transport of moist air masses from the Atlantic to the Mediterranean, and caused the drier events apparent in the terrestrial records. Climate numerical simulations suggest that episodic Greenland ice melt and runoff, as a result of excess warmth, may have contributed to short-term AMOC weakening and increased climate instability throughout the LIG (Tzedakis *et al.* 2018). Accelerated freshwater input into the North Atlantic as a result of current global warming is expected to weaken the AMOC (Caesar *et al.* 2018). Though the LIG is not a strict analogue for future anthropogenically driven changes, what emerges is that an "excess warmth" maybe responsible for enhanced centennial-scale climate instability, affecting ocean dynamics and continental hydrological patterns.

DURATIONS AND DYNAMICS OF THE BEST HOLOCENE ANALOGUOUS. – Among past interglacial periods the MIS19 is particularly interesting because its orbital geometry was very similar to that of the present interglacial, with a low eccentricity and a similar phasing between obliquity and precession (Fig. 1). Modelling studies have highlighted that the MIS19 is the best analogue for the (preindustrial) Holocene when annual and seasonal temperatures are taken into account (Yin & Berger 2012). The MIS19 is well expressed in the marine and ice core record. However, chronologies of these records are totally or partly based on *a priori* assumptions on the phasing between the changes in the astronomical parameters and their attendant climate response. Thus, any estimation of its length rests on the validity of the orbital tuning approach. The lacustrine sequence from the Sulmona Basin offers the unique opportunity to develop an independent chronology based on tephra layers (Giaccio *et al.* 2015; Regattieri *et al.* 2019). As for the MIS5, the Sulmona $\delta^{18}O$ record show changes that can be tracked in marine records from the North Atlantic, allowing the transfer of the high-quality terrestrial chronology to the marine record, and particularly to the sub-polar North Atlantic core ODP-983 (Kleiven *et al.* 2011, Fig. 4).

The definition of glacial/interglacial boundaries is mostly related to ice volume and sea level. An indirect indication of the ice growth is provided by the millennial-scale occurrence of ice rafted debris (IRD) produced by iceberg discharges to the North Atlantic once a critical ice sheets size is reached. These IRD events are associated to cooling of the NH and warming of Antarctica, in the so-called thermal bipolar seesaw pattern, which is a pervasive feature of the glacial periods of the last 800 ka. The IRD events can be also tracked in the Mediterranean as intervals of reduced precipitation. Following the conceptual model proposed by Tzedakis *et al.* (2012) we define the length of the MIS19 interglacial on the Sulmona record by posing its onset at the end of the last bipolar see-saw oscillation during the glacial termination, and its end some millennia before of the first IRD that follow the interglacial (which occurs only when the ice sheets reach the critical size for collapsing), within the millennial-long cooling trend observed in the marine record and within the Sulmona drying trend that represents the local hydrological response to ice sheet growth (Fig. 4). It results that the total length of the MIS19 interglacial was 10.7 ± 2.8 ka, *i.e.*, more or less the time already elapsed since the beginning of the Holocene. To better compare the MIS19 and the Holocene, we align the Sulmona MIS 20/19 record with a Late Glacial-Holocene sea surface paleotemperature record from the W Mediterranean (Martrat *et al.* 2014), both anchored to their respective orbital parameters and using the abrupt end of the last see-saw oscillation, clearly documented at the glacial-interglacial transition of both series (Fig. 4). The alignment shows that the astronomical configuration required for driving the MIS 1 glacial inception should have already been reached (Giaccio *et al.* 2015). Consequently, by analogy between MIS 19 and MIS 1, the current interglacial should be very close to its natural end. However, considering the other relevant factors required for triggering a glacial inception, *i.e.*, the atmospheric greenhouse gas concentrations, a substantial difference between MIS 19 and MIS 1 emerges. Indeed, at the time of the MIS 19 glacial inception, the atmospheric CO_2 concentration was ~250 ppm. In the Holocene, it never fell below ~260 ppm and from 8-6 ka it shows an increasing trend which led to a preindustrial CO_2 concentration of ~280 ppm. This trend was proposed to be the results of an early anthropogenic impact on the climate, mostly due to the onset of agriculture practices altering the global carbon budget (Ruddimann 2007). The case of delayed or failed glaciation caused by the progressive, possibly anthropogenic, increase of atmospheric CO_2 concentrations seems to be supported by the results of our study (Giaccio *et al.* 2015).

REFERENCES

Alley R.B. *et al.* (2003). Abrupt climate change. Science 299(5615): 2005-2010.

Berger A., Loutre M.F. (1991). Insolation values for the climate of the last 10 million years. Quaternary Science Reviews 10: 297-317.

Caesar L. *et al.* (2018). Observed fingerprint of a weakening Atlantic Ocean overturning circulation. Nature 566: 191-196.

Drysdale R.N. *et al.* (2005). Stalagmite evidence for the onset of the Last Interglacial in southern Europe at 129±1 ka. Geophysical Research Letters 32(24). doi:10.1029/2005GL024658.

Giaccio B. *et al.* (2015). Duration and dynamics of the best orbital analogue to the present interglacial. Geology 43: 603-606.

Hellstrom J. (2006). U-Th dating of speleothems with high initial ^{230}Th using stratigraphical constraint. Quaternary Geochronology 1: 289-295.

Kleiven H.K.F. *et al.* (2011). Coupled deep-water flow and climate variability in the middle Pleistocene North Atlantic. Geology 39: 343-346.

Lisiecki L.E., Raymo M.E. (2005). A Plio-Pleistocene stack of 57 globally distributed benthic δ^{18}O records. Paleoceanography 20: 1-17.

Lowe D.J. (2011). Tephrochronology and its application: a review. Quaternary Geochronology 6: 107-153.

Lüthi D. *et al.* (2008). High-resolution carbon dioxide concentration record 650,000-800,000 years before present. Nature 453(7193): 379-382.

Margari V. *et al.* (2010). The nature of millennial-scale climate variability during the past two glacial periods. Nature Geoscience 3: 127-131.

Martrat B. *et al.* (2014). Similarities and dissimilarities between the last two deglaciations and interglaciations in the North Atlantic region. Quaternary Science Reviews 99: 122-134.

Past Interglacials Working Group of PAGES (2016). Interglacials of the last 800,000 years, Rev. Geophys. 54. doi:10.1002/2015RG000482.

Regattieri E. *et al.* (2014). A continuous stable isotope record from the penultimate glacial maximum to the Last Interglacial (159-121 ka) from Tana che Urla Cave (Apuan Alps, Central Italy). Quaternary Research 82: 450-461.

Regattieri E. *et al.* (2015). Hydrological variability over the Apennines during the Early Last Glacial precession minimum, as revealed by a stable isotope record from Sulmona basin, Central Italy. Journal of Quaternary Science 30: 19-31.

Regattieri E. *et al.* (2017). A Last Interglacial record of environmental changes from the Sulmona Basin (Central Italy). Palaeogeography, Palaeoclimatology, Palaeoecology 472: 51-66.

Regattieri E. *et al.* (2019). Frequency and dynamics of millennial-scale variability during Marine Isotope Stage 19: Insights from the Sulmona Basin (Central Italy). Quaternary Science Reviews 214: 28-43.

Ruddiman W.F. (2007). The early anthropogenic hypothesis: Challenges and responses. Reviews of Geophysics: 45, RG4001.

Ulbrich Ü. *et al.* (2012). Climate of the Mediterranean: Synoptic patterns, temperature, precipitation, winds, and their extremes. In: Climate of the Mediterranean Region. From the Past to the Future (pp. 301-346). Elsevier, Amsterdam.

Tzedakis P.C. *et al.* (2009). Interglacial diversity. Nature Geoscience 2: 751-755.

Tzedakis P.C. *et al.* (2012). Determining the natural length of the current interglacial. Nature Geoscience 5: 138-141.

Tzedakis P.C. *et al.* (2018). Enhanced climate instability in the North Atlantic and Southern Europe during the Last Interglacial. Nature Communications 9: 4235.

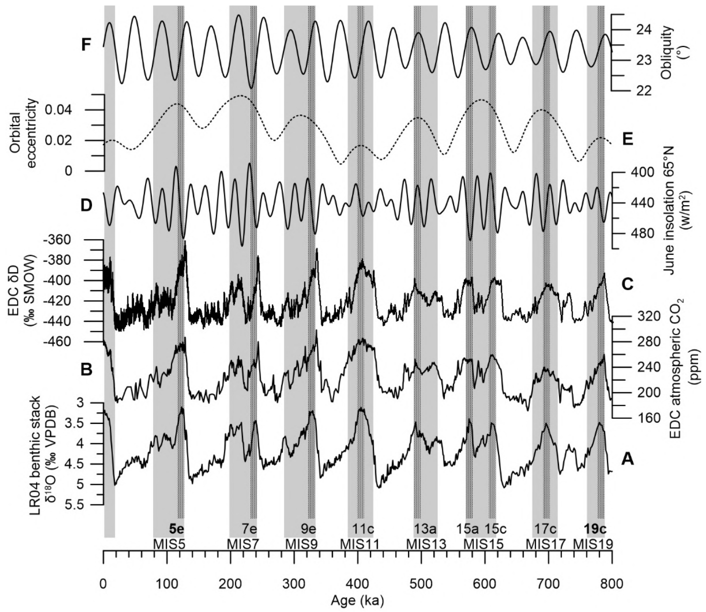


FIG. 1. Boundary conditions and paleoclimatic parameters for the last 800 ka. A) The LR04 stack, a proxy for the global ice volume (Lisieki and Raymo 2005; B) Atmospheric CO_2 concentration from Antarctic ice cores (Lüti *et al.* 2008); C) Deuterium composition from Antarctic ice cores, a proxy for air temperature); D) June insolation at 65°N; E) Eccentricity of the Earth's orbit; F) Obliquity of the Earth's axes (orbital parameters from Berger and Loutre 1991). Grey rectangles indicate the warm Marine Isotope Stages (MIS); the terrestrial interglacial portion of each stage is highlighted in darker grey. In bold, the two intervals discussed in this study.

FIG. 2. Location of sites mentioned in the text.

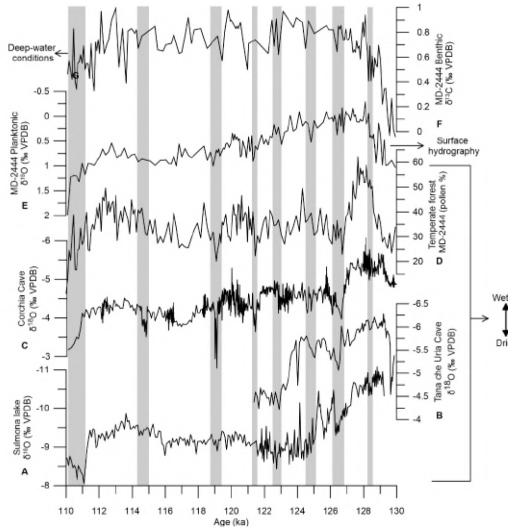


Fig. 3. $\delta^{18}O$ records from central Italy sites (A, Sulmona; B, Tana che Urla; C, Corchia) compared to proxies from the marine core MD01-2444 from the western Iberian margin (D, Percentage of temperate forest pollen; E $\delta^{18}O$ planktonic foraminifera; F, $\delta^{13}C$ benthic foraminifera. Grey rectangles indicate common events of reduced precipitation and of perturbations of oceanic conditions.

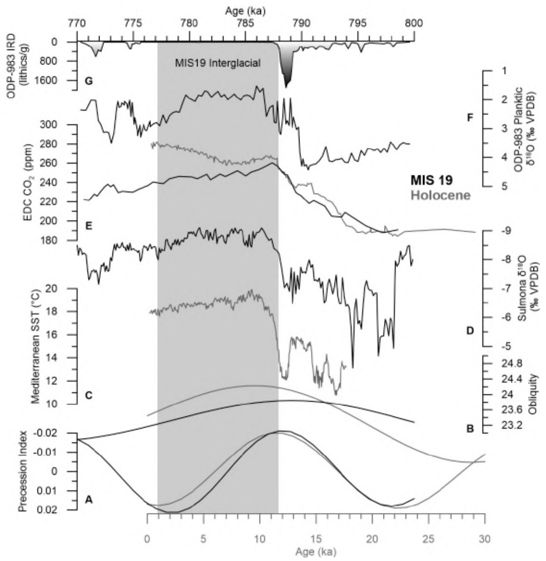


Fig. 4. Comparing Holocene and MIS19. A), B) orbital parameters (precession and obliquity, black: MIS19, grey: Holocene); C) Sea Surface Temperature from marine core ODP967, D) Sulmona $\delta^{18}O$; E) Planktonic $\delta^{18}O$ and F) Ice Rafted Debris (IRD) from marine core ODP-983.

Climatic instability and drier phases in the central Mediterranean in the last thousands of years: lessons from the past to understand future changes

GIOVANNI ZANCHETTA[1*], ELEONORA REGATTIERI[1], ILARIA ISOLA[2], RUSSELL N. DRYSDALE[3], MONICA BINI[1]
[1]Dipartimento di Scienze della Terra, University of Pisa, Via S. Maria, 53 - 56126 Pisa
[2]Istituto Nazionale di Geofisica e Vulcanologia, Sez. di Pisa, Via della Faggiola, 32 - 56126 Pisa
[3]School of Geography, The University of Melbourne, 3010 Victoria, Australia

Keywords: climatic change, North Atlantic Oscillation, Late Holocene, Apuan Alps

ABSTRACT. – Given predictions of future climate, changes in meteoric precipitation and water resources seem certain to have important socio-economic and political impacts in the Mediterranean region. Understanding the hydrological variability of this region over different time scales is therefore an essential prerequisite for establishing a baseline for projected future climate change and its possible impact on human society. In this paper we review some of the evidences of drier climate periods discovered over the Apuan Alps (central Italy) using speleothems (cave calcite precipitates, *e.g.*, stalagmites, flowstones) geochemical proxies in the period covering approximately the last thousands of years. There is a certain number of evidences that century-scale drier periods occurs in condition with westerly have a more pronounced zonal flow, reducing the advection of vapour masses to the Mediterranean, a condition that in winter is comparable to positive index of the North Atlantic Oscillation, as it was in the last decades. However, there are some contrasting evidences, which indicate that there are still the necessity to elucidate many mechanisms on Mediterranean climate.

INTRODUCTION. – Mediterranean climate is characterised by strong seasonal contrasts in precipitation with warm and dry summer and wet and mild winters (Lionello *et al.* 2006). In particular winter precipitations determines the water availability and has strong socioeconomic implication in this densely populated region. The Mediterranean Basin has been defined a “hot spot” for future climatic changes (*i.e.*, a region particularly sensitive to the current warming, Giorgi 2006), in particular

[*]Corresponding author: giovanni.zanchetta@unipi.it

concerning meteoric precipitations. In the central Mediterranean, the Apennine where rainfall concentrates and recharges rivers and aquifer (Fiorillo *et al.* 2015) represents a critical area. However, current climate model simulations for future changes tend to show a progressive summer drying but data on winter are less clear (*e.g.*, IPCC 2013). The uncertainty on projections for winter precipitation limits the models utility for this area as supporting tool for decision makers. A major source of uncertainty in models is the lack of long-term, empirical baseline data. Indeed, time series of measured data do not cover the entire range of expected climatic changes and climatic variability experienced by the Earth System in the last thousandth of years; a knowledge, which needs to be implemented using different natural archives and proxy (Bradley 2000). Paleoclimate reconstructions need additionally to be complemented by historical and archaeological data to understand the potential impact on climatic changes on societies (*e.g.*, Sadori *et al.* 2015). Owing to the importance of precipitation in the Mediterranean region, the study of period of reduced rainfall in the past is of paramount importance for understanding future climatic changes. In this paper we review some examples of rapid climatic changes (*i.e.*, multidecadal-to-centennial scale events) occurred during the last thousands of years whose evidences was obtained from speleothems (cave carbonate concretion) collected from Apuan Alps caves, which was one of the main focus of our research group in the last years. This shows how different synoptic circulations can be responsible for long-term drought representing potential analogues for the present current warming.

SITE DESCRIPTIONS. – The Apuan Alps (Fig. 1) are one of the rainiest area of the northern Apennine (Piccinini *et al.* 2008). Apuan Alps are located at the border of the Genoa Gulf, the most important cyclogenetic centre of the Mediterranean area (Lionello *et al.* 2006) and acts as traps of vapour masses advected from the Atlantic and Western Mediterranean seas. Precipitation, especially during winter, are significantly negatively correlated with the North Atlantic Oscillation (NAO, López-Moreno *et al.* 2011), whereas temperature are not, as for most of the Apennine. Two caves are considered for this review: Corchia Cave and Renella Cave (Fig. 1). Both caves have been described in details elsewhere (Piccini *et al.* 2008; Zhorniak *et al.* 2011) and will not be discussed here. Speleothems considered in this review are stalagmites CC26 (Zanchetta *et al.* 2007; Regattieri *et al.* 2014) and CC27 (Isola *et al.* 2019) for the

Corchia Cave and the flowstone RL4 for Renella (Drysdale *et al.* 2006; Zanchetta *et al.* 2016). All these records possesses robust age controls assured by dense U/Th dating, and have been investigated using a multi-proxy approach. Ages are reported in BP (Before Present, *i.e.*, 1950 BP) to be comparable with the commonly radiocarbon dated records.

Discussion. – Figure 2 shows the records discussed in this review for the last 6000 yr. Unfortunately, the records did not contains detailed information on prominent and well known historical climatic oscillation like the Late Antique Little Ice Age, Medieval Climatic Anomaly and the Little Ice Age (*e.g.*, Bradley *et al.* 2003). This has been variously interpreted, as related to the progressive obsolescence of the drip path and to the disturbance operated by human activity above the soil of the cave catchment producing extremely low growth rates and/or speleothem growth cessations. For comparison we show the high-resolution $\delta^{18}O$ record of RL4 (Zanchetta *et al.* 2016) and the "mean anomaly index" obtained for CC26 and CC27 stalagmites (Regattieri *et al.* 2014; Isola *et al.* 2019) (Fig. 2). The "mean anomaly index" was obtained combining detrended, smoothed and normalized Mg/Ca, $\delta^{18}O$, and $\delta^{13}C$ time series for CC26 and Mg, U, P, Y and stable isotope time series for CC27, assuming that all the combined variable respond sensitively to hydrological variations and particularly to changes in cave recharge (Regattieri *et al.* 2014; Isola *et al.* 2019). This statistical treatment better highlight significant changes and is considered a more robust paleo-hydrological indicator than a single proxy for this deep cave (Regattieri *et al.* 2014; Isola *et al.* 2019). For RL4 instead only $\delta^{18}O$ is plotted. This proxy is considered, at first approximation, a good indicator for hydrological change in a shallow cave (Drysdale *et al.* 2006). The essential structure of the RL4 $\delta^{18}O$, is captured also by the $\delta^{13}C$ and Mg/Ca ratio time series although the latter were investigated at lower resolution (Drysdale *et al.* 2006). Therefore, for both caves, the investigated proxies can be considered as general indicator of cave recharge, related to the effective infiltration in the catchment and representing a relatively accurate proxies of amount of rainfall (in particular those falling in the aquifer recharge season that for this area can be considered winter), even if smoothed by different effect (Bini *et al.* 2019). Observing fig. 2, two main periods of drier conditions (*i.e.,* reduction in cave recharge) can be inferred (within age uncertainities related to both models). One centred at ca. 4.2 cal yr BP (*ca.* 3.8 to 4.4 cal yr B) and one centred at *ca*. 3.0

cal yr BP (ca. 2.8-3.2 cal yr BP). Basing on CC26 $\delta^{18}O$ record only, Zanchetta *et al.* (2014) suggested the existence of contemporaneous short drier phases in Central and Eastern Mediterranean at ca. 5.2 cal ka BP and at 5.6 cal ka BP (Fig. 3). These two events apper not completely replicated in the records of Fig. 2, which uses a major number of proxies, with only weak evidences for the 5.2 event in RL4 and CC27. It is interesting to note (Fig. 3) that the $\delta^{18}O$ drier climatic interval shows a correlation with increased westerlies strength in North Atlantic as reconstructed, for instance, at Hólmsá loess profile in Iceland (Jackson *et al.* 2005). Two phases of increasing grain size at Hólmsá (Fig. 3) indicating elevated wind strength occurred precisely at 5.2 and 5.6 ka, which are consistent with increasing zonal westerly flows and reduction of vapour advection in the Mediterranean. This suggests that these drier events correspond to periods resembling positive NAO phases. During positive NAO phases, a reduction in winter precipitation is expected over the Central Mediterranean (López-Moreno *et al.* 2011). However, the existence of these two climatic oscillations, as shown in fig. 2, is still elusive and needs to be investigated in more detail in the next future.

The interval showing the largest and pronounced evidence of drier condition over the Apuan Alps is the period comprised between ca. 4.4 to 3.8 ka BP. This event found extremely well documented evidences all over the Mediterranean region (Bini *et al.* 2019), and it has been suggested to be an event occurring at global scale (the so-called 4.2 cal ka BP event, Weiss 2016) causing severe impact on ancient civilizations (*e.g.*, Weiss 2016). However, timing, progression and structure of this event is not yet completely resolved (Bini *et al.* 2019). The correlation with the reconstructed NAO index (Fig. 4; *i.e.*, Olsen *et al.* 2012), seems to indicate that this event occurred within a frame of generally positive NAO. This again is consistent with reduction in winter precipitation as effect of reduced transport of vapour masses from Atlantic and reduced cyclogenesis in the Gulf of Genoa (Isola *et al.* 2019). However, according to Olsen *et al.* (2012) this interval is a part of a longer period of almost positive NAO index and between 3.8 and 4.4 ka the reconstructed record does not show a particularly prominent positive phase. In addition is important to note that not all the variations in the NAO have a clear expression in the Apuan Alps proxy records. However, a drier phase associated to positive NAO conditions is also consistent with data produced for the Medieval Climate Anomaly in other sectors of the Mediterranean (Trouet *et al.* 2009). This may suggest that a persistent positive NAO is a precondition for a climate characterised by hydrological deficit over central Mediterranean. Noteworthy, observation data shows that in the last decades the NAO index moved from prevailing negative towards prevailing positive mode (Hurrell 1995; Visbeck *et al.* 2001), which can herald, according to paleoproxy, a long period of reduced precipitation in the Mediterranean. Paleoproxy of the Apuan Alps indicate that similar condition may last potentially for centuries and representing an important warning related to possible concerns to future hydrological budget in the region.

The second event seems to last between *ca.* 2.8 to 3.2 cal yr BP. This event is recognizable with different expression in the three records suggesting few centuries of precipitation decrease. The chronology of this event is however, not always consistent. However, there are several evidences that this event is widespread over the Mediterranean (Finné *et al.* 2019; Kaniewski *et al.* 2010), North Europe and has been suggested to be global in extent (Beer and van Geel 2008). In the Eastern Mediterranean and the Levant it is associated to evident societal changes (*e.g.*, Kaniewski *et al.* 2010) and in Northern Italy this climatic deterioration is invoked as the potential responsible of the end of the Terramare culture (Cremaschi *et al.* 2016).

The period of reconstructed reduced precipitation not precisely correspond to a period of positive NAO conditions (Fig. 4). This correlation probably needs to be explored in more details in future researches. However, this may challenge the idea that persistent condition of a positive NAO mode is a dominant controlling factor in the predisposing the developing of drier condition. Proxy records for NAO conditions are not perfect and different reconstruction shows some but significant differences, also related to differences in age models (*e.g.*, Baker *et al.* 2015). It is also possible that the present regional distribution of rainfall in relation to NAO condition is not completely representative of past distribution and different configuration would possible (Roberts *et al.* 2012; Zanchetta *et al.* 2014).

CONCLUDING REMARKS. – Past drier periods reconstructed over Apuan Alps during the last 6000 yr using speleothem proxy records seem to indicate that long drier periods are favoured during positive NAO phases when westerlies are more zonal and less vapour is advected toward the Mediterranean. The tendency of prevailing positive NAO condition observed over the last decades is then potentially predisposing to progressive drying possibly exacerbated by the increase of greenhouse gases concentration in the atmospehere. However, the comparison with different paleoproxy is not always clear and other conditions in the general circulation can be predisposing aridity, a point, which needs to be investigated in a better details in the near future to understand the hidden climatic mechanism.

ACKNOWLEDGMENTS. – The authors are indebted to the Federazione Speleologica Toscana for the logistical and economical support during the last years. This work is part of Australian Research Council Discovery Projects grant DP110102185 and the ARCA project "Arctic: present climatic change and past extreme events" founded by MIUR and the project "Clima ed eventi alluvionali estremi in Versilia: integrazione di nuove tecniche geoarcheologiche, geomorfologiche, geochimiche e simulazioni numeriche", funded by "Fondazione Cassa di Risparmio di Lucca".

REFERENCES

Baker A., Hellstrom J.C., Kelly B.F.J. *et al.* (2015). A composite annual-resolution stalagmite record of North Atlantic climate over the last three Millennia. Scientific Reports 5: 10307, doi: 10.1038/srep10307.

Beer J., van Geel B. (2008). Holocene climate change and the evidence for solar and other forcings. In: Battarbee R.W., Binney H.A. (eds) Natural Climate Variability and Global Warming: A Holocene Perspective. Chichester: Wiley-Blackwell, pp. 138-162.

Bini M., Zanchetta G., Perşoiu A. *et al.* (2019). The 4.2 ka BP Event in the Mediterranean Region: an overview. Climate of the Past 15: 555-577.

Bradley R.S. (2000). Past global changes and their significance for the future. Quaternary Science Reviews 19: 391-402.

Bradley R.S., Hughes M.K., Diaz H.F. (2003). Climate in Medieval Time. Science 302: 404-405.

Cremaschi M., Mercuri M.A., Torri P. *et al.* (2016). Climate change *versus* land management in the Po Plain (Northern Italy) during the Bronze Age: New insights from the VP/VG sequence of the Terramara Santa Rosa di Poviglio. Quaternary Science Reviews 136: 153-172.

Drysdale R.N., Zanchetta G., Hellstrom J. *et al.* (2006). Late Holocene drought responsible for the collapse of Old World civilizations is recorded in an Italian cave flowstone. Geology 34: 101-104.

Finné M., Woodbridge J., Labuhn I. *et al.* (2019). Holocene hydro-climatic variability in the Mediterranean: a synthetic multi-proxy reconstruction. The Holocene 29: 847-863.

Fiorillo F., Petitta M., Preziosi E. *et al.* (2015). Long-term trend and fluctuations of karst spring discharge in a Mediterranean area (Central-Southern Italy). Environmental Earth Science 74: 153-172.

Giorgi F. (2006). Climate hot Spot. Geophysical Research Letters 33: L08707.

Hurrell J.W. (1995). Decadal Trends in the North Atlantic Oscillation: Regional Temperatures and Precipitation. Science 269: 676-679.

IPCC (2013). Annex I: Atlas of Global and Regional Climate Projections (van Oldenborgh G.J., Collins M., Arblaster J. *et al.* (Eds)]. In: Climate Change 2013: The Physical Science Basis. Contribution of WG I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Isola I., Zanchetta G., Drysdale R.N. *et al.* (2019). The 4.2 ka event in the central Mediterranean: new data from a Corchia speleothem (Apuan Alps, Central Italy). Climate of the Past 15: 135-151.

Kaniewski D., Paulissen E., Van Campo E. *et al.* (2010). Late second-early fist millennium BC abrupt climate changes in coastal Syria and their possible significance for the history of the Eastern Mediterranean. Quaternary Research 74: 207-215.

Jackson M.G., Oskarsson N., Tronnes R.G. *et al.* (2005). Holocene loess deposition in Iceland: evidence for millennial-scale atmosphere–ocean coupling in the North Atlantic. Geology 33: 509-512.

Lionello P., Bhend J., Buzzi A. *et al.* (2006). Cyclones in the Mediterranean region: climatology and effects on the environment. In: Lionello P., Malanotte-Rizzoli P., Boscolo R. (Eds) Mediterranean Climate Variability. Elsevier, Amsterdam, pp. 272-324.

López-Moreno J.I., Vicente-Serrano S.M., Morán-Tejeda E. *et al.* (2011). Effects of the North Atlantic Oscillation (NAO) on combined temperature and precipitation winter modes in the Mediterranean mountains: Observed relationships and projections for the 21st century. Global and Planetary Change 77: 62-76.

Olsen J., Anderson N.J., Knudsen M.F. (2012). Variability of the North Atlantic Oscillation over the past 5200 years. Nature Geoscience 5: 808-812.

Piccini L., Zanchetta G., Drysdale R.N. *et al.* (2008). The environmental features of the Monte Corchia cave system (Apuan Alps, Central Italy) and their effects on speleothems growths. International Journal of Speleology 37: 153-173.

Regattieri E., Zanchetta G., Drysdale R.N. *et al.* (2014). Lateglacial to Holocene trace element record (Ba, Mg, Sr) from Corchia Cave (Apuan Alps, Central Italy): paleoenvironmental implications. Journal of Quaternary Science 29: 381-392.

Roberts N., Moreno A., Valero-Garcés B.L. *et al.* (2012). Palaeolimnological evidence for an east–west climate see-saw in the Mediterranean since AD 900. Global Planetary Change 84-85: 23-34.

Trouet V., Esper J., Graham N.E. *et al.* (2009). Persistent positive North Atlantic oscillation mode dominated the medieval climate anomaly. Science 324: 78-80.

Sadori L., Giraudi G., Masi A. *et al.* (2016). Climate, environment and society in Southern Italy during the last 2000 years. A review of the environmental, historical and archaeological evidence. Quaternary Science Reviews 136: 173-188.

Visbeck M.H., Hurrell J.W., Polvani L. *et al.* (2001). The North Atlantic Oscillation: Past, present, and future. Proceeding of the National Academy of Science 28: 12876-12877.

Weiss H. (2016). Global megadrought, societal collapse and resilience at 4.2–3.9 ka BP across the Mediterranean and west Asia. Pages 24: 62-63 doi: 10.22498/pages.24.2.62.

Zanchetta G., Bar-Matthews M., Drysdale R.N. *et al.* (2014). Coeval dry events in the Central and Eastern Mediterranean basin at 5.2 and 5.6 ka recorded in Corchia (Italy) and Soreq Cave (Israel) speleothems. Global and Planetary Change 122: 130-139.

Zanchetta G., Drysdale R.N., Hellstrom J.C. *et al.* (2007). Enhanced rainfall in the Western Mediterranean during deposition of Sapropel S1: stalagmite evidence from Corchia Cave (Central Italy). Quaternary Science Reviews 26: 279-286.

Zanchetta G., Regattieri E., Isola I. *et al.* (2016). The so-called "4.2 event" in the Central Mediterranean and its climatic teleconnections. Alpine and Mediterranean Quaternary 29: 5-17.

Zhornyak L.V., Zanchetta G., Drysdale R.N. *et al.* (2011). Stratigraphic evidence for a "pluvial phase" between ca. 8200-7100 ka from Renella Cave (Central Italy). Quaternary Science Review 30: 409-417.

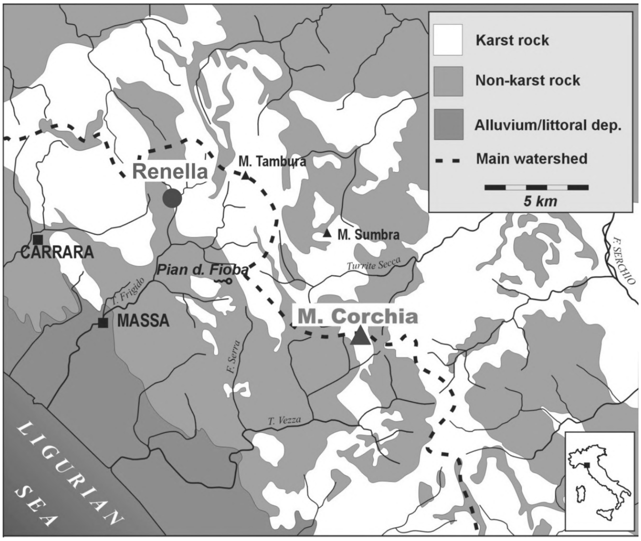


FIG. 1. Location maps of the two caves.

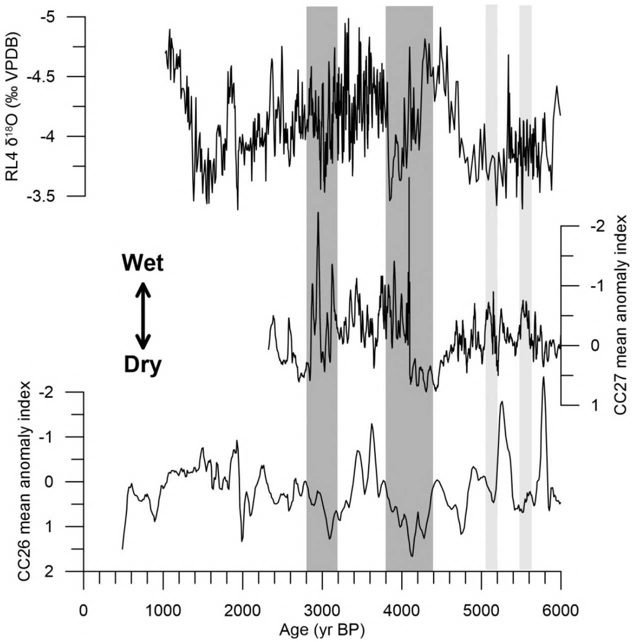


FIG. 2. Records discussed in the text. For CC26 and CC27 (Regattieri *et al.* 2014; Isola *et al.* 2019) "mean anomaly index" is reported; for RL4 only oxygen isotope composition is used (Zanchetta *et al.* 2016). Lighter shadowed intervals are the interval identified by Zanchetta *et al.* (2014) in CC26 $\delta^{18}O$ record.

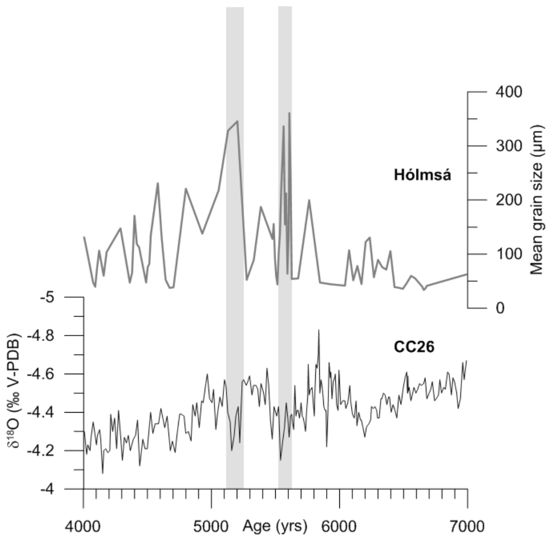


Fig. 3. Comparison between $\delta^{18}O$ records from Corchia (Zanchetta *et al.* 2007) and Hólmsá loess profile in Iceland (Jackson *et al.* 2005). Two phases of increasing grain size indicating elevated wind strength occur precisely at 5.2 and 5.6 ka, consistent with increasing zonal westerly flows and reduction of vapour advection in the Mediterranean are highlighted. Ages are reported as AD 2000.

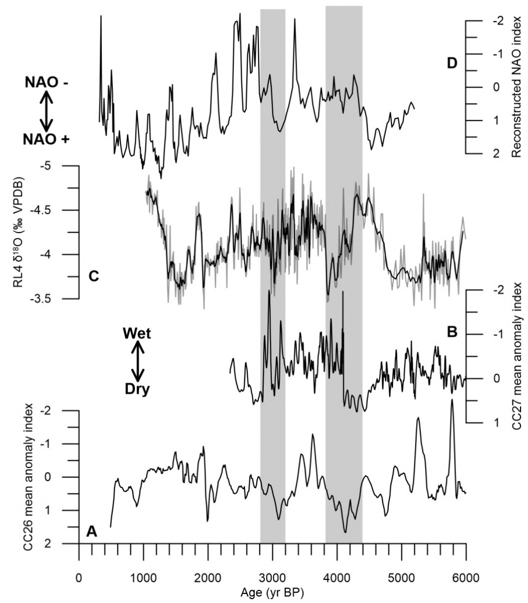


Fig. 4. Comparison between CC26, CC27 and RL4 records with NAO index reported for North Atlantic by Olsen *et al.* (2012).

SESSION 6
EFFECTS ON MARINE ENVIRONMENT

Legal aspects of the marine science on climate change

CLAUDIA CINELLI*
Law Department, University of Pisa

Keywords: international law of the sea, State jurisdiction and control, international cooperation

ABSTRACT. – Oceans and seas are key components in climate systems. The strong need for more specific knowledge and its systematic delivery and application, including in relation to climate effects on marine environment, led to the recent adoption of the the UN Decade of Ocean Science for Sustainable Development (2021-2030). From an international law of the sea perspective, the increasing marine scientific research activities and the use of novel technologies rise the question on the adequacy of the current applicable regulatory framework. This paper focuses on the main legal aspects of marine science on climate change and call for a paradigm-shift: from unilateralism to multilateralism in the interests of mankind.

INTRODUCTION. – International law and climate science have always been in complementary tension with each other, and each influences the progressive development of the other. Accordingly, the 2015 Paris Agreement states that "[a]ccelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development [art.10 (5)]". Particularly, marine science relies on the assumption that oceans and seas are constantly exposed to climate effects which challenge their ecosystems. On June 2019, the United Nations proclaimed a Decade of Ocean Science for Sustainable Development (2021-2030) to support efforts to improve scientific understanding and "adapt strategies and science-informed policy responses to global change ocean community to plan for the next ten years in ocean science and technology to deliver, together, the ocean we need for 'the future we want".

Because of oceans are a key component in climate systems, scientific research activities at sea has increased more and more in recent years. In their efforts to carry out marine climate research activities, States (and

*claudia.cinelli@unipi.it

their national scientists) have contended with several legal uncertainties. Rights and duties of States to conduct marine scientific research on climate change, including the deployment or use of any observing installations and equipment in different maritime zones, are mainly governed by the international law of the sea, codified by the 1982 UN Convention on the Law of the sea (UNCLOS).

This paper focuses on the main legal aspects of the marine science on climate change. In more general terms, the topic related to legal aspects of scientific research activities is carried out within the research agreement between the Law Department (University of Pisa) and the National Institute for Nuclear Physics - National South Lab (INFN-LNS), under the scientific direction of Prof. Simone Marinai (University of Pisa) and with the collaboration of the Interdipartimental Centre of Law and Frontier Technologies (DETECT, University of Pisa). Responsibility for any error or omission lies exclusively with the author.

MARINE SCIENTIFIC RESEARCH: OVERVIEW OF THE INTERNATIONAL LEGAL FRAMEWORK. – UNCLOS generally regulates the use of the oceans and seas and of their natural resources. UNCLOS Part XIII is specifically devoted to the regulation of marine scientific research. Variable factors determine the applicable law to such research activities, mainly depending on *who* conducts the scientific research, *where* it is conducted and *what* such activities at sea are.

As for *who* conducts scientific research at sea, actors may be mainly three: coastal State; and/or, other researching States, and/or (directly or indirectly) a competent international organization. The legal situation changes according to whether coastal State and researching State(s) have signed a research agreement or whether coastal State is a State Part to a competent international organization.

As for *where* scientific research is conducted, it is generally adopted a zonal-management approach to the regulation of scientific activities at sea. Briefly, as for internal waters, they are on the landward side of the baseline of the territorial sea (Art. 8 UNCLOS), while for the case of archipelagic States, UNCLOS provides a specific regime ruled by its Part IV; as for the territorial sea, its breadth is up to 12 nautical miles, measured from baselines (Art. 3 UNCLOS); as for the contiguous zone, if declared by the coastal State, its breadth is up to 24 nautical miles, measured from baselines (Art. 33 UNCLOS); as for the economic exclusive zone (EEZ), if declared by the coastal State, its breadth is up to 200 nautical miles, measured from baselines (Art.57 UNCLOS); as for the continental shelf (CS), its breadth is up to 200 nautical miles, measured from baselines. All parts of the sea that are not included in the EEZ, in the territorial sea or in the internal waters of a State (or in the archipelagic waters of an archipelagic State), are high seas (Art. 86 UNCLOS), while the Area is the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction (Art. 1 and Part XI UNCLOS).

As for *what* research activities at sea are, applicable law mainly depends on whether they are considered as marine scientific research or non-marine scientific research. Different regulations are indeed provided for activities carried out at sea that have as their scientific object the marine environment (*i.e.*, marine scientific research), from those that have the same scientific object (marine environment) but are not carried at sea, such as through remote satellites systems. Applicable law is different also for activities carried out at sea, but that have as their scientific object, for example, the astronomical observation (and not the marine environment).

Research activities on climate change effects on the marine environment may be included in the concept of marine scientific research. Therefore, UNCLOS Parts XIII regulates the coastal State jurisdiction as well as other researching State rights and obligations in relation to such activities on climate change.

THE REGULATION OF MARINE SCIENTIFIC RESEARCH WITHIN NATIONAL JURISDICTION: COASTAL STATE CONSENT-REGIME APPLICABLE TO INTERNAL WATERS, ARCHIPELAGIC WATERS AND TERRITORIAL SEA. – Coastal State jurisdiction within its internal waters, archipelagic waters, and territorial sea is absolute. Any kind of research and survey activities must be conducted with the express consent of the coastal State and subject to any conditions it imposes. This normally implies the adoption of domestic procedures for granting licences to permit its national scientists as well as scientists of a foreign State to conduct marine scientific research on climate change within these waters in conjunction with local scientists.

Coastal State control over research and survey activities in its territorial sea is further reinforced by other rules, not included within its Part XIII. Such rules state that a passage of a foreign vessels through a territorial State is considered as a "non-innocent passage" when the foreign ship carries out research and/or survey activities without the prior authorization of the concerned coastal State. Further, in straits used for international navigation and in archipelagic sea lanes, foreign ships may not carry out any research or survey activities without the prior authorization of the States bordering straits during their transit passage or archipelagic sea lanes passage.

Coastal State consent-regime applicable to EEZ and CS. – A coastal State has a general right to regulate, authorize and conduct marine scientific research in both EEZ and CS (art. 246 UNCLOS; See also arts. 56.1 (b) (ii) and 77 UNCLOS). At the same time, UNCLOS promotes marine scientific research conducted by the scientific community in the common interests of the international community. In this sense, coastal State has a general obligation to grant its consent in "normal circumstances" for research carried out "exclusively for peaceful purposes in order to increase scientific knowledge of marine environment for the benefit of all mankind" (Art. 246 (3) UNCLOS). In relation to the consent in "normal circumstances", coastal State has a due diligence obligation not to delay or deny it unreasonably by adopting appropriate domestic rules and procedures.

Which circumstances should be considered as "normal circumstances" are not specified by the UNCLOS. According its art. 246 (5), a coastal State may, in its discretion, withhold consent for the conduct of marine scientific research in the EEZ and on the CS, in four specified cases if: a) it is of direct significance for the exploration and exploitation of natural resources, whether living or non-living; b) it involves drilling into the continental shelf, the use of explosives or the introduction of harmful substances into the marine environment; c) it involves the construction, operation or use of artificial islands, installations and structures referred to in articles 60 and 80 UNCLOS (see below); d) it contains inaccurate project information or if the researching State or competent international organization has outstanding obligations to the coastal State from a prior research project.

The request by the researching State or a competent international organization to conduct marine scientific research must be submitted to the coastal States at least six months in advance of the expected starting date of the research activities with a full description of the research project.

In turn, the conduct of the coastal State in response to requests for consent to conduct scientific research in its EEZ or CS is that to grant, in normal circumstances, its consent (expressly or implicitly; art. 252 UNCLOS) for marine scientific research projects by other States or competent international organizations to be carried out in accordance with the Convention (art. 246 (3) UNCLOS).

If a coastal State is a member of or has a bilateral agreement with a competent international organization, which intends to undertake, directly or under its auspices, a research project in that State's EEZ or CS, the coastal State is presumed to have granted its consent for the project to be executed if it approved the project at the time the international organization took the decision to undertake the project and it has not expressed any objection within four months of the notification of the project to it by the organization. This provision is especially relevant for research projects which require access to the maritime areas of several coastal States.

Once costal State grants consent to marine scientific research, the authorization is not on a *carte-blanche* basis. When undertaking marine scientific research in the EEZ or CS of a coastal State, researching States and competent international organizations are subject to a series of obligations (art. 249 UNCLOS). In particular, they are required, *inter alia*, to ensure the right of the coastal State to participate in or be represented in the project, especially on board research vessels and other craft or scientific research installations, when practicable, without payment of any remuneration to the scientists of the coastal State and without obligation to contribute towards the costs of the project. Suspension or cessation of marine scientific research activities may be required by the coastal State if research activities are not being conducted in accordance with the information communicated (*i.e.*, suspension). On the other hand, cessation can be envisaged mainly in two cases: firstly if, after a suspension, the situations are not rectified within a reasonable period of time; or, secondly, if non-compliance with the provisions amounts to a major change in the research project (art. 253 UNCLOS).

Following completion of the research, the researching State has a few obligations, including providing the coastal State, at its request, with the preliminary reports and final results and conclusions; access to all data and samples derived, including assistance in their assessment and interpretation. Furthermore, researching State should make internationally available the research results. Finally, after the research is completed, scientific research installations or equipment should be removed, unless otherwise agreed.

With respect to the removal of offshore installations or structures, UNCLOS underlines that any installation that has been abandoned or disused shall be removed to ensure safety of navigation, while having, at the same time, due regard to fishing, the protection of the marine environment and the rights and duties of other States. In addition, appropriate publicity shall be given to the depth, position and dimensions of any installations or structures not entirely removed. Specifically, the International Maritime Organization (IMO) Assembly Resolution on *Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone* defines the standards to be followed by the coastal State when making decisions regarding the removal of abandoned or disused installations and structure.

REGULATION OF MARINE SCIENTIFIC RESEARCH IN INTERNATIONAL MARITIME SPACES: HIGH SEAS AND THE AREA. – UNCLOS ensures that not only coastal States, but also landlocked and other geographically disadvantaged States, have the right to conduct marine scientific research in the high seas, including on the water column beyond national jurisdiction. This refers to a water column beyond EEZ, if a State established it; or beyond territorial sea, if a State, like Italy, decided to not establish any EEZ, leaving (almost) all superjacent waters above the continental shelf as high seas. Freedoms of high seas include the freedom of scientific research pursuant to art. 87 UNCLOS, which is not limited to marine scientific research but also extends to all kind of research and survey activities. While the freedom of scientific research is to be exercised with due regard for the interests of other States in their exercise of the freedoms of the high seas, and also with due regard for the rights related to activities in the Area, marine scientific research at high seas is subject to more specific requirements related to the promotion of international cooperation, the creation of favorable conditions and publication and dissemination of information and knowledge (arts. 242-244 UNCLOS). Beyond the national continental shelf, the UNCLOS provides for a specific regime (*i.e.*, the common heritage mankind-regime) applicable to the International Seabed Area, *i.e.*, the Area.

The legal content of the principle of the common heritage of mankind only applies to administering the resources of the Area (UNCLOS Part XI). It involves a specific mechanism regime governed by an international organization (the International Seabed Authority, ISA) entitled to act on behalf of mankind in the exercise of rights over the resources. All States have the right to conduct marine scientific research in the Area, in conformity with Part XI and exclusively for peaceful purposes and for the benefit of mankind. The ISA has indeed been established to organize and control activities of exploration for, and exploitation of, the mineral resources of the Area. In relation to such activities, the ISA has a general responsibility to promote and encourage the conduct of research relating to the Area and its mineral resources, and to coordinate and to disseminate the results of such research and analysis, when available, with particular emphasis on research related to the environmental impact of activities in the Area (art. 142 UNCLOS). As for non-minerals, marine scientific research seems to be largely left to self-regulation. Limits are related to the requirements in high seas, *i.e.*, those related to the promotion of international cooperation, the creation of favorable conditions and publication and dissemination of information and knowledge.

THE DEPLOYMENT AND USE OF INSTALLATIONS AND/OR EQUIPMENT: THE ARGO FLOATS ON CLIMATE CHANGE. – Rights and obligations and related conditions ruled by UNCLOS for the conduct of marine scientific research in any maritime areas apply also to the deployment and use of installations and equipment for such research in the area concerned (art. 258 UNCLOS). It is also specified that research installations and equipment do not possess the status of islands, and thus they have no territorial sea and their presence does not affect the delimitation of any maritime zones (art. 259 UNCLOS). As specified above, coastal States may withhold consent regarding the use of installation and equipment that are of direct significance for the exploration and exploitation of natural resources, whether living or non-living, or the construction, operation or use of artificial islands, installations and structures referred to in articles 60 and 80 UNCLOS.

Current legal questions are related to the use of floating objects, vehicles or other devices for marine scientific research on which it is difficult to maintain complete control as they may be carried by currents some distance from their place of deployment, into areas under foreign State's jurisdiction. It might be considered as an internationally wrongful act due to the research consent-regime of the coastal State, including in terms of providing accurate information at least six months in advance (art. 248 UNCLOS).

Further related questions that arise are on State jurisdiction over floating objects. The position in the territorial sea (absolute jurisdiction of the coastal State) and in high seas (absolute jurisdiction of deploying, flag State) is quite clear. The matter is not resolved in the EZZ and CS. The placement of research infrastructure on (or connected to) the seabed is covered by arts. 60 and 80 UNCLOS, which give coastal State exclusive jurisdiction over the construction and use of the installation and structures. For floats and gliders (*i.e.*, pre-programmed autonomous submersible vehicles for data collection), there are no specific rules in Part XIII. It could be understood that coastal States would have jurisdiction in a sense of an overall control over researching States' conduct during marine scientific research. Indeed, they have the duty to comply with certain conditions, including requiring prior agreement for making internationally available the research results of a project of direct significance for the exploration and exploitation of natural resources.

Instruments and equipment deployed at sea for marine scientific research face the urgent need to be protected from accidental damage, vandalism and/or loss.

This is particularly relevant for floating high-tech equipment as well as moored oceanographic instruments in water columns beyond national jurisdiction. Despite the existence of specific international rules, it is easily deducible that the cooperation of all States is essential for appropriate arrangements being put in place for receiving reports, communicating them without delay to all relevant authorities and alerting neighbouring States and ships in the area to incidents or threats of incidents.

Recently in relation to a pilot project of global ocean and climate observation systems, the ARGO Project, promoted mainly by the Intergovernmental Oceanographic Commission of UNESCO (IOC) and the World Meteorological Organization, in which over 30 countries from the various continents and the European Union participate. To date, the ARGO project has deployed over 4000 floating devices as measuring points for temperature and salinity, from the sea surface to a depth of 2000 m.

Despite the scientific enthusiasm, the legal status of these floats and the regulation of their use remains to be clarified. As observed, such devices are, first and foremost, interdisciplinary scientific research equipment, marine and non-marine, including the possible dual-use civil and military; and, secondly, the geographical variable is likely to be modified since the they are free to move, depending on the currents, from high seas to EEZs of coastal States, which do not participate in the ARGO project and which do not have expressed their authorization to conduct such research activities on climate change in their own EEZs.

Some attempted solutions have been found in practice. With the aim of creating the conditions favorable to the conduct of scientific research, the IOC adopted Resolution XX-6 in which it establishes that the coastal States concerned must be previously informed, through appropriate channels, of all the devices that could go adrift in waters under their jurisdiction, indicating the exact location of the same.

This example shows how, in accordance with UNCLOS regulatory framework, it is possible to boost international cooperation in scientific matters through a competent international organization, to achieve a balance between the exercise of freedom of scientific research and control over that. Otherwise, through the adoption of unilateral acts, it would probably have resulted in diplomatic tensions at the expense of scientific progress.

CONCLUSION. – Law of the sea in respect to legal actions on climate effects on marine environment rests on the tension between the freedom of research of all States and the protection of interests of coastal States. On one hand, freedom is a prerequisite to developing scientific research; on the other hand, scientific research may raise sensitivities associated with economic, social and security interests of coastal States. How to reconcile the freedom of scientific research with the safeguarding of the interests of coastal State is the legal question.

Multilateralism seems to be the best solution, which grants the achievement of balanced interests, while "[s]trengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making [Preamble, Paris Agreement]".

Taking up the slogan of the UN Decade of Ocean Science for Sustainable Development, "the marine science we need for the 'future we want', international law of the sea should be applied in order to ensure an appropriate regulatory framework based on international cooperation on climate research activities at sea.

A paradigm-shift is necessary. Today, UNCLOS Part III implementation is characterized by unilateral acts within a decentralized legal order. But climate change cannot be addressed unilaterally. Therefore, the shift brought about multilateralism, *i.e.*, scientific cooperation in respect of the sovereignty and jurisdiction of the coastal States of a given sea or ocean, and of the reciprocity of the advantages deriving from the scientific climate results, without precluding the protection, realization and respect of the general interest of humanity.

REFERENCES

G. Andreone, G. Cataldi (2014). *Sui generis* zones. In: D. Attard, M. Fitzmaurice and N.A. Martínez (Eds), *IMLI Manual on International Maritime Law Vol. I, Law of the Sea*, Oxford University Press, Oxford, 217-238.

G. Andreone (2011). Immigrazione clandestina, zona contigua e Cassazione italiana: il mistero si infittisce. *Diritti Umani e Diritto Internazionale* 5: 183-188.

G. Arangio-Ruiz (1989). The Italian Continental Shelf Delimitation Agreements and the General Law on Shelf Delimitation. *Rivista di Studi Politici Internazionali* 56: 245-265.

J. Barret, R. Barnes (2016). *Law of the Sea: UNCLOS as Living Treaty*. British Institute of International and Comparative Law, London.

K. Bork J., Karstensen, M.Visbeck *et al.* (2008). The Legal Regulation of Floats and Gliders-In Quest of a New Regime? *Ocean Development and International Law* 39: 298-328.

C. Buggenhoudt (2017). *Common Interests in International Litigation: A case study on natural resource exploitation disputes*. Intersentia, Cambridge.

F. Caffio (2015). Gli spazi marittimi del Mediterraneo tra unilateralismi e intese di delimitazione. *Rivista di Studi Politici Internazionali* 82: 545-558.

L. Caflisch, J. Piccard (1978). The legal regime of marine scientific research and the Third United Nations Conference on the Law of the Sea. *Zeitschrift fur Auslandisches Offentliches Recht und Volkerrecht* 38: 848-901.

R. Casado Raigón (2016). La investigación cienitifíca en los espacios reconocidos por el derecho internacional. *Revista Española de Derecho Internacional* 68: 183-206.

C. Esposito, J. Kraska *et al.* (Eds.) (2017). *Ocean and Policy: 20 years under UNCLOS.* Brill/Nijhoff, Leiden.

D. Freestone (Ed.) (2013). *The 1982 Law of the Sea Convention at 30: Successes, Challenges and New Agendas*. Brill, The Hague.

M. Hubert (2017). Marine scientific research and the protection of the oceans and seas. In: R. Rayfuse (Ed.), *Research handbook on International marine environmental law*. Edward Elgar Publ., Cheltenham, 313-336.

J.A. Knauss (1973). Development of the freedom of scientific research issue of the third law of the sea conference. *Ocean Development and International Law* 1: 93-120.

M. Kotzur, N. Matz-Lück, A. Proelss *et al.* (Eds) (2018). *Sustainable Ocean Resource Governance: Deepsea Mining, Marine Energy and Submarine Cables*. Brill/Nijhoff, Leiden.

V.J. Juste Ruiz, J.M. Sánchez Patrón (2014). *Derecho del mar y sostenibilidad ambiental en el Mediterráneo.* Tirant lo Blanch, Valencia, 575 pp.

U. Leanza, L. Sico (1988). The Mediterranean Continental Shelf: Delimitation and Legal Regime. Oceana Publications, Dobbs Ferry NY, 4 volumes.

A. de Marffy (1999). Marine scientific research. In: R.-J. Dupuy and D. Vignes (Eds), *A Handbook on the New Law of the Sea*, vol. 2, Springer, Dordrecht, 1127-1146.

E. Milano, I. Papanicolopulu (2011). State responsibility in disputed areas on land and at sea. Zeitschrift für Ausländisches Öffentliches Recht und Völkerrech 71: 587-640.

Ministero dello Sviluppo Economico. Dipartimento per l'Energia. Direzione Generale per le Risorse Minerarie ed Energetiche (2013). *Il Mare - Supplementi al bollettino ufficiale degli idrocarburi e delle georisorse.*

A. Morrison-Saunders (2018). *Advanced Introduction to Environmental Impact Assessment,* Edward Eldgar Publ., Cheltenham.

M.H. Nordquist, J. Norton Moore, R. Long (Eds) (2018). *Legal Order in the World's Oceans: UN Convention on the Law of the Sea*. Brill/Nijhoff, Leiden.

A.G. Oude Elferink (2013). Artificial Islands, Installations and Structures. Max Planck Encyclopedia of Public International Law. Oxford University Press, Oxford.

A.G. Oude Elferink, T. Henriksen and S.V. Busch (Eds) (2018), *Maritime Boundary Delimitation: The Case Law. Is it Consistent and Predictable?* Cambridge University Press, Cambridge.

I. Papanicolopulu (2015). Mediterranean Sea. In: D.R. Rothwell, A.G. Oude Elferink, K.N. Scott and T. Stephens (Eds), *The Oxford Handbook of the Law of the Sea*, . Oxford University Press, Oxford, 604-625.

R. Rayfuse (2015). *Research Handbook on International Marine Environmental Law*. Edward Elgar Publ., Cheltenham.

N. Ronzitti (2019). *Introduzione al diritto internazionale*. Giappichelli, Torino.

A.H.A. Soons (1982). *Marine scientific research and the law of the sea*. Martinus Nijhoff, Leide, 219 pp.

T. Stephens and D.R. Rothwell (1995). Marine Scientific Research. In: D.R. Rothwell, A.G. Oude Elferink and K.N. Scott, *The Oxford Handbook of the Law of the Sea*, 559-581.

Y. Tanaka (2018). *The I International Law of the Sea*. Cambridge University Press, Cambridge.

T. Treves (1989). *Il Diritto del mare e l'Italia*. Giuffrè, Milano.

T. Treves (2008). Marine Scientific Research. *Max Planck Encyclopedia of Public International Law.* Oxford University Press, Oxford.

H.N. Scheiber (2015). *Science, Technology, and New Challenges to Ocean Law*. Brill Nijhoff, Leiden.

T. Scovazzi (2012). The governance of the Mediterranean Sea. In: J.F.C. DiMento and A.J. Hickman (Eds), *Environmental governance of the great seas. Law and effect.* Edward Elgar Publ., Cheltenham.

T. Scovazzi, G. Francalanci (1990). A partial *de facto* delimitation of the continental shelf between Italy and Malta? In: Grundy-Warr (ed.), *International Boundaries and Boundary Conflict Resolution: 1989 IBRU Conference Proceedings.*

R. Veal, M. Tsimplis, A. Serdy (2019). The Legal Status and Operation of Unmanned Maritime Vehicles. Ocean Development and International Law 50: 23-48.

F.H.T. Wegelein (2005). *Marine scientific research. The operation and status of research vessels and other platforms in international law*. Martinus Nijhoff, Leiden.

Sea level rise scenarios in a changing climate. Learning from the past to predict the future

MATTEO VACCHI*, MARTA PAPPALARDO
Dipartimento di Scienze della Terra, Università di Pisa, Via Santa Maria, 53 - 56126 Pisa

Keywords: coasts, Holocene, coastal geology, climate change

ABSTRACT. – Geological investigations of Holocene (last 12 ka) sea-level stands represent a crucial contribution to quantify any possible post-industrial (*i.e.*, last 150 years) acceleration in sea-level rise and provide new constrains into the effects of on-going global change on the coastal areas. In particular, definition of both the pattern and the magnitude of the land vertical motions is controlled by the isostatic adjustment along the global coastlines. We present here the results of a number of recent studies that were carried out along the coast of north and south America and of the Mediterranean Sea. These data allowed quantifying the recent acceleration in sea-level rise and to define future scenarios of coastal inundation along the global coastlines.

INTRODUCTION. – Understanding climate change is one of the most challenging scientific issues of the 21st century. Climate change is foreseen to have impacts on a plethora of assets, from human health, to economics and natural systems. Since 1901, Global Mean Sea Level (GMSL) has risen by ~18 cm, largely in response to global warming. Coastal zones are thus exposed to a range of hazards related to sea-level rise such as erosion, coastal inundation, habitat loss and ecosystem damage. Furthermore, flooding of coastal areas may lead to degradation of coastal wetlands and contamination of underground water. The Intergovernmental Panel on Climate Change (IPCC) predicted a likely increase in GMSL of 28-98 cm by 2100 compared to the GMSL observed between 1986 and 2005. However, such global projections do not reflect the expected spatial variability of regional sea-level change that will range from sea-level fall to a rise much greater than GMSL because of a range of physical processes.

Sea level changes are driven by different processes that cause changes in the volume or mass of the world oceans and result in globally

*Corresponding author: matteo.vacchi@unipi.it

uniform mean sea level variations. These changes, called eustatic, are independent from local factors (such as tectonics or subsidence) and are, by definition, global (Rovere *et al.* 2016). Land uplift or subsidence can result in, respectively, a fall or rise in sea level that cannot be considered eustatic as the volume or mass of water does not change.

Any sea level change that is observed with respect to a land-based reference frame is defined a Relative Sea-Level (RSL) change. RSL changes are driven by the net effect of eustatic, isostatic (glacio- and hydro-), ocean dynamic, tectonic, and local (*e.g.*, subsidence triggered by sediment consolidation) factors that act over a variety of spatial and temporal scales. Since the Last Glacial Maximum (LGM; 26 ka), RSL changes have been driven by the melting of ~50 million km^3 of land-based ice as the Earth transitioned from glacial to interglacial climatic conditions. This transfer of mass from land ice to the global ocean both increased ocean volume and triggered a large, ongoing isostatic response of the solid Earth (Khan *et al.* 2015).

SPATIAL VARIABILITY OF RELATIVE SEA-LEVEL CHANGES. – Determining the rates, mechanisms and geographic variability of relative sea-level change is then a priority science question for the next decade of ocean research (*e.g.*, Rovere *et al.* 2016). The contribution of Greenland and Antarctic ice loss to sea-level rise has increased significantly since the early 1990s, comprising ~19% of the total observed rise in GMSL between 1993 and 2010 (IPCC, 2015) and ~40% of the total observed rise in Global Mean Sea Level (GMSL) between 2003 and 2008 (Cazenave *et al.* 2009).

Our understanding of current rates of sea-level rise from tide gauge (Church & White 2006) and satellite (Cazenave *et al.* 2009) data, and of the ongoing mass loss from the major ice sheets by the Gravity Recovery and Climate Experiment (GRACE) requires correction for Glacial Isostatic Adjustment (GIA) effects that are both calibrated to, and independently tested by, observations of geological markers of past sea level stands (Kemp *et al.* 2009). In fact, geographic variability in past, present and future sea-level changes is dominated by isostatic adjustment processes (GIA, Khan *et al.* 2015). Geophysical models of the GIA process are needed to interpret past and present Relative Sea-Level records (*e.g.*, Cazenave *et al.* 2009; Church & White 2011) and provide regional predictions of sea-level rise (Kopp *et al.* 2015). Holocene RSL data provide a vital parameter to constrain GIA models, which cannot be estimated from direct measurements.

In the last decade, geological sea-level data were intensely used to reconstruct past sea-level rise rates (pre-industrial, before 1900 AD), to robustly quantifying the variability of land level changes vertical components (GIA and subsidence) and to better constraining the post-industrial sea-level rise acceleration derived from on-going instrumental methods (such as satellite altimetry, GPS or tidal gauges).

AN IMPROVED DATASET TO ASSESS THE POST-INDUSTRIAL SEA-LEVEL ACCELERATION. – Here we present the results of recent sea-level investigations that span distinct spatial and climatic regions of the globe: the Atlantic and Pacific coast of North America, Patagonia and the Western Mediterranean Sea. These studies used a wide range of past sea-level indicators from geological and archaeological investigations yielding more than 2500 sea-level data points (Engelhart *et al.* 2015; Vacchi *et al.* 2016, 2018a,b; Pappalardo *et al.* 2019). The indicators are derived mainly from salt and freshwater marshes or adjacent estuarine sediment, isolation basins, beach ridges, fixed biological indicators, beachrocks and coastal archaeological structures. The result is a comprehensive and quality-controlled analysis of sea-level histories for a large portion of American and Mediterranean coastlines which allows us to compare and contrast data from different geomorphological contexts in order to obtain basin-scale insights into the processes driving postglacial RSL changes. The data better constrains GIA spatial variability and its role in the evolution of RSL in different coastal areas.

These studies outlined some of the common difficulties and provide potential solutions to analyze sea-level data in such different climatic and depositional environments. In particular, we emphasize the problems related to the definition of standardized indicative meaning (*i.e.*, the relationship between the indicator and paleo mean sea level), to the tidal datum references and to the re-evaluation of old radiocarbon samples (Vacchi *et al.* 2018a; Pappalardo *et al.* 2019). The results of these investigation provided fresh insights into the sea-level evolution since the last glacial maximum. In those regions located below the former ice-sheet, such as the Hudson Bay coasts (Canada) and much of Atlantic Patagonia, the sea-level evolution is largely controlled by the isostatic response of the crust associated to the ice-caps melting. Sea level fall reached rates up to 35 mm/y in the mid-Holocene (*e.g.*, 8.0 to 4.0 ka ago) in the Hudson Bay (Fig. 1).

Along the western and eastern coast of north America, a significant post-industrial acceleration of sea-level rising rates is observed. This is exacerbated by GIA effect at the periphery of the former ice-sheet due to the collapse of the mantle forebulge (Engelhart *et al.* 2009, 2015).

Along the Mediterranean coasts, we observed a significant post-industrial acceleration of the sea-level rising rates. The longer tidal gauge records available in the Mediterranean (Marseille, Genoa, Venice and Trieste). indicate that sea-level is currently rising with rates ranging from 1.3 to 2.5 mm/y. These rates are at least 1 mm/y faster than those observed in the pre-industrial period (Fig. 2).

All these data, coupled with similar studies carried out in other geographic and climatic contexts allows for a global assessment of the recent acceleration in sea-level rise representing a key insight into the definition of future scenarios of coastal inundation in the changing climate.

REFERENCES

Cazenave A., Dominh K., Guinehut S. *et al.* (2009). Sea-level budget over 2003-2008: A reevaluation from GRACE space gravimetry, satellite altimetry and Argo. Global and Planetary Change 65: 83-88.

Church J.A., White N.J. (2006). Sea-level rise from the late 19th to the Early 21st Century. Surveys in Geophysics 32: 585-602.

Church J.A., White N.J., Aarup T. *et al.* (2008). Understanding global sea levels: Past, present and future. Sustainable Science 3: 9-22.

Engelhart S.E., Horton B.P., Douglas B.C. *et al.* (2009). Spatial variability of late Holocene and 20th century sea-level rise along the Atlantic coast of the United States. Geology 37: 1115-1118.

Engelhart S.E., Vacchi M., Horton B.P., Nelson A.R., Kopp B. (2015). A sea-level database for the Pacific coast of Central North America. Quaternary Science Reviews 113: 78-92.

Kemp A.C., Horton B.P., Culver S.J. *et al.* (2009). Timing and magnitude of recent accelerated sea-level rise (North Carolina, United States). Geology 37: 1035-1038.

Khan N.S., Shaw T., Ashe E. *et al.* (2015). Relative sea-level changes from near-, intermediate-, and far-field locations since the Last Glacial Maximum. Current Climate Change Reports 1: 247-262.

Kopp R.E., Horton R.M., Little C.M. *et al.* (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future 2: 383-406.

Pappalardo M., Baroni C., Bini M. *et al.* (2019). Challenges in relative sea-level change assessment highlighted through a case study: The Central coast of Atlantic Patagonia. Global and Planetary Change: 103008.

Rovere A., Stocchi P., Vacchi M. (2016). Eustatic and relative sea-level changes. Current Climate Change Reports 2: 221-231.

Vacchi M., Marriner N., Morhange C. *et al.* (2016). Multiproxy assessment of Holocene relative sea-level changes in the Western Mediterranean: sea level variability and improvements in the definition of the isostatic signal. Earth-Science Reviews 155: 172-197.

Vacchi M., Engelhart S.E., Nikitina D. *et al.* (2018a). Postglacial relative sea-level histories along the Eastern Canadian coastline. Quaternary Science Reviews 201: 124-146.

Vacchi M., Ghilardi M., Melis R.T. *et al.* (2018b). New relative sea-level insights into the isostatic history of the Western Mediterranean. Quaternary Science Reviews 201: 396-408.

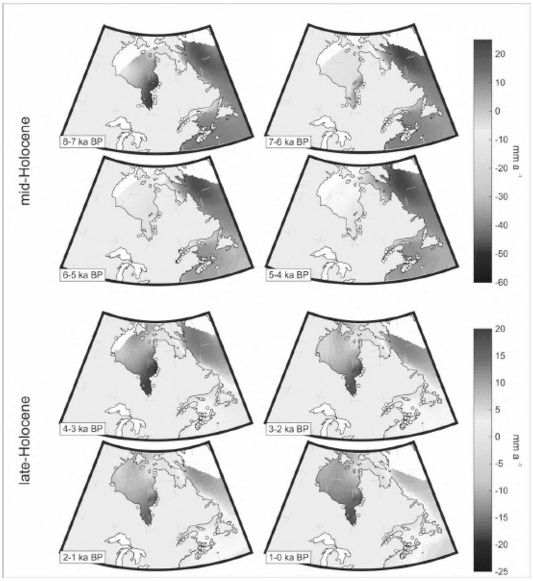


Fig. 1. Mean estimates of rates of RSL change calculated from the spatio-temporal statistical model in mid (8-4 ka BP) and late Holocene (4-0 ka BP) along the eastern Canadian coast. White dots indicate the approximate position of the geological sea-level data (modified after Vacchi *et al.* 2018).

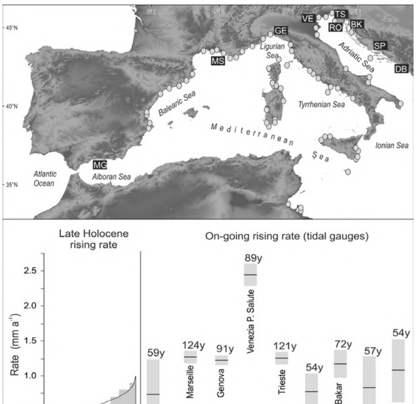


Fig. 2. Above: Approximate location of the index points plotted (red dots) and not plotted (gray dots) in panel a, see Section 6.3 for details. Below: Normal distribution of late Holocene rising rates plotted against the 20th century RSL rise (with error) derived from long-term Mediterranean tidal gauges. Number above squares denotes the number of years used to compute the trend. MG, Malaga; MS, Marseille; GE, Genova; VE, Venezia P. Salute; TR, Trieste; RO, Rovinj; BK, Bakar; SP, Split Gradska; DB, Dubrovnik (modified after Vacchi *et al.* 2016).

SESSION 7
ECONOMIC, SOCIAL AND POLITICAL ISSUES

The Anthropocene: between scientific controversy and political ambiguity

LUIGI PELLIZZONI*
Department of Political Sciences, University of Pisa, Via Serafini, 3 - 56126 Pisa

Keywords: new materialisms, post-nature, post-politics

ABSTRACT. – The paper addresses the controversy over the notion and the narrative of the Anthropocene. It is shown that the scientific diatribe on the beginning of the alleged new era interweaves with that over its social and political implications. Concerns about the post-social, post-political and post-natural ontology entailed by the notion are addressed. Overall, it is unclear whether the Anthropocene implies and expresses a strong case for a change in the relation of humans with the nonhuman world or supports an intensification of business-as-usual, yet there are indications that the latter is the option backed by ruling élites, though emergent mobilizations testify to an increasing public awareness. The issue deserves further inquiry and a constant updating.

* * *

When the chemist Paul Crutzen and the biologist Eugene Stoermer coined the term "Anthropocene" in the early 2000s, they had probably not imagined the success it would have enjoyed, and the controversies it would arouse in the following years. The notion, as we know, intends to suggest that the capacity for transformative intervention of human beings on the planetary environment has now equated that of geological forces, profoundly affecting the setting established with the end of the last glaciation, conventionally placed 11,700 years ago. But when exactly does this new era begin? And what political and social implications should be drawn? Is it correct and useful, or vice versa incorrect and misleading, to use this concept?

In a few years the notion of Anthropocene has gained momentum not only in scientific but also in political debates, ending up overlapping to a remarkable extent with the theme of climate change. Part of the dispute over it is strictly scientific. The issue is to identify the distinctive

*luigi.pellizzoni@unipi.it

features of the alleged new era; features that need to be sufficiently clear to mark a sharp distinction from the previous one, the Holocene.

The International Commission on Stratigraphy launched a research program in this regard in 2009, but this did not help to cool down the debate. What is one to look at? The change in the chemical composition of the atmosphere, in particular the levels of carbon dioxide? Traces of radioactive fallout from nuclear experiments? The presence in sediments of seeds and pollens of cultivated plants or of bones of bred animals? The clues are obviously numerous and it is not easy to find an agreement. Above all, the dating of the Anthropocene is one of the clearest examples of how scientific controversies (perhaps all the most important ones) can be intertwined with social controversies. This not only according to how Thomas Kuhn (1962) has described the progress of science, as a succession of phases of "normality" and "revolution" whose pace is also that of the scientists who confront each other on the evidence gathered, its reliability and its meaning, but also in the broader sense proposed by Ludwik Fleck (1979), for whom what seems sensible to research and the conceptual categories used to understand and communicate what is found are linked to the social and cultural context in which scientific communities operate.

Dating the Anthropocene, as it has been proposed, with the beginning of agriculture, the rise of modern industrialization or in coincidence with the technological, industrial and demographic "Great Acceleration" begun in the aftermath of World War II, or else, as also suggested (Lewis & Maslin 2019), starting in 1610, that is the year when, as a result of the decline in population due to wars and epidemics especially related to the meeting of the Old and the New world, carbon dioxide in the atmosphere fell to record lows, has in fact important implications on allocations of responsibility and indications about what can and has to be done, and by whom. If the Anthropocene begins with agriculture, then it coincides with *homo sapiens*, and therefore, in a sense, it is nobody's fault; indeed, it makes no sense to speak of guilt. If it starts with industrialization, then perhaps it is technology, along with the science that supports it and the economy that drives it, what needs to be addressed. If it is an issue begun in the middle of the last century, then the problem concerns more specifically the "Great Acceleration", the pursuit of unlimited growth as the only conceivable destiny of humanity which continues to guide the action of governments and economic elites.

In this way we are already confronted with the social and political side of the controversy; side that, as it happens more and more frequently, science feeds instead of placating, with the appeal to "facts" becoming an element of the conflict instead of a means for its composition (Pellizzoni 2012). The Anthropocene, it has been said, proposes a simultaneously "post-political", "post-social" and "post-natural" ontology (Lövbrand *et al.* 2015), provided with ambiguous implications.

Post-social: the more the Anthropocene is assigned to humanity as such, from its beginning, the less it becomes possible and sensible to try to distinguish differentiated responsibilities, impacts and tasks. As a result, the discourse of "environmental justice" (Walker 2011) – namely, the recognition of an isomorphism between resource and power inequalities and differentials in the impact of, and ability to respond to, ecological threats – fades away. In this regard, the position taken by Dipesh Chakrabarty, a historian known internationally for his contributions to post-colonial studies and therefore particularly sensitive to this issue and in general to the universalistic claims of Western humanism, has elicited a sustained debate. For Chakrabarty, the advent of the Anthropocene concerns humanity as a species that, faced with the climate crisis, is charged with a common responsibility and is subject to a shared vulnerability; which, among other things, "determines the collapse of the old humanist distinction between natural history and human history" (Chakrabarty 2009).

Post-politics: various authors, including for example the political geographer Erik Swyngedouw (2010), depict with this term a situation in which the confrontation on causes, consequences and directions to take is suffocated by a depoliticized, consensualist and technocratic vision, according to which, climate change being a universal threat, it goes beyond political disputes and entrusts expert with the decision on what to do, in the implicit assumption that the current economic and social model is out of question. In this way a strange mix of catastrophism and institutional immobility is produced.

Post-natural: here we are probably at the heart of the matter. If Anthropocene means equalization and blurring of natural and human forces, then the ontological distinction between nature and society, and all the others that it underpins and from which in turn it is nourished (matter/information, living/non-living, mind/body, natural/artefactual, order/disorder, etc.), fails. From this point of view, it should be noted that the notion and narration of the Anthropocene do not come out of the blue but constitute a result of a vast process that involved philosophy, social sciences and humanities and also the conceptual apparatus of the "hard" sciences (in particular, but not limited to, the life and computational sciences); a process that began in the 1970s to take growing momentum since the 1990s, initially aimed at challenging Cartesian objectivism and naturalism in favour of the pre-eminence of language in the constitution of reality (the so-called post-modernist current), and subsequently at questioning the last residual dualism, that is precisely the distinction between material reality and language (or information). The expression often used to gather an otherwise differentiated movement under one roof is that of "new materialisms" (Coole & Frost 2010; Pellizzoni 2016).

Like all major intellectual waves, new materialisms entertain a complex relationship, of criticism and mutual influence, with the evolution taking place at the same time in the social order, particularly in the political and economic sphere. In this sense, the coincidence between the development of new materialisms and the advent and intensification of neoliberalism cannot go unnoticed. The issue does not have a merely academic interest, as it affects the political significance of the Anthropocene. On the one hand, new materialist scholars generally draw more or less markedly "antisystem" consequences from their theorizing, in the sense of both a specific critique of neoliberal capitalism and a broader criticism of ontological dualisms, seen as the expression and justification of relations of domination (within human society and in relation to the nonhuman or, as it is now often said, "more-than-human" world). The equation, in other words, is: dualism = domination; non-dualism = emancipation; and the thesis is that the ecological crisis should induce a change of attitude towards the world, from exploitation to care (Puig de la Bellacasa 2011). On the other hand, it has to be acknowledged that traditional objectivism is far from being superseded, if not perhaps at the cutting edge of research and technological development (not only concerning the life sciences and ICTs but also, for example, chemistry and materials technology, as well as, obviously, physics). With regard to climate change, it is striking how the discourse of the Anthropocene is combined with the ontologically traditional thesis of "planetary boundaries" (Rockström *et al.* 2009), according to which it is possible to identify, in earthly geo-biological processes, thresholds whose respect can ensure a "safe operating space" for humanity; a space that, paradoxically, corresponds to the continuation of the Holocene and therefore to the very negation of the advent of the Anthropocene.

Yet, these contradictions are recomposed in a broader framework, within which they assume – deliberately or not – first of all a tactical function. One moves fluidly, in the public sphere, from a conventionally naturalist discourse like that of the planetary boundaries to a post-natural one, like the agri-food industry's claim that what they do with gene biotechnologies is nothing more than a more accurate version of what humans always did and above all nature itself does (Thacker 2006), nature being in this way integrally assimilated to technology and technology to nature. Another function of the planetary boundaries discourse is to create a temporal structure of eschatological type, the affirmed presence of a threshold of catastrophe (or regeneration, as in the transhumanist utopias) becoming the picklock thanks to which any kind of intervention on the social and non-social world is permitted – from burgeoning apparatuses of social control to impending geoengineering programs such as "solar radiation management", bound to add turbulence to an already chaotic system like the terrestrial atmosphere (Pellizzoni 2020). The very discourse of the planetary boundaries, on closer inspection, assigns to human beings a more integrated role in processes equally more "active" than in the framework of the mere reactivity that traditional naturalism assigns to matter.

All this leaves the scientific, political and social significance of the Anthropocene in ambiguity, and therefore in need of extensive research. When Crutzen states that "nature is us", or that "it's we who decide what nature is what it will be", entrusting human beings with an unprecedented task of stewardship of planetary processes (Crutzen & Schwägerl 2011), is he advocating the cause of an ethics of care or is he re-proposing, with a new vocabulary that actually strengthens it, the usual vision of human sovereignty over the world? The question is open, but there are indications that the second option is by and large prevailing. On the one hand, a stewardship role in the face of radical challenges would require equally radical responses, of which not much can be seen, not only in Crutzen but in most of the scientific and political voices involved in the debate on the Anthropocene. On the other, and above all, standpoints emerge that celebrate the end of, or the liberation from, nature and the advent of a "post-natural sustainability", according to which humans can freely decide their future on a planet where natural and human-made capital cannot be distinguished anymore, there being virtually only "cultivated capital" (Arias-Maldonado 2013). Emblematic in this sense is the controversial *Ecomodernist Manifesto* promoted by an American neoliberal think-tank, which "affirm[s] one long-standing environmental ideal, that humanity must shrink its impacts on the environment to make more room for nature, while reject[ing] another, that human societies must harmonize with nature to avoid economic and ecological collapse" (Breakthrough Institute 2015). All sorts of activities, from farming to energy extraction, must be intensified thanks to the application of increasingly powerful technologies; and this, it is argued, in order to decouple society from the biophysical world, overcoming the crisis, allowing growth to continue and to safeguard, if one so wishes, pieces of nature for aesthetic or spiritual purposes. What is most interesting, in a similar discourse, is not only and not so much that capitalism as a world order is not even touched by such radical transformations, but above all that technological intensification is equated with a decoupling from, rather than an ever closer entwining with, the biophysical world; which, combined with the residual, "optional" role attributed to it, indicates that nature is conceived as an internal differentiation within a reality technological all the way down (Pellizzoni 2020).

In conclusion, there are elements that lead to cast doubts on the concept and the narrative of the Anthropocene as a declination of climate change and what humanity is called to do in this regard supporting a real change of direction in human affairs. There are instead indications that the case for the Anthropocene may strengthen business-as-usual. That of the Breakthrough Institute can be, and most likely is, a wishful thinking bound to sink miserably in front of cataclysms hard to even imagine. However, the diffusion of this vision among political and economic élites should not be underestimated, because what will or will not be done in the next, probably decisive, years is likely to depend more on such élites than on a public opinion fragmented and distracted by allegedly more pressing political and economic urgencies. On the other hand, the spread in the public sphere of the theme of the Anthropocene and of related responsibilities indicates and elicits an increase in awareness which is certainly important and encouraging, at least in perspective, as the *Fridays for Future* mobilizations seem to indicate. The question is open and, as said, worthy of an accurate and constantly updated study; study that falls within the priorities of my current research program.

REFERENCES

Arias-Maldonado M. (2013). Rethinking sustainability in the Anthropocene. Environmental Politics 22: 428-446.

Breakthrough Institute (2015). An Ecomodernist Manifesto. *http://www.ecomodernism.org/manifesto* [Accessed 30 March 2016].

Chakrabarty D. (2009). The climate of history: four theses. Critical Inquiry 35: 197-222.

Coole D., Frost S. (2010) (Eds). New materialisms. Duke University Press, Durham.

Crutzen P., Schwagerl C. (2011). Living in the Anthropocene: toward a new global ethos, Yale Environment 360. *http://e360.yale.edu/features/living_in_the_anthropocene_toward_a_new_global_ethos* [Accessed 24 May 2018].

Fleck L. (1979 [1935]). Genesis and development of a scientific fact. University of Chicago Press, Chicago.

Kuhn T. (1962). The structure of scientific revolutions. University of Chicago Press, Chicago.

Lewis S., Maslin M. (2019). The human planet: how we created the Anthropocene, Yale University Press, New Haven.

Lövbrand E., Beck S., Chilvers J. *et al.* (2015). Who speaks for the future of Earth? How critical social science can extend the conversation on the Anthropocene. Global Environmental Change 32: 211-218.

Pellizzoni L. (2012). The politics of facts: local environmental conflicts and expertise. Environmental Politics 20: 765-785.

Pellizzoni L. (2016). Ontological Politics in a Disposable World: The New Mastery of Nature. Routledge, London.

Pellizzoni L. (2020). The environmental state between pre-emption and inoperosity. Environmental Politics 29(1).

Puig de la Bellacasa M. (2011). Matters of care in technoscience: assembling neglected things. Social Studies of Science 41: 85-106.

Rockström J., Steffen W., Noone K. *et al.* (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14: 32, *http://www.ecologyandsociety.org/vol14/iss2/art32/* [Accessed 15 January 2012].

Swyngedouw E. (2010). Apocalypse forever? Post-political populism and the spectre of climate change. Theory, Culture & Society 27: 213-232.

Thacker E. (2006). The Global Genome. MIT Press, Cambridge, MA (USA).

Walker G. (2011). Environmental justice. Routledge, London.

The provision of public goods by agri-environmental-climatic policies

FABIO BARTOLINI*, DANIELE VERGAMINI, MARIA ANDREOLI
Department of Agriculture, Food and Environment, University of Pisa

Keywords: Common Agricultural Policy, public goods, agriculture

ABSTRACT. – The provision of public goods by agriculture is perceived as one of the main reasons for maintaining the agricultural sector support. The common agricultural policy (CAP) has become the main environmental regulation in agri-food sector. The CAP is an example of policy mix characterized by the implementation of a mixture of compulsory and voluntary instruments. Despite a thirty-year application, the current provision of public goods is unsatisfactory due to policy failures. A fertile debate about CAP reform started and the European Commission proposed radical changes to the design of agri-environment and climate schemes (AECSs). This contribution aims to review inefficiencies that can hinder the achievement by CAP of the desired level of public goods. The contribution is developed within the H2020 project CONSOLE (CONtract SOLutions for Effective and lasting delivery of agri-environmental-climate public goods by EU agriculture and forestry).

INTRODUCTION. – There is growing consensus about the pivotal role of the agri-food systems in achieving sustainable development goals (SDGs), stemming from the interaction between environmental, health and social dimensions (Caron *et al.* 2019). Public regulation in this sector has been historically strategic in contributing at reaching the level of public goods as desired by society. In addition, the contribution at SDGs is perceived by EU Citizens as one of the main arguments to subsidise agricultural systems through the CAP. Therefore, in all developed economies public regulation of agriculture uses a very large share of public funds. In spite of this, many scientific contributions have shown that the current policy framework does not effectively align the provision of public goods with their socially desirable levels, especially for environmental public goods (Pe'er *et al.* 2019). The provision of environmental

*Corresponding author: fabio.bartolini@unipi.it

public goods within the CAP is a real example of a policy mix (Bartolini & Vergamini 2019), where a mixture of compulsory and voluntary instruments is applied (*i.e.*, cross-compliance, greening and agri-environmental climatic schemes). These instruments are designed in accord with two different principles ("polluters pay" principle for the first two and "providers get" principle for the latter). This green architecture of CAP is going to be deeply modified with the introduction of new principles and mechanisms for the next programming period (2020-2027). Two main novelties are going to be implemented for environmental regulation within the CAP: 1) a new delivery model, and 2) more results-oriented measures. The new delivery model is rooted in the subsidiarity principle, which argues that a decentralised design and implementation of measures should be encouraged when aiming at a higher effectiveness. Thus, the EU will identify some specific objectives and a menu of broad measures and each Member State will identify in its own "national plan" specific needs and interventions tailored to meet them. Finally, each Member State is in charge of accounting for its results by quantifying the improvement of environmental performance using a set of indicators proposed by EU. In other words, the proposal for post-2020 CAP indicates a more flexible and outcome-based approach (*i.e.*, measures that focus on payment for results achieved), giving Members States further room of manoeuvre to adopt measures tailored to local conditions and environmental priorities. This debate has pushed higher attention on the AECSs design by claiming results-based measures whose payments are assigned on the basis of environmental quality provided.

INEFFICIENCY IN AESCS (CONTRACTUAL ISSUE). – Although the impact of AECSs on sustainability is a traditional topic addressed by agricultural economics literature, its contribution on the environment quality remains a debated topic with lack of convergences. Two factors can contribute at the difficulties to compare literature findings: outcomes based on specific case-studies and application of different methodologies. Firstly, the great majority of papers are built on case-studies that apply different proxies of environmental quality changes, while few studies use composite and overall indicators. Secondly, the existing works apply heterogeneous methodologies with a plethora of alternative assumptions and restrictions. The methods differ by used data, by measurement proxies of environmental changes, by the possibility to build a counterfactual and by complexity in creating policy scenarios and finally by interpretation of causality (D'Alberto *et al.* 2019). Altogether, academic literature highlights several causes and barriers that can reduce the expected benefit of the AECSs. These motivations can encompass both a policy failure (in each step of policy cycle) in private motivation and an opportunist behaviour as well as an asymmetric information (Figure 1 describes both the farm system and the policy system).

Two conditions deeply affect the inefficiency of AECS contracts, *i.e.*, the type of payment, which in accord with World Trade Organization (WTO) green box should be merely compensative, and the voluntariness of the proposed mechanism. This implies for example that a decision-maker can design two types of measures based on the relation between payment level and type of environmental commitment required (*i.e.*, narrow and deep measures VS broader and shallow measures). Therefore, a higher payment can determine higher environmental quality (Lefebvre *et al.* 2015).

Agricultural economics literature has detected that the following factors determine inefficiencies and policy failures: a) an interplay between targeting, policy parameters and farmers' strategic behaviour (Vergamini *et al.* 2017), and b) adoption mechanisms (Raggi *et al.* 2015). Morris and Potter (1995) identify four profiles related to participation in AECSs. Payments can affect behaviour only of two profiles while other reasons can better motivate the participation although not profitable (*i.e.*, personal attitudes and lifestyles). Such profiles reduce the potential ability of payments to affect the decision to engage in AECSs (Mills *et al.* 2017).

The second point concerns adverse selection and moral hazard due to asymmetric information. The former is likely to reduce the effectiveness of a measure when payments are fixed and when agents have private information on compliance costs. In fact, the policy-makers' lack of knowledge of participation costs can increase the probability of subsiding farmers that already implement the sustainable practices or have lower participation cost. On the other hand, as design, implementation, targeting, and monitoring are costly, and often farmers can take hidden actions. Therefore, this results in a sub-optimal and acceptable level for monitoring activities which is in a function of expected costs and benefits (Bartolini *et al.* 2012).

Solutions. – There is evidence that efficiency of agri-environmental schemes may be improved through better designed contracts. The studies on principal agent model represent a milestone in understanding the role of incentive compatible contracts for the production of environmental goods and services. They provided solutions to the problems of inefficiency and ineffectiveness caused by uniform policy incentives

(Viaggi *et al.* 2008), lack of targeting (Wätzold & Drechsler 2005), adverse selection and moral hazard (Latacz-Lohman & Schillizzi 2005; Bartolini *et al.* 2012), leading to the change in policy needs by moving towards more result-oriented policies (Schillizzi & Latacz-Lohmann 2016). Results show a co-evolution of policies and contract solutions proposed by agricultural economics studies, that start from action-based policies and instruments (such as incentive-compatible payment under the first European agri-environmental programs) to new outcome-based instruments such as tendering contracts aiming to link contract payment to environmental outcomes. *Vice versa*, results show a weak ability in understanding interaction of policy instruments with private supply chain standards.

REFERENCES

Bartolini F., Vergamini D. (2019). Understanding the Spatial Agglomeration of Participation in Agri-Environmental Schemes: The Case of the Tuscany Region. Sustainability 11: 2753.

Bartolini F., Gallerani V., Raggi M. *et al.* (2012). Modelling the Linkages between Cross-Compliance and Agri Environmental Schemes Under Asymmetric Information. Journal of Agricultural Economics 63: 310-330.

Caron P., de Loma-Osorio G.F., Nabarro D. *et al.* (2018). Food systems for sustainable development: proposals for a profound four-part transformation. Agronomy for Sustainable Development 38(4): 41 doi: 10.1007/s13593-018-0519-1.

D'Alberto R., Zavalloni M., Raggi M. *et al.* (2018). AES impact evaluation with integrated farm data: Combining statistical matching and propensity score matching. Sustainability, 10 doi:10.3390/su10114320.

Latacz-Lohmann U., Schilizzi S. (2005). Auctions for Conservation Contracts: A Review of the Theoretical and Empirical Literature. Report to the Scottish Executive Environment and Rural Affairs Department.

Lefebvre M., Espinosa M., Gomez y Paloma S. *et al.* (2015). Agricultural landscapes as multi-scale public good and the role of the Common Agricultural Policy. Journal of Environmental Planning and Management 58: 2088-2112.

Mills J., Gaskell P., Ingram J. *et al.* (2017). Engaging farmers in environmental management through a better understanding of behaviour. Agriculture and Human Values 34: 283-299.

Morris C., Potter C. (1995). Recruiting the new conservationists: Farmers' adoption of agri-environmental schemes in the U.K. Journal of Rural Studies 11: 51-63.

Pe'er G., Zinngrebe Y., Moreira F. *et al.* (2019). A greener path for the EU Common Agricultural Policy. Science 365(6452): 449-451.

Raggi M., Viaggi D., Bartolini F. *et al.* (2015). The role of policy priorities and targeting in the spatial location of participation in Agri-Environmental Schemes in Emilia-Romagna (Italy). Land Use Policy 47: 78-89.

Schillizzi S., Latacz-Lhoman U. (2016). Incentivizing and tendering conservation contracts: The trade-off between participation and effort provision. Land Economics 92: 273-291.

Vergamini D., Viaggi D., Raggi M. (2017). Integrating spatial econometric information and optimisation models to improve agri-Environmental payment design: A resource allocation model for Emilia-Romagna (Italy). Agricultural Economics Review 18(2): 40-59.

Viaggi D., Raggi M., Gallerani V. (2008). Evaluating the potential contribution of contract auctions to Agri-Environmental Policy efficiency: A simulation model for Emilia-Romagna (Italy). Agricultural Economics Review 11(2): 18-28.

Wätzold F., Drechsler M. (2005). Spatially uniform *versus* spatially heterogeneous compensation payments for biodiversity-enhancing land-use measures. Environmental & Resource Economics 31: 73-93.

Wezel A., Brives H., Casagrande M. *et al.* (2016). Agroecology territories: places for sustainable agricultural and food systems and biodiversity conservation. Agroecology and Sustainable Food Systems 40: 132-144.

White B. (2005). An Economic Analysis of Ecological Monitoring. Ecological Modelling 189: 241-50.

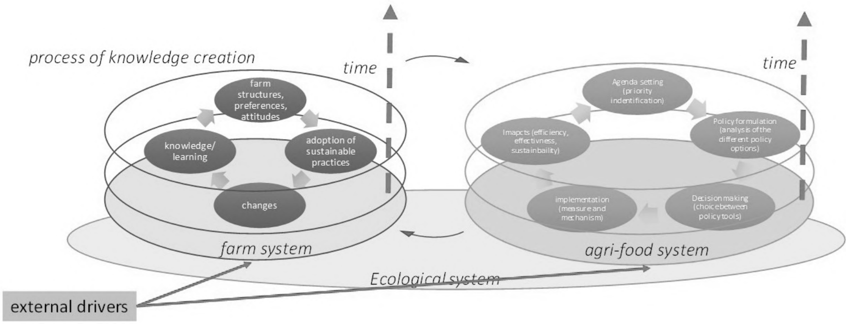


FIG. 1. Representation of farm and policy systems.

Societal transition for a sustainable economy

SIMONE D'ALESSANDRO*, ANDRÉ CIEPLINSKI, TIZIANO DISTEFANO, PIETRO GUARNIERI
Department of Economics and Management, University of Pisa, Via Cosimo Ridolfi, 10 - 56124 Pisa

Keywords: low-carbon transition, inequality, technological progress, renewable energy

ABSTRACT. – The perils from catastrophic climate events and socila instablity due to growing inequality are at the top of the international political agenda as global threats in both developed and developing countries. A wide range of policies and strategies, under the *aegis* of "green growth", have been proposed to boost renewable energy and technological progress toward a low-carbon transition. However, the effects of these measures on labor market and income inequality are often underestimated. To fill this gap, our team developed a dynamic macrosimulation model, at the country-scale (for France and Italy), to evaluate the short- and long-run aftermaths from alternative scenarios. We compare the green growth scenario with other policy-mixes that include radical social policies, such as a job guarantee plan and working time reduction. The aim is to explore the viability, effectiveness, and possible synergies and trade-offs among the current policy options to ensure a socially just and planned low-carbon transition. Our results, for both the French and Italian cases, suggest that coping environmental policies with radical social policies can achieve significant emissions reductions and improvements in social equity without compromising public balance.

BACKGROUND. – The strict connection between social inequality and environmental sustainability dates back to the Brundtland Report in the late 1980s and is now encompassed by international treaties, such as the last 24th Conference of Parties held in Poland in 2018. The proposed strategies stand on the pillar of the "green growth" argument that supports technological progress, economic growth, and increasing energy efficiency to stay below the 1.5°C temperature limit (Hulme 2016).

*Corresponding author: simone.dalessandro@unipi.it

Although social issues, such as solidarity and fairness, are encouraged, no explicit social policies are suggested to contrast inequality. A step forward, in this line of thought, is represented by the so-called "Green New Deal" (Pollin 2018), proposed by Representative Alexandria Ocasio-Cortez and Senator Ed Markey on February 7, 2019 in the US, which aims at reconciling economic growth with planetary boundaries and social needs. However, there is still debate on the validity of the presumptions behind green growth (Shor & Jorgenson 2018).

Two of the main criticisms to green growth are: questioning the feasibility of limitless growth in a limited world (Roegen 1971) and advocating the necessity to implement radical social policies to reduce inequality (O'Neill *et al.* 2018). Both of these concerns are covered in the so-called "post-growth" paradigm. This viewpoint expresses a concern that the current high unemployment rates may be structural; hence, it advances radical social policies to sustain jobs in a context of low-growth or de-growth (Kallis *et al.* 2012; Jackson & Victor, 2016).

We develop a dynamic macro-simulation model, at the country-scale, to evaluate the short- and long-run aftermaths from the implementation of alternative policy-mixes, to say the joint application of several social and energy policies. The main purpose is to provide a wide and consistent framework to answer the following research questions: What are the impacts, in terms of unemployment and inequality, of automation and energy strategies, as advocated by the green growth proponents? Are radical social interventions required to balance the adverse effects of technological progress? How to drive the system toward a socially and fiscally sustainable low-carbon transition?

In what follows we briefly summarize the main features of the model and the main insights emerging from the simulation outcomes in the French economy, although another application to Italy confirms the main findings (Cieplinki *et al*. 2019).

METHODOLOGY. – Ecological macroeconomics explicitly introduces environmental and social variables in their models to investigate the trade-off between economic growth and socio-physical constraints. Among the efforts to contribute to this task it deserves particular attention the ongoing development of the so called "Ecological Macroeconomics" (Victor 2008; Røpke 2016; Hardt-O'Neill 2017). By following this approach, we develop a macrosimulation model as represented in a schematic way by Figure 1. For the sake of simplicity, it shows only the main modules and the key relationships and systemic feedback effects. Following a non-reductionist approach (Spash 2011) we decided to define several indicators for each dimension here considered – *i.e.*, social, economic, and environmental – to highlight the inescapable presence of trade-offs and the absence of a unique best technical solution to complex problems.

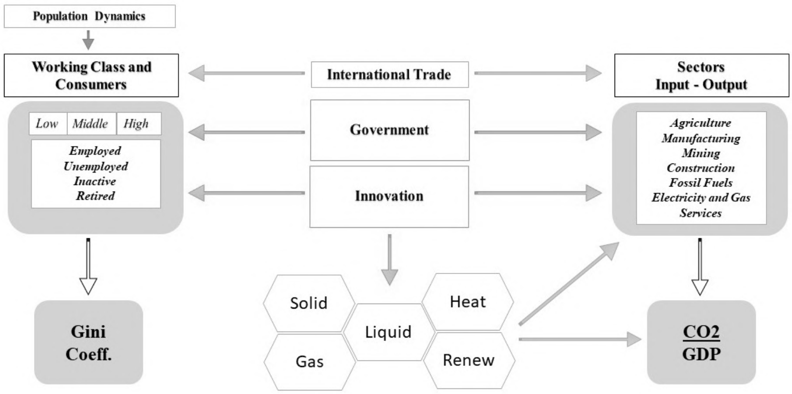


Fig. 1. Macroview. Schematic representation of the model applied for the French case, as described in D'Alessandro *et al.* (2018).

The proposed model aims at capturing the complex interconnections among the key variables that compose a macroeconomic system. It combines the *system-dynamic* modelling approach with the *input-output* architecture. The former allows to analyze the interconnections and feedbacks among socio-economic and environmental variables, while the latter provides a consistent economic framework, coherent with the official national accounts, to study inter-industry trade. Moreover, following the post-Keynesian tradition we model a demand-driven open economy with novel features.

First, we divide the households in heterogeneous groups classified according to their economic status (employed, unemployed, inactive, and retired) and educational attainment or skill (low, medium, and high). Second, we define a realistic welfare system with a detailed account of the main sources of public revenues and expenditures to ascertain the fiscal burden of alternative policy instruments over time. Third, we assess the energy flows, that arise from industry and household energy demand, produced with a mix of polluting and clean sources, to calculate greenhouse gas emissions. Forth, we develop an innovation process driven by the input-cost ratios of energy and labour. Each industry selects the cost-minimizing among new, randomly extracted, technologies. Additionally, innovations in energy efficiency affect the composition of intermediate trade in the two energy industries: fossil fuel and electricity and gas supply. An increase in energy efficiency (*i.e.*, output per unit of energy) in any industries, results in a reduction of the shares of intermediate purchases from the two energy sectors. Finally, the calibration and estimation of uncertain parameters provide a realistic representation of the economy at the national scale.

RESULTS AND REMARKS. – The current version of the model is based on the French economy, developing numerical simulations starting from the year 2014 up to the year 2050. However, an extended version of the model has been applied to study the Italian case too (see Cieplinski *et al.* 2019). We set up three alternative scenarios determined by the application of alternative energy and social policy-mix, to be compared with the Baseline (*i.e.*, the business as usual). Namely:

1. ***Green growth*** (*G.G.*): simulates a transition to a low-carbon production driven by fast technological progress, economic growth, and investments in renewable energy sources. It boosts *energy efficiency* and *automation*, promotes an expansion of electric power generation, and introduces carbon taxes on national and imported polluting products.
2. ***Policies for Social Equity*** (*P.S.E.*): this scenario considers a mix of environmental and social policies for a low-carbon transition with social justice. It adds to *G.G.* a *job guarantee* (JG) program (up to a maximum of 300,000 workers/year employed by the public sector) and *working time reduction* (WTR) (from about 35 to 30 weekly working hours).
3. ***De-growth*** (*D.G.*): this policy-mix adds to the *P.S.E.* the effects of a voluntary reduction in private consumption and exports, together with an increase of a wealth tax up to about 1.5% in average.

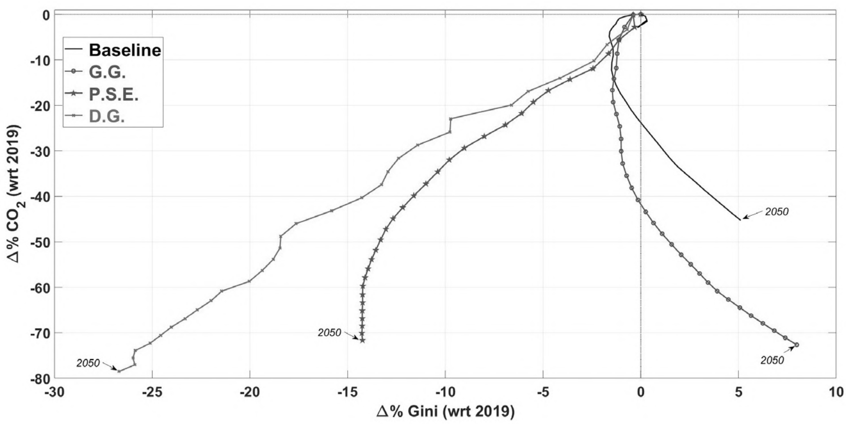


Fig. 2. Scenario comparison of the evolution of air pollution and inequality. Cumulative percentage variation, from 2014 to 2050, of air pollution in CO_2 equivalents (y-axis) and inequality in Gini-points (x-axis) with respect to the year 2019 in which the policies are introduced. Comparison of the Baseline pathway with the green growth (G.G.), policies for social equity (P.S.E.), and degrowth (D.G.) scenarios, respectively.

Figure 2 shows the cumulative percentage variation with respect to the year 2019 (in which the policies are introduced) of the two key indicators that we select to grasp the relation between environmental performance and income inequality. The GHG emissions reduction is the main index of air pollution, strictly tied with the adverse effects of climate change, while the Gini coefficient is a synthetic measure of income distribution and inequality. In general terms, a decrease (*i.e.*, negative cumulative percentage variations) in both indicators points out an improvement of both environment and social dimensions.

The market-based plan, advocated by the *G.G.,* proponents, appears to increase income concentration and unemployment rates (Table 1); these conditions might undermine the social stability necessary to sustain the low-carbon transition itself. On the contrary, under *P.S.E.* the introduction of JG and WTR, together with environmental policies, significantly reduces emissions while improving income distribution and employment. The *D.G.* policy-mix generates improvements in social equity and is the only scenario that achieves the GHG reduction goal by 2050 due to the additional implementation of bold social policies together with a wealth tax and a volountary consumption reduction.

TABLE 1. – Scenario comparison of the the long-run socio-economic impacts.				
Scenario	*GDP growth*	*Deficit/GDP*	*Labor share*	*Unemployment*
Baseline	+	-	-	+
G.G.	+	-	-	+
P.S.E.	+	+	+	-
D.G.	-	++	+	--

Table 1 summarizes the main long-run effects of the proposed policy-mix, indicating that social and environmental improvements might be obtained even in a context of low-/de-growth, suggesting that slow down economic growth does not necessarily entail catastrophic social consequences if sustained by public policies. Finally, combining energy plans with radical social policies seem rather promising to ensure a low-carbon transition in a fair societal context.

REFERENCES

Cieplinski A., D'Alessandro S., Distefano T. *et al.* (2019). *Book Chapter* in "Capitalism, Conflict, and Cooperation: A Celebration of the Work of Samuel Bowles & Herbert Gintis", *forthcoming*.

D'Alessandro S., Distefano T., Cieplinski A. *et al.* (2018). "EUROGREEN Model of Job Creation in a Post-Growth Economy." Greens|EFA Publications.

Hardt L., O'Neill D.W. (2017). Ecological macroeconomic models: Assessing current developments. Ecological Economics 134: 198-211.

Hulme M. (2016). 1.5°C and climate research after the Paris Agreement. Nature Climate Change 6: 222.

Jackson T., Victor P.A. (2016). Does slow growth lead to rising inequality? Some theoretical reflections and numerical simulations. Ecological Economics 121: 206-219.

Kallis G., Kerschner C., Martinez-Alier J. (2012). The economics of degrowth. Ecological Economics 84: 172-180.

O'Neill D.W., Fanning A.L., Lamb W.F. *et al.* (2018). A good life for all within planetary boundaries. Nature Sustainability 1: 88-95.

OECD (2011). Towards Green Growth: a summary for policy makers. OECD Publishing, Paris.

Pollin R. (2018). De-growth *vs* a Green New Deal. New Left Review 112: 5-25.

Roegen N.G. (1971). The entropy law and the economic process. Harvard University Press, Harvard.

Røpke I. (2016). Complementary system perspectives in ecological macroeconomics - the example of transition investments during the crisis. Ecological Economics 121: 237-245.

Schor J.B., Jorgenson A.K. (2019). Response to Bob Pollin. Review of Radical Political Economics 51: 333-335.

Spash Clive L. (2011). Social ecological economics: Understanding the past to see the future. American Journal of Economics and Sociology 70: 340-375.

Victor P.A. (2008). Managing without growth: slower by design, not disaster. Edward Elgar, Cheltenham.

RELATED PROJECTS

LOCOMOTION (*https://www.locomotion-h2020.eu/*). [RIA call H2020-LC-CLA-2018-2] - The project "Low-carbon society: an enhanced modelling tool for the transition to sustainability" is meant to enhance existing Integrated Assessment Models (IAMs) in order to provide policy makers and relevant stakeholders with a reliable and practical model system to assess the feasibility, effectiveness, costs and impacts of different sustainability policy options, and to identify the most effective transition pathways towards a low-carbon society.

EUROGREEN report - "A fair and sustainable post-growth economy: study and model project" funded by Greens/EFA Group in the European Parliament (*https://people.unipi.it/simone_dalessandro/wp-content/uploads/sites/78/2018/10/EUROGREEN_Project.pdf*).

Banks and climate change: "the state of the art"

PAOLA FERRETTI*
Dipartimento di Economia e Management - Università di Pisa

Keywords: sustainability, risks, authorities, lending

ABSTRACT. – At present there is a strong call for the financial sector to assume a special role in dealing with the economics of climate change, as one of the greatest challenges to face. This is also due to the several and severe impacts the climate-related natural events have on the real economy and consequently on the financial system. In this respect, it is of utmost importance that all the financial intermediaries, banks in particular, are adequately prepared to tackle such threats: banks are therefore called to address new and detrimental risks, but also to exploit business opportunities in a context of changing climate.

WHAT IS THE INVOLVEMENT OF THE FINANCIAL SYSTEM IN THE CLIMATE CHANGE ISSUES? – "Improving climate intelligence by establishing a knowledge network of people from different backgrounds and cultures [has] the ultimate goal of reaching a greater understanding of the complex interlinkages between our planet's ecosystem and today's global financial system" (Signorini 2017). This statement may be considered a starting point to understand and explain the role that the financial system (both as a whole and in relation to its components: central banks, regulators, intermediaries, etc.) has to play in achieving the long-term sustainable development in general and the climate-resilient development in particular.

In fact, despite climate-related matters for a long time have been prerogatives of environmentalists, over the most recent years many efforts have been done to align the financial system with sustainable practices and goals. Particularly, there is a strong call for the financial sector to assume a special role in dealing with the economics of climate change, as one of the greatest challenges to face. The reasons of such relevance is specifically linked to the several and severe impacts the climate-related natural events have on the real economy and consequently on the financial system. In this respect, it is of utmost importance that the financial system is adequately prepared to tackle such threats.

It is widely-known that there is the need for decisive policy actions in the face of the extreme weather events and natural disasters occurred

*paola.ferretti@unipi.it

globally in the last years; this highlights the prominence of serious risks that all the countries must face in terms of likelihood and impact of such events. Certain countries, among which Italy stands out, are particularly susceptible to climate-induced stress.

All this has contributed to the increasing involvement, both at international and national level, of the financial sector in developing, researching, implementing programs to enhance the awareness of climate-related risks and the associated need to mitigate them.

Below, we report the main steps of the global cooperation about the climate change and the contribution of the financial, international and national, community in this respect.

Following the Rio Earth Summit, at the beginning of the 1990s (exactly in 1992) the adoption of the United Nations convention on climate change gave rise to the Tokyo Protocol (1997) and the Paris Agreement (2015). With reference to the latter, in December 2015, at the Conference of the Parties 21 in Paris, 195 countries for the first time meet to forge a climate change agreement, aimed to keep the increase in global average temperature to well below 2 degrees Celsius above pre-industrial levels; to pursue efforts to limit the increase to 1.5 degrees, since this would considerably reduce risks and impacts of climate change; to ensure that the global emissions peak as soon as possible (recognizing that it takes longer for developing countries) and decline thereafter in accordance with the best available science. Therefore, the Paris Agreement sets a milestone in global climate action, as it states the above-mentioned goals and at the same time aims to enhance the ability of countries to deal with the effects of climate change.

Another important step in the evolution of the international policy measures aimed to accelerate climate actions by all actors in the global economy is given by the United Nations Sustainable Development Goals (SDGs). At the United Nations Sustainable Development Summit on 25 September 2015, more than 150 world leaders adopt the 2030 Agenda for sustainable development, including the SDGs. These are designed as a continuation of the Millennium Development Goals (adopted in 2000) representing a progress of the previous goals, as they include more ambitious objectives, seeking to eliminate rather than reduce poverty, applying to all countries and all people, finally covering issues previously neglected, among which climate change. The SDGs are 17 and the thirteen is about climate actions.

Additionally, still during 2015 (December), the Financial Stability Board established the task Force on Climate-related Financial Disclosures (TCFD) to promote a more efficient and effective transparency on climate change issues provided by companies in favour of investors, lenders, insurers and other stakeholders.

In 2016, the G20 launched the Green Finance Study Group – GFSG to promote private green investments; in 2018 it was replaced by the Sustainable Finance Study Group (SFSG) maintaining the same mandate. In December 2016, the European Commission established the High Level Expert Group on Sustainable Finance (HLEG) which published the Final Report (January 2018) representing the basis for the Action Plan for financing sustainable growth adopted by the Commission in March 2018. This Action Plan sets out an extensive strategy to connect finance and sustainability. Some of the most important key drivers of the Plan are the following: i) to establish a EU taxonomy for sustainable activities, in order to create a common language for all the actors in the financial system; ii) to establish EU labels for green financial products in order to allow investors to identify products compliant or not with green or low-carbon criteria; iii) to clarify requirements for asset managers and institutional investors regarding sustainability.

Finally, the Network of Central Banks and Supervisors for Greening the Financial System has been established (December 2017) with the goal to share experiences and best practices, promote climate risk management in the financial sector, support the transition to a sustainable economy (among others, Lautenschläger 2018).

In the global context of increasing number of measures about the climate-related matters, also at Italian level there are initiatives aimed to understand how the climate-related issues may impact on the economy and consequently on the financial system, considered as a whole and in its components. To this end the Italian Ministry of Environment, Land and Sea in 2016 established the National Dialogue on Sustainable Finance in order to promote the integration of sustainability factors across the Italian financial sector (Ministero dell’Ambiente e della Tutela del Territorio e del Mare 2016). Thereafter, at the beginning of 2018, the Ministry established the Italian Observatory on Sustainable Finance with the task of assuring the promotion, coordination and monitoring of the above mentioned integration, and at the same time encouraging the financial community to make the financial market more dynamic, innovative and attractive in terms of sustainability.

BANKS AND CLIMATE CHANGE: RISKS AGAINST OPPORTUNITIES. – The increasing interest of the international and domestic authorities in climate-related issues has led banks (more generally all the financial intermediaries) to include climate considerations into their operational and strategic decisions. It is commonly known that climate risks may be classified into the following categories:

- *Physical risks*: connected to negative effects of climate-related events on property and economic activity (*e.g.*, trade disruption).
- *Transition risks*: financial risks tied to the transition to a low-carbon economy (as one og the goals of the Paris Agreement). As for these risks, it is important to underline their potential negative impacts on the stability of the financial system considered as a whole. In fact, during the transition (especially if not well managed) to a low-carbon economy, energy prices could increase significantly due to the fact, among others, that the alternative energy sources are more expensive. On this respect, Visco (2019) states: "Since the short-term demand for energy is not very reactive to price variations due to the fixed costs associated with changing the sources and forms of supply, a possible increase in prices would heighten the financial vulnerability of firms and households owing to the higher cost of purchasing energy goods. A sharp drop in the value of assets and infrastructures linked to the mining, transformation and use of fossil fuels (coal, oil and gas) could also trigger a rush to sell the securities of the most exposed companies and may make it more difficult for them to cover their liabilities towards the banking system and the market, with consequences that could significantly affect the economic system and financial stability".
- *Liability risks*: linked to the situation in which insured parties having suffered damage seek compensation from those they hold responsible, that are insurance intermediaries (Osservatorio italiano sulla finanza sostenibile 2019).

Physical risks are particularly crucial for banks, as they represent the exposure of both the households and firms to the climate-related events (floods, landslides, etc.): the intensity of such events may damage fixed assets of firms (property, plant and equipment) and therefore reduce their capacity to repay any loan. Such events, in other words, may adversely affect the economy in different ways. They could destroy physical capital and disrupt business, imposing the need of new financial resources for their reconstitution. At the same time, such damages and disruption could reduce the value of the collateralized assets and hence dramatically affect the lending capacity of firms and households. On this respect, among others, Faiella & Natoli (2018) find that lending to non-financial firms is negatively correlated to their flood exposure, especially in the case of small and medium enterprises. A significant contribution to this end could come from the increasing insurance coverage on properties, as a mitigation tool of certain risks (Signorini 2017).

Additionally, climate shocks may increase the levels of non performing loans of those banks that are particularly exposed to firms and households located in risk areas, with possible negative consequences in terms of credit rationing and ultimately of financial instability. Batten *et al.* (2016) report those and other impacts of a climate disaster on the financial system (Figure 1). Faiella (2019) summarizes some examples of risks related to climate events, focusing on Italian banks (Table 1).

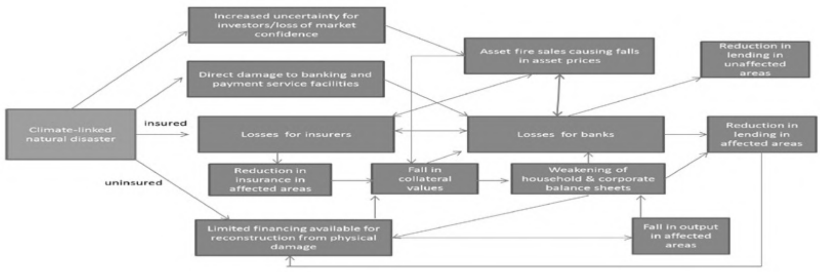


FIG. 1. Climate-related shocks and financial system (Batten *et al.* 2016).

TABLE 1. – *Climate risks (Faiella 2019).*

	Market risk	Credit risk
Physical risk	- Losses from a reduction in the value of assets owned by the bank and damaged by climate events - Losses from a reduction in the value of shares/bonds in the bank portfolio issued by firms whose performance is affected by climate change (*e.g.*, lower productivity, dependence from energy-water, etc…).	- Climate events affect the output of firms/households and make them more financial vulnerable, by reducing their ability to repay their debts. - Climate events affect the value of the collateral of indebted firms/households.
Transaction risk	- Losses/Profits from a reduction/increase in the value of shares/bonds/assets in the bank portfolio issued by firms whose future performance is affected by climate change policies (*e.g.*, energy intensive companies, policies to limit land use).	- Losses due to the non performing loans from firms whose future performance is affected by climate change policies.
Systemic risk	If the effects (in particular of transition risk) are affecting a whole sector (*e.g.*, constructions, agriculture, etc.) there is a risk of spillover effect across all the financial system.	

The growing importance of the risks connected with the climate events should force banks to integrate climate risks, as well as all the issues related, into their financial risk management framework, to enrich traditional approaches focused on reputational risk and to share responsibilities and capabilities with the Corporate Social Responsibility (Salvucci & Verachi 2019).

In this sense, the recent initiative of Intesa SanPaolo is noteworthy: the Italian banking group has already included social and environmental information into the corporate rating model, in order to improve the companies credit risk assessment. This is an example of how the climate-related issues, beyond posing new and detrimental risk exposures, may motivate banks to have a proactive approach to a new challenge, and that this should also be seen as an opportunity: business opportunities may come for example from the low-carbon transition, that will require very important financing. Hence, banks' management can identify promising lending opportunities by assessing the future potential market (Colas *et al.* 2019).

REFERENCES

Batten S., Sowerbutts R., Tanaka M. (2016). Let's talk about the weather: the impact of climate change on central banks. Bank of England. Working Paper. No. 603 - May, London.

Colas J., Khaykin I., Pyanet A. (2019). Climate Change. Managing a new Financial Risk: *https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2019/feb/Oliver_Wyman_Climate_Change_Managing_a_New_Financial_Risk1.pdf.*

Faiella I. (2019). Rischi climatici e rischi finanziari. Sviluppo sostenibile, finanza e rischio climatico. *https://www.bancaditalia.it/pubblicazioni/altri-atti-convegni/2019-sviluppo-sostenibile/Faiella.pdf.*

Faiella I., Natoli F. (2018). Natural catastrophes and bank lending: the case of flood risk in Italy. Questioni di Economia e Finanza. Banca d'Italia. No 457 - October. *https://www.bancaditalia.it/pubblicazioni/qef/2018-0457/QEF_457_18.pdf.*

Lautenschläger S. (2018). Post-Basel III supervisory challenges. International Conference of Banking Supervisors – ICBS. November. *https://www.bis.org/bcbs/events/icbs20/ws4.pdf.*

Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2016). Report of the Italian National Dialogue on Sustainable Finance. December.

Osservatorio italiano sulla finanza sostenibile (2019). Il rischio climatico per la finanza in Italia. *https://www.minambiente.it/sites/default/files/archivio/allegati/sviluppo_sostenibile/rapporto_wg3_rischio_climatico_finanza_italia_marzo2019.pdf.*

Salvucci F., Verachi F. (2019). Integrazione dei rischi ESG e climate change nel sistema di valutazione e gestione dei rischi. Sviluppo sostenibile, finanza e rischio climatico. *https://www.bancaditalia.it/pubblicazioni/altri-atti-convegni/2019-sviluppo-sostenibile/Intesa-Sanpaolo.pdf.*

Signorini L.F. (2017). The Financial system, environment and climate: a regulator's perspective. *https://www.bancaditalia.it/pubblicazioni/interventi-direttorio/int-dir-2017/Signorini_06.02.2017.pdf.*

Visco I. (2019). Sviluppo sostenibile e rischi climatici: il ruolo delle banche centrali. Festival dello Sviluppo Sostenibile 2019 "La finanza e i sistemi finanziari per lo sviluppo sostenibile". Alleanza Italiana per lo Sviluppo Sostenibile. *https://www.bancaditalia.it/media/notizia/festival-dello-sviluppo-sostenibile-2019-intervento-del-governatore-ignazio-visco/.*

Flood risk: financing for resilience using insurance adaptive schemes

ANDREA JONATHAN PAGANO[1], FRANCESCO ROMAGNOLI[1],
EMANUELE VANNUCCI[2*]
[1]Riga Technical University
[2]University of Pisa, Department of Economics and Management

Keywords: flood risk, insurance, resilience, smart contracts, blockchain

ABSTRACT. – This paper shows how insurance markets can be used for mitigating the economic consequences of climate changes, in particular for facing flood risk. Not only providing financial compensation for losses, but also for financing resilience through mitigative infrastructures. This approach is similar to one allowed by the so called resilience bonds, financial instruments whose cash flows depend on the occurrence of contractually settled (catastrophic) events and part of the economic value of the investment is devoted to finance resilience actions. Our propose is based on an adaptive design of the insurance contract, based on information collected at each checking time and the (eventual) surplus of the premium paid respect to the payments occurred for damages has to be (automatically, settled in contractual conditions) used for financing mitigative infrastructures. The cost of these infrastructures, the time to build up, the implied risk reduction, have to be assessed by an engineering expertise and even we need a legal framework into which the actuarial quantitative model can be implemented. The periodic renewals of the contract (surplus evaluation, changing in risk exposure due to the infrastructures already built,…), can be interpreted as a sort of smart contracting and in this framework the novelty of blockchain technology could be used to collect new information from various sources.

INTRODUCTION. – Since the early 1970s extreme events associated to natural disaster have been growing both in frequency and intensity. Specifically during the last 15 years has been recorded an increase of 2% per year. This increase is reflected also on economic losses, in fact addressing the attention of the scientific and professional arenas to novel and effective methods of insurance as resilient management tools

*Correspondent author: emanuele.vannucci@unipi.it

for risk reduction. In U.S. context the devastating impact of Hurricane Katrina in 2005 was quantify in more than 1,800 people losses within an area of 230,000 km^2 of the U.S. The recovery phase investment from the federal government were quantify on 100 billion $.

These trends highlights the need to strengthen the interdisciplinary aspect towards the disaster risk management involving policy and law makers, engineers, insurance company and researchers in difference disciplines able to create tailored community resilience strategies.

Since now there have been several example on how singularly each expertise community was proposing the implementation of both mitigation and adaptive solution in *ex-ante* and *ex-post* disaster occurrence. Engineers tried to promote innovation diffusion meantime redefine more specific codes and standards to have more resistant structure. Planners were reorganizing and reassessing the land use for the development of the urban area prone to hazards.

In this context the need to have a more resilient insurance system is essential in order to be more flexible and optimizing the management of the residual risks. The example of the CAT bonds is going in this direction in fact strengthening the key role of insurance as one of the key Disaster Risk Reduction (DRR) measure with a consist effect during the recovery phase of the built environmental and the social dimensions.

Nevertheless there is evidence of a relevant decrease of the ratio of insured losses *vs* uninsured losses due to the increased exposure and which may be partly limited financial availability. Several authors stressed on how insurance plays a key role in food risk management like in France and UK. During the post disaster has been highlighted how insurance can substantially decrease the recovery phase in fact provide a more quick way to have repayment of the losses compared to government support.

More in specific as stated in a recent document from European Commission, for insurance in adaptation to climate change, the role of insurance should be more and more effective in the future, respect to what happened in the past. Insurance mechanisms can provide financial compensation for large disaster losses, so that those affected can recover faster. The sooner and more comprehensive the recovery, the smaller the impacts of a disaster are likely to be in the long run, which helps to make society more resilient.

Insurance companies can play a large role in assessing, communicating and signalling risk through premiums, deductibles and payments.

Stakeholders involved in the insurance sector can generate incentives or requirements for risk management, which in turn can limit the potential impacts of an extreme weather event. Another option would be to include requirements that relate to resilience in the insurance policy: if an insurance-taker does not take any measures against the risk to which he/she is exposed, the pay-out will be lower. So, the role of insurance could be considered not only for financial compensation for losses after an extreme weather event, but also providing incentives for risk reduction as, for example for flood risk, the building of mitigative infrastructures.

Some features that allow to make an insurance scheme more efficient are an interaction between public and private sectors with a commonly stated and understood objective. Governments and the insurance sector exchange data, set common objectives and divide responsibilities.

One key point for increasing resilience against extreme weather events, as floods, is the construction of mitigative infrastructures which has to be financed by the stakeholders, as public administrations. There is an important novelty in the finance-insurance market precisely regarding this kind of need, that are the so-called resilience bonds.

They provide a transfer of the insurance risk, from the insurance to the financial market, as already done by the more famous cat-bond, bonds whose payments are linked to a contractual cat-event (storm, flood, earthquake,…), but they add also a project financing of infrastructures which can mitigate the original risk. For example, focusing on flood risk, the costs of such infrastructures has to be assessed using an hydraulic engineering expertise. Then the time necessary to finish such buildings, more than one year, which is the typical duration of an insurance contract, is a constraint which implies the consideration of multi year contracts, which is the natural environment for bonds.

During this period, we need to collect data of different nature, climatic, insurance (damages), engineering… and one instrument which seems useful to this aim is the so-called “Blockchain technology”, which is raising up a lot of interest for applications in a wide range of fields. The key function of its use is to collect reliable information that could be used for a dynamic updating of contracts, that is one of the main opportunity given by smart contracting, with an adequate support of law’s context in which such contracts are merged, that is one of the main issue to be developed for the full functioning of this kind of innovative business model.

Blockchain and the connected smart contracting, seem very interesting even for insurance business, in particular for the bayesian adaptive approach which is a classic issue of actuarial science, based on the updating of premium evaluation using the collection of new information of risks phenomena.

The new opportunity of collecting offered by the so-called big data even for classic insurance risks as for example, health, driving, climate and seismic events, together with the validating role of Blockchain approach, seem to be the perfect scenario for a massive use of smart contracting in insurance business.

In this paper we describe the scheme of a flood risk insurance, the bayesian adaptive design of the contract, using Blockchain to validate both new data of risk phenomenon and the effect of mitigation of the faced risk due to infrastructural works.

In the first paragraph the engineering point of view of measuring and mitigating flood risk is presented. In the second we provide an overview of the legal aspects of smart contracts in a multiperiodic scenario. In the third paragraph the bayesian adaptive design of the contract according to an actuarial approach is proposed. Then we propose some conclusions and mainly some comments of possible developing lines of this multidisciplinary research.

ASSESSMENT OF FLOOD RISK FOR CRITICAL INFRASTRUCTURAL SYSTEMS. – *FLOOD AND CRITICAL INFRASTRUCTURE.* – Since the early 1970s extreme events associate to natural disaster have been growing both in frequency and intensity. Specifically during the last 15 has been recorded an increase of 2% a year [see 1].

The same increased trend was also reflected on the number of disaster flood events more than 600 from the year 2007 [let see 2]. What happened in the year 2013 in the Central Europe was particularly impactful: 16.5 billion in economic losses (large-scale damage across Germany, the Czech Republic, Hungary and Poland) for 4.1 billion in insurance paid claims. The year 2013 has a record of the increasing flood damages of approximately 50% respect the period 2003-2012 and to show for first time three consecutive losses exceeding 100 billion in a 10 years period time [see 1, 3]. These figures represent an evidence how the increase of the population in urban areas [let see 1] and the consequential increase of their complexities of both social and technological dimensions define a bottleneck within flood risk management.

In fact, the rapid growth of human concentration and urbanized areas has increased the exposure to the existing flood recurrence time making more difficult the realization of proper mitigation measures such as the availability of the land to be settled as potential flood risk zone. Among different assets which flood risk increased, exposure of Critical Infrastructures (CI) needs to be highlighted.

Critical infrastructures represent body of systems, networks and assets that are essential for the functioning of a society, public's health and/or safety and economy of a nation. CI are thus engineering and technological networks, such as energy/water supply, transport services, water supply, oil and gas supply, banking and finance, and ICT (information and communication technology) systems. All these systems are important (and thus critical) to maintain essential functions of society, and their failures can heavily seriously affect the population, economy, and national security [see 4, 5]. Such CI systems, facing with the increase of the population in urban systems must increase the service there are providing in turn increasing both the interconnection of the CI and thus the overall vulnerability [see 5, 6].

This is the reason that addressed the attention of policy-makers, economist, urban planners, engineers, insurance companies and scientist to find innovative Risk Management frameworks to more sustainable and more resilient approaches towards decreasing the negative effects of climate change and natural hazards [see 7]. A new approach has thus been gradually developed, based on the concept of urban resilience, nowadays implemented within the Sendai Framework for Disaster Risk Reduction [see 8], however a robust methodology that is based on scientific research for quantitative assessment of benefits to flood risk reduction from mitigating infrastructural solutions is still not well defined and is the next desired improvement for risk management field.

Regarding the flood impact during the last decade the disruption and damage to the urban context increased $21 billion in 2015 to US $25 billion in 2016.

It is this essential to implement proper tool, mechanism and strategy able to reduce Risk mostly in term of strengthened infrastructural resilience. It is of utmost importance how to properly quantify the risk to most effectively apply the optimal strategy for strengthening the Critical Infrastructural resilience.

The concept of Infrastructural Resilience. – Due to the complexity and interdependency of infrastructure in urban areas there is higher risk to have cascading effects in fact generating secondary effects in areas much more far from the real flooded area [see 6, 9]. This is a key aspect to consider in order to minimize the secondary problems that are directly affecting the networks may have [see 10].

In order to make urban areas more resilient a novel risk reduction approach based on a strategic development of urban and infrastructural systems has been proposed within the last Sendai Protocol developed in the 2015 based on the resilience concept [see 11]. Sendai Protocol also foresees building the capacity to learn and thus anticipate the effect of a catastrophe, which is a substantial element for increasing resilience against natural hazards [see 1].

For this purpose the introduction of the term resilience has important role, however the term itself is interpreted in many different ways depending on the field of science. This concept is "essential" to describe the functionality of the communities, infrastructures or any other type of systems under the effect of hazard [let see 12]. Based on the United Nations Office for Disaster Risk Reduction (UNISDR), in disaster risk management resilience is used to describe "ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management". In this context the resilience is also being actualised by EU Commission to ensure appropriate planning and preparation for disaster risk management and sustainable development.

Some studies suggest that infrastructure resilience has direct connection with term of resilience proposed by Holling [10] and used in ecology. This definition is generalized as capacity of a system to absorb disturbances and to recover after a major disruption and to restart an activity on the territory. Based on this, different methods have been proposed to assess resilience and role of the infrastructural resilience within it. For example, in the work of Serre *et al.* [1] is proposed for urban/engineering networks are able to propagate flood risk the overall urban resilience is identified into 3 main capacities namely: Resistance capacity, Absorption capacity and Recovery capacity. Similarly approach for looking at resilience was proposed by Bruneau *et al.* [11] with the introduction of the "4Rs" (*i.e.*, Robustness; Redundancy; Resourcefulness;

and Rapidity), according to which resilience of specific system is described in by qualities of the system matching these 4Rs.

Such conceptual and (semi) quantitative model approaches based on the selection of a set of proper indicators can serve as the base for development of a framework for assessing the effectiveness of specific mitigation and/or adaptation strategies.

Flood Risk and Resilience. – As mentioned urban population increase and the consequential rise of the increase complexity of the CI represent factors that amplify the level of local vulnerability [see 12, 13]. In fact there is a direct connection of the natural hazard losses to the number of people and complex infrastructure living in areas prone to hazards.

Thus the assessment of the Risk losses is not a trivial task since both the engineering dimension as well as the social impact should be evaluated. Generally the Risk to natural disaster including flood is defined within the probability perspective in terms of occurrence time of a certain hazards, factored by the severity of its consequences [see 14], according to the following formula:

$$Risk = Probability \ x \ Consequence \quad \rangle \qquad \rangle \qquad \rangle \ (1)$$

Thus Risk represents a key instrument and criteria leading to flood zone management policy, land and infrastructural development planning [see 15]. It is thus evident the important role of the engineering dimension to assess the potential cost/benefit in terms of decreased flood risk level once a specific (or other engineering system) is strengthened and/ or newly built.

Risk formula presents also other expended description on where the probabilistic dimension of the Hazard is then related to the Exposure and Vulnerability. Both aspects are related to the intrinsic propensity of a certain asset to be at Risk. Thus, the engineering aspect to understand the effects of an hazard of a certain magnitude is essential. This general formula is reported below:

$$Risk = Hazard \ x \ Exposure \ x \ Vulnerability \quad \rangle \qquad \rangle \qquad \rangle \ (2)$$

Within the proposed Risk assessment there the need to use GIS-based system on which hazard (*e.g.*, flood), vulnerability and assets maps are combined through the use a weighing process and normalization. This task has to be replicated for each climate-related impact [see 16].

In this way the flood risk assessment is translated in terms of potential loss and damages costs. This is most of time impossible to be done for each infrastructure and/or asset at risk due to data scarcity. In these way insurance companies' databases are often using proxies to overcome this bottleneck.

As reported by Kaspersen and Halsnes [17] Danish Insurance Company define a damage function and unit damage costs based on flood levels for different buildings during extreme precipitation. In this case health costs (based on number of people exposed to mixed rain-sewage water) and expected costs for different rain patterns considering extremes climate event are calculated in monetary values as losses for each asset and damage costs.

Since quantitative and probabilistic approaches are not always possible to be used and converted into a monetary dimension (mostly in connection to the social dimension, the effectiveness of Risk Reduction scenarios through a Multicriteria Assessment (MCA) towards urban adaptation planning [see 18].

Normally with adaptation strategies are beneficial for the overall resilience of certain system and thus its risk reduction. According to [19] for physical systems can be identified in 2 types of measures namely hard and soft. The first referred to (semi)permanent installation within the area of the potential flood, the second ones are those relate to natural process for example like are tackling flood in terms of erosion decrease and or increase of roughness in the flooded areas [see 1, 20].

AN OVERVIEW OF THE LEGAL ASPECTS FOR CONVENTIONAL AND MULTI-PHASE SMART CONTRACT. – To highlight the scientific and applicative gap of a specific smart insurance contract against natural hazard, the first methodological approach, specifically the legal one, leads to an overview of the state of the art of the thematic areas of implementation of smart contracts themselves.

Our focus is to propose how a Smart Contract could act in an insurance scheme and let see Lamberti *et al.* [21, 22] and Sayegh [23] to have an overview of the application of Blockchain approach to the insurance sector. There is no universally accepted definition of Smart Contract, due to its recent appearance on the scene and its technological complexity [see 24].

A simple definition is that of an agreement whose performance is automatic, so an algorithm for computer transactions, which comply with the terms of the contract [see 25]. Perhaps a more correct definition, even thinking about the applicative scope of the paper was provided by the Italian IVASS (Italian Institute for Insurance Supervision), according to which smart contracts are contracts that are written in a specific language that can be understood, translated and executed by a computer, whose clauses can produce actions without external intervention based on information received in input and processed according to predefined rules [see 26].

As regards and more closely related to the development of the paper, the most analysed state of the art, to obtain a link to the current regulatory substrate referred to in the blockchain, was clearly that of the insurance dynamics. In the insurance sector, forms of insurance have developed that use Smart Contracts. The first example is InsureETH, an UK startup, in the field of airline reimbursements/compensations. Another case is that of the pilot project of the American International Group (AIG) together with IBM and Chartered Bank who worked together for a multinational insurance coverage, preparing a blockchain insurance Smart Contract.

It is worth adding that recently AXA insurance in order to refunds following delay or cancellation of the flight, has developed an extremely interesting smart contract. The insurance called Fizzy, appears revolutionary because, as described in the AXA portal, it excludes any kind of negligence, typical instead of the traditional insurance dynamics. The smart insurance, regardless of any external event or subjective/objective liability, automatically compensates in case of flight delay.

In order to the title section, what would be the difference of a standard smart insurance contract, therefore with instant effect, compared to a multi-phase contract? One of the main differences was highlighted at the end of the section just ended, and it is quite clear that the main difference is about multiphase.

The desired multiphase implementation within the smart insurance contract is subject to the fact that, periodically, through the storage of data from external certified sources, using the blockchain technology, the contractual structure can change, such as the insurance premium, the sum of compensation or the determination of the percentage of risk. In the title of this paper we make a clear recall to this kind of insurance adaptive scheme and therefore, even if in a perspective about natural disasters, the scanned periods may be related to prolonged periods, the determination of multi-mode concerns the scanning of temporal phases in which it is possible to change and modify essential elements of the contract without the latter termination or requiring a new agreement between the parties.

The second difference concerns the method of using the blockchain technology. Picking up one of the smart contracts mentioned above in the insurance field, the blockchain is simply used in two steps: 1) validation of the insured event, such as the hours of flight delay, and 2) the payment of the sum of money [see 27].

In other words, in the very few applicative experiences that took place in the last few years, insurances first of all made use of blockchain technology as an instrument to verify the insured event. The information, using as an example the AXA contract, deriving from the airline are stored within the blockchain data flow and any event of delay beyond the allowed limit “unblocks” and acts as a check and authorization for the second step.

The one-dimensional perspective of the contract in relation to the uniqueness of the period, understood as a contractual phase, emerges clearly. The data entered and the “transformation” of these through blockchain technology into legal effects, such as compensation, are contained in a single phase, without any possibility, that extends or changes the contractual structure. Therefore, in a one-dimensional perspective, the will of the parties, the economic agreements, regardless of information, external events, blockchain technology acts exclusively as a verifying agent of the insured event, relegated to a kind, using a parallel with civil law, of contract for future effects.

On the other hand, the contract that, hopefully, should be implemented, involves a completely different dimension, that of periodic data scanning, aimed not at the termination of the contract, but at its evolution, change and adaptation.

It is essential to delineate, first, the minimal and necessary features of a multi-phase contract mentioned above, and secondly, to highlight if there are examples, even partials that can be joined from a regulatory point of view to the latter.

As regards the specific legal section, it is possible to summarize the fundamental features of the insurance contract to be implemented, in possession of the technical and legal requirements, as well as in compliance with national and supranational regulations, such as written form of the contract, multiperiod scan and related termination of the contract, initial risk, determination of the premium and possibility to use eventual surplus in risk mitigation assets.

Some of the previous point have already been clarified, then down below, it shall be pointed out the residual parts and, in general, summarized the whole framework.

First of all, in accordance with Italian and European regulations, some points, that is the essential and fundamental minimum requirements emerge clearly, and from these latter the foundations must be laid for practical implementation.

In particular, the contract includes, with a view to an initial Italian implementation, the following rules: Art. 1882 *et seq*. Italian Civil Code, Article 8-*ter* of Legislative Decree 135.2018 converted into L 12/2019, Article 41 of Regulation (EU) n. 910/2014 of the European Parliament and of the Council, of 23 July 2014, EU Regulation 2017/1129 of the European Parliament and of the Council, of 30 June 2019, Directive 2016/97, recently implemented in Italy with Legislative Decree May 68/2018 EU Regulation of the European Commission (EU) 2017/1469 of 11 August 2017.

The second focal point relates to the mandatory written form, prescribed for all insurance contracts. in compliance with article 8-ter of Decree Law 135.2018 converted into L 12/2019 Smart contracts meet the requirement of written form subject to the IT identification of the interested parties, through a process having the requirements set by the Digital Agency for Italy (AGID) with guidelines to be adopted within ninety days from the date of entry into force of the law converting this decree. On the one hand the written form is prescribed, or rather the recognition of the validity of the smart contract in all the contracts that require the written form, on the other the guidelines of the AGID, recently diffused, say nothing against the prescriptions of the written form.

In a supranational context, in accordance with the regulations 910/2014, 2017/1129 and 2017/1469, if on the one hand the written form is prescribed, or rather the recognition of the validity, on the one hand of the information content of the insurance contract, compulsorily in writing, on the other hand as regards the smart contract, or more generally, any electronic document lacks the guidelines of individual member states.

The second profile is related to multi-periodality. This profile is allowed in the sense in which the contract is intended as a *unicum* in order not to incur the prohibition of which, in the event of a risk reduction, as originally calculated, the insurer must apply the lower premium starting from the deadline following the related communication, or, as an alternative, the express right of the contractor to withdraw from the agreement within two months of notification and with effect from the following month is reserved. In the reverse case, of an increase, therefore, of the ab initio established risk, the insured is, on the one hand obliged to give immediate notice to the insurer, and on the other, the latter has the right to withdraw from the contract with effect to date from the following month, while he cannot, continue the agreement by raising the premium or reducing the sum insured, without the express consent of the insured. The multi-period must be understood, therefore, as a multiple temporal scan within a single contractual period.

Even in the supranational panorama it seems plausible to be able to give the same conclusions as in the legislation concerning Italy, with the specification that the supranational provisions of the information content do not seem to obstruct the desired declination.

In accordance with the provisions of the Italian civil code, in compliance with the guarantees granted to the parties, it does not seem possible to change the premium without the express consensus at the time of determination of the same. Both from what can be deduced from the contrary in the provision of the Regulation of 11 August 2017 in the payment execution section, and from the provisions of the major European civil law systems, it seems that a variation, in order to the performance of the contractual, assumed as an unicum, is not feasible. Because of this, the premium, shall remain the same during the entire duration of the contract.

As regards the possible destination of a sum for mitigative infrastructures, the multi-period, and not the multi-year, therefore framing the contract as a unicum time scan, could grant the expedient of the initial fixed premium, potentially higher than a standard quantification. The allocation of part of the premium, at fixed intervals, according to the data flow, within the single time period scan, referred to in the contractual life, does not seem to suffer any prohibition. It seems therefore that this financial and environmental tool can be implemented in the sense that, since a payment by the weak party (insured) of a fixed premium, there do not seem to be any impediments to the disbursement of part of it, at certain periods and in certain circumstances, for the implementation of mitigative infrastructures.

THE ACTUARIAL MODEL: AN INSURANCE ADAPTIVE SCHEME. – In the first subsection we present the basic model to face flood risk, which implies the choice of the stakeholder, for example the public administration responsible for flood risk in a certain area, among no insurance for such risk, insurance or insurance and investment in mitigative infrastructures. In this subsection we don't consider the role of new information, collected after choice time, which can be considered into contract design, for example in terms of trend variations of the risk exposure, of the registered losses, of comparison between the premium paid and the registered losses till a certain time, and so on. This last point could be considered in order to generate potential surplus which can be invested in mitigative infrastructures.

THE BASIC MODEL: NO INSURANCE, INSURANCE OR INSURANCE AND RESILIENCE. – In this paragraph we describe the multiphase insurance adaptive scheme facing flood risk in a certain area. Let consider a random variable Y which describes the risk level in the insured area. Such random variable could describe or the rainfall registered in a fixed unit of time (hours, days, weeks,…) or the water level of one or more rivers which flow in the insured area, or some other indexes measuring the primarily source of flood risk. We assume to have historical series of the observations of this random variable, yi, with i=1,2...n, from which we can estimate the distribution of r.v. Y, FY.

Let X the random variable which describes the random loss due to flood risk in a fixed unit of time into insured area without any mitigative infrastructures. We also assume to have historical series of the observations of this random variable, xi, with i=1,2...n, from which we can estimate the distribution of r.v. X, FX.

In that case, applying a premium principle based on the distribution of X, we can determine a premium P[X] in the unit of time.

The insurance contractual conditions have to take count of the estimates relative to r.v. X, but it should be interesting even to estimate a regression model between X and Y, from which contractual conditions could be directly linked to the original source of risk, that can be useful (or necessary), for example, in case of losses data scarcity.

Let l be the regression function between X and Y without any mitigative infrastructures, that is X=l(Y).

From hydraulic engineering expertise we can estimate the regression function between X and Y in case of various mitigative infrastructures are built.

Let assume Ci, with i=1,2...m, an increasing sequence of infrastructures costs, more and more efficient, such that the regression functions li, with i=1,2,...m, describe a decreasing risk exposure, given the distribution of Y.

So, let P[Xi], i=1,2...m be the premium in the unit of time, in case of infrastructures i is built, with the same premium principle applied before, in this case to r.v. $X_i = l_i(Y)$. From the previous assumption on the efficiency of mitigative infrastructures we have, $P[X_i] < P[X_{i+1}]$, for each i.

If ti is the time necessary to build up infrastructures i, let assume that before the infrastructures is not finished, the risk exposure remains the original one, even if from an engineering point of view we can have a more detailed assumption in term of the evolution of risk exposure during the building time. With some further refinements to the quantitative model is possible to take count even of these aspects, but we prefer to focus on a simplified version.

The fundamental choices of the stakeholder, for example the public administration responsible of the flood risk in the area, are three:

- no insurance (and no resilience action) and payment of the random losses (in average E[X] for each unit of time);
- no insurance and resilience action through mitigative infrastructure i and payment of the random losses (in average E[X] for each unit of time) plus the constant amount ci/ti;
- insurance and no resilience action and payment of a constant amount P[X];
- insurance and resilience action through mitigative infrastructures i and payment of a constant amount P[X] + ci/ti till time ti, after that the premium $P[X_i] < P[X]$ for each unit of time.

Indeed we have to take count that the possible infrastructures are m, and so strategies II and IV have m different scenarios.

The comparison between I and III only depends by the randomness of future losses respect to the average value estimated for the past. Roughly the same comparison of II and IV, but we have to consider that we don’t have observation of the losses relative to r.v. X_i, for each i=1, 2… m, since the historical series cannot take count of risk mitigation given by infrastructures i. So the estimation relative to r.v. Xi, is founded only in engineering expertise.

So we focus on the crucial choice between III (in average is the same of I) and IV (in average is the same of II), for each infrastructures i, with i=1,2,… m, that is between no resilience and resilience.

Let consider the present value (PV) of the total cost, with a discount rate r, which can be fixed with many types of assumptions that we don't explore now. We have to assume a time horizon which can be + ∞ or a fixed time T. Let consider this second choice.

So the present value of the total cost in case of strategy III

$PV(III) = \sum_{j=1,2,...,T} P[X] (1+r)^{-tj}$

While the present value of the total cost in case of strategy IV with infrastructure i (ti is the time to build it), for i=1,2,...,m

$PV(IV, i) = \sum_{j=1,2,...,i} (P[X]+ c_i/t_i)(1+r)^{-tj} + \sum_{j=i+1, i+2,..., T} P[X_i] (1+r)^{-tj}$

So the optimal strategy is one that minimizes this total cost.

THE ADAPTIVE SCHEME: SURPLUS FOR FINANCING MITIGATIVE INFRASTRUCTURES. – Given the scenario described in the previous subsection, let consider a regular time grid si, i=0, 1, 2 … k at which we reset the insurance contract in such a way.

We start without any infrastructure and we know the engineering expertise estimation on infrastructures costs and their risk reduction effects.

If P is the constant total premium paid from si to si+1, i=0, 1, 2,… k-1, and X(i, i+1) is the total loss paid in the same interval, we have two different cases.

The first P < X(i, i+1) and in that case the larger losses is covered by the insurance system.

In the second we have a surplus P – X(i, i+1) and the adaptive design of the contract could provide that part of it, a in (0,1), is given back to the insured.

These surplus are summed up and the insured, the public administration, have to choice in which kind of infrastructure invest it. In case the decision is for infrastructure i, the stakeholder has to wait to accumulate a total surplus equal to its cost, ci.

At the time, one of the regular grid introduced before, a new contract starts: the premium paid by the insured has to be estimated using information collected till that time, for a contract of further duration ti, the time necessary to build up infrastructure i. After this further duration the insurance contract will proceed with premium E[Xi], given the expected loss with infrastructure i.

Let observe that with this adaptive model the starting premium P has to be higher than the expected loss, since it has to produce the surplus necessary to finance the mitigative infrastructure. Only when the necessary surplus is raised up, then the insurance premium has to be fair compared to expected losses.

We remark that this design with a fixed premium and the distribution of the surplus is allowed by the law environment of smart contracts. For the new definition of the premium is necessary a new deal between the 2 counterparts, as stated by the same law environment.

So the optimization problem in this adaptive insurance scheme has to determine the strategy that minimizes the total cost as seen in the previous subsection. The optimal strategy has to be defined in terms of the couple P and infrastructure i. Let consider that even in this optimization problem we have to compare also the equivalent strategies no insurance or only insurance (without resilience).

The total cost for the stratey (P*, i*) is given by, let si the expected time at which the necessary surplus ci is collected.

PV (P*, i*) = Σ j =1,2,..., i P (1+r) -sj + Σ j=i +1, i +2..., i+ti P[X] (1+r) -tj +
+ Σ j = i +ti +1, i +ti +2,..., T P[Xi] (1+r) - tj

The role of blockchain for this insurance adaptive scheme, is to certificate the information (data relative to the source of risk, to losses, to surplus, to infrastructure building) in order to allow for automatic renewals of the contract when it is not necessary a new deal between the counterparts to the contract.

COMMENTS AND FURTHER RESEARCH RECOMMENDATIONS. – This paper has presented an insurance contract facing flood risk in a multiperiodic scenario, based on an adaptive bayesian scheme, pointing out the opportunities and the criticisms by the point of view of the disciplines which are involved: actuarial, engineering, law. We disregard to detail the informatics aspects linked to the blockchain technology, leaving this issue to the specialist informatics literature. We underline that a classical actuarial approach, the bayesian adaptation due to the collection of new reliable information on the considered risk, could be inserted in a smart contract approach, with the support of blockchain technology.Since the risk is the flood one, we remark that an automatic updating scheme of the contract could concern also the infrastructures which have the role of risk mitigation and that also such component of the contract could be linked to the certification of blockchain approach.

Develops of this research could be imagined in various directions. The engineering and the actuarial approach have to dialogue in order to make their own analyses usable and useful one for the other and the legal overview has to clarify all the aspects such that the automatism provided by smart contracts in multiperiodic scenarios can be effectively conceivable in real cases.

REFERENCES

1. Serre D., Heinzlef C. (2018). Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. International Journal of Disaster Risk Reduction 30: 235-243.
2. Zevenbergen C., Cashman A., Evelpidou N. *et al.* (2010). Urban Flood Management. CRC Press, 340 pp.
3. Swiss Re Institute (2014). Natural catastrophes and man-made disasters in 2013. *https://www.swissre.com/institute/library/sigma-2014-01-en.html.*
4. Galland J.P. (2010). Critique de la notion d'infrastructure critique. Flux 81: 6-18.
5. Serre D. (2018). DS3 model testing: assessing critical infrastructure network flood resilience at the neighbourhood scale. In: Fekete A., Fiedrich F. (Eds), Urban Disaster Resilience and Security. Springer: 207-220.
6. Pescaroli G., Kelman I. (2017). How critical infrastructure orients international relief in cascading disasters. J. Contingencies Crisis Manag. 25: 56-67.
7. Quenault B. (2014). La résurgence/convergence du triptyque «catastrophe-résilienceadaptation» pour (re)penser la «fabrique urbaine» face aux risques climatiques. Développement durable et territoires 5(3) - *https://journals.openedition.org/developpementdurable/10683.*
8. UNISDR (The United Nations International Strategy for Disaster Reduction) (2015). Sendai Framework for Disaster Risk Reduction 2015-2030. - *https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.*
9. Lhomme S., Serre D., Diab Y. *et al.* (2013). Analyzing resilience of urban networks: a preliminary step towards more flood resilient cities. Nat. Hazards Earth Syst. Sci. 13: 221-230.
10. Holling C.S. (1973). Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4: 1-23.
11. Bruneau D., Chang M., Eguchi S. *et al.* (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake Spectra 19: 733–752.
12. Roberts R.S. (2012). Economic Strategies for Coastal Disaster Risk-Reduction: A Case Study of Exmouth. Ph.D. thesis, Murdoch University, Western Australia. - *https://pdfs.semanticscholar.org/70c3/8ec47c84a99baba0e0ab6ad6c2eea6d77354.pdf.*
13. Botzen W.J.W., van den Bergh J.C. (2008). Insurance against climate change and flooding in the Netherlands: present, future, and comparison with other countries. Risk Anal. 28: 413-426.
14. Rumson A., Hallett S., Brewer T. (2017). Coastal risk adaptation: the potential role of accessible geospatial Big Data. Marine Policy 83: 100-110.
15. Filatova T., Veen A. (2006). Microeconomic motives of land use change in coastal zone area: agent based modelling approach. In: Voinov A., Jakeman A. & Rizolli A. (Eds.), Proceedings of the 3rd Summit on Environmental Modelling and Software, Burlington, Vermont, USA.
16. Bertoldi P. (Ed.) (2018). Guidebook How to develop a Sustainable Energy and Climate Action Plan (SECAP) – Part 2 - Baseline Emission Inventory and Risk and Vulnerability Assessment. EUR 29412 EN, Publications Office of the EU, Luxembourg.
17. Kaspersen P.S., Halsnæs K. (2017). Integrated climate change risk assessment: a practical application for urban flooding during extreme precipitation. Climate services 6: 55-64.
18. EEA (2016). Urban adaptation to climate change in Europe 2016. Transforming cities in a changing climate. European Environmental Agency report, No 12/2016, 140 pp.
19. Rumson A., Hallett S., Brewer T. (2017). Coastal risk adaptation: the potential role of accessible geospatial Big Data. Marine Policy 83: 100-110.

20. UNISDR (2011). Global Assessment Report on Disaster Risk Reduction – Revealing Risk, Redefining Development - Geneva.
21. Lamberti F., Gatteschi V., Santamaria V. (2017). Blockchain or not blockchain, that is the question of the insurance and other sectors. Computer Science doi:10.1109/mitp.2017.265110355.
22. Lamberti F., Gatteschi V., Demartini C. *et al.* (2018). Blockchain and Smart Contracts for Insurance: Blockchain and smart contracts for insurance: Is the technology mature enough? Future Internet 10(2): 20.
23. Sayegh K. (2018). Blockchain application in insurance and reinsurance. Skema Business School, *www.researchgate.net/publication/327987901*.
24. Buterin V. (2014). A Next-Generation Smart Contract and Decentralized Application Platform, *https://github.com/ ethereum/wiki/wiki/White-Paper*.
25. Grasso A. (2018). Smart Contracts: Adoption value for enterprises and general use case - *https://www.researchgate.net/publication/330115021.*
26. IVASS (2016). Relazione sull'attività svolta dall'Istituto nell'anno 2016 - . *https://www.ivass.it/pubblicazioni-e-statistiche/pubblicazioni/relazione-annuale/*.
27. Macrinici D., Cartofeanu C., Gao S. (2018). Smart contract applications within blockchain technology: A systematic mapping study. Telemat. Informatics 35: 2337-2354.

Welfare state and ecological crisis: action-research perspectives towards sustainable social policies

MATTEO VILLA*
Department of Political Science and Interdisciplinary Centre "Sciences for Peace" of the University of Pisa

Keywords: sustainability, ecological transitions, comparative policy analysis

ABSTRACT. – The paper discusses the challenges of welfare environmental sustainability in social policy analysis and a methodological contribution on the matter. The concept of welfare sustainability arises from the growing awareness that welfare systems are an important driver of a unsustainable model of development. The emergence of this problem is linked to the increasing demands of social protection and the fiscal crisis of welfare states, giving rise to a sort of triple sustainability crisis. The paper briefly presents the main points discussed in the current debate, some criticisms about the latter, and few aspects of our research direction. Criticisms particularly point out a sort of reductionist trap in social policy analysis that makes it difficult to observe and deal with the kinds of social risks emerging from the climate crisis, their trans-contextual dynamics, the implications of transition processes, and the role of social contexts and organizational processes in making the welfare systems more or less ecologically sustainable or parasitical. The action-research approach is then briefly presented as a way promoted by our research group to contribute in the debate, supporting integrated experiences and research paths, as well as taking part in international programs and networks on the topic.

INTRODUCTION. – According to the Social policy literature, western welfare systems are entrapped in a sort of double crisis. On the one hand, there are the increasing demands of social protection due to the changing configuration of the classical or old social risks and the emerging of new ones. On the other one, there is the fiscal crisis of the welfare state resulting from the States' responses to the economic downturn in the wake of the austerity doctrine. The twos are in many ways connected fostering one another and imposing complicated dilemmas for political choices. They are also differently interpreted and tackled through poli-

*matteo.villa@unipi.it

tics of expansion or, more frequently, recalibration and retrenchment. Moreover, all these strategies are at least partly biased and entrapped into-the-box of the ways *keynesian* and *neoliberal* paradigms have shaped in the past decades dynamics and design of capitalist accumulation and social protection, hence creating a further massive dilemma. Indeed, while cutbacks risk to increase inequality and deprivation, particularly for weaker people, groups and communities, possible additional state expenditures risk to further boost an environmentally unsustainable growth, and both risk to enhance the emergence of new social risks.

The current environmental crisis has brought additional types of social risks, connected to the diversified impacts of climate change, destruction of habitats and biodiversity, impoverishment of soils and natural resources. Climate change for instance, in the short run "mainly works as an aggravator of existing social risks such as health, poverty, inequality and human security" (Johansson 2016), mainly hitting vulnerable communities and territories as well as further boosting displacement and migration processes. But in the long run, particularly in case of weak anticipation, mitigation and conservation policies, climate change could become the main driver of social risks, with sever effects on the conditions for livelihood for many people and communities, the natural and artificial resources on which they depend (food, energy, infrastructures), their economies and, hence, the same employment-insurance regime on which their welfare system is designed. Ian Gough (2017) identifies four categories of implications for social policy: first, the direct risks to well-being through destructive events and changing and adverse environmental conditions which pose new challenges for social programs ("for example, new housing and settlement patterns, new insurance costs, health demands of extreme climatic events, the management of natural disasters and their dislocations and traumas"). Second, the indirect risks to well-being, for instance connected to climate migration from the unsafe areas mainly located in the developing world. Third, the implications of climate adaptation policies which could create "fiscal competition between welfare and environmental demands, unless synergies are exploited". Fourth, the implications for 'traditional' social policy of climate mitigation policies, for instance related to the potential regressive effects of fiscal measures to reduce carbon emissions. Moreover, both direct and indirect environmental-based social risks have tricky distributional implications, between individuals and populations, between social classes and between geographical contexts.

These are among the reasons why "climate change is essentially political" (Ruser 2018), and why the current one may be defined a triple sustainability crisis of welfare state: *economic*, *social* and *environmental*. As a consequence, this crisis could and should probably be seen as a complex non-linear systemic process of interconnected loops of causation (Bateson 1972; Room 2011), while aspects and variables referring to the three fields of investigation are little and only recently analyzed together in both the social policy and sustainability literatures (Gough 2017). Moreover, the possible strategies to face the climate crisis – such as mitigation, adaptation, geo-engineering and conservation – should involve not only technical solutions, but also, and probably above all, political choices at many levels, complex institutional processes of implementation and more or less deep changes in patterns of behavior, lifestyles and organization of consumption, production, redistribution, investment, use natural resource, as well as criteria of legitimacy of them all.

Unfortunately, there are still limited although increasing contributions which try to figure out ongoing dynamics and scenarios, experiments and experiences, and that start to link up hitherto separate research traditions. Particularly in Italy the topic is still very little discussed. In this context is placed the work started in Pisa about "welfare sustainability" aimed at developing a specific research approach, contributing in the debate, supporting integrated experiences and research paths, as well as taking part in international programs and networks[1]. Few points about the current debate and our research direction are briefly outlined below.

ASPECTS OF THE DEBATE. – *TOWARDS AN ECO-SOCIAL STATE?* – Some scholars assert that only strong states and robust public welfare have the capacity to facilitate/promote de-carbonization strategies, enhance notions of public and common good, and design both monetarily and ecologically efficient public welfare services (Bailey 2015). The controlling idea is that, to improve the conditions for future generations sorts of Eco-Investment State strategies are needed. Under this perspective, the emergence of the Social Investment Welfare State paradigm (SI, *henceforth*) is regarded as an opportunity for integrating climate mitigation/adaptation efforts and socio-economic transformative strategies, as the social-democratic countries experience seems to display (Gough 2017). However, the SI paradigm has to date seen only limited applications, while the link between environmental performances and kinds of welfare systems cannot yet be supported by empirical findings

[1] The work is developed by a small group of researchers named *Opss (Organizations, Policies and Socio-ecological Systems),* including Marta Bonetti, Giulia Colombini, Irene Masoni.

and needs to be further investigated. Also, SI strategies are deemed controversial with regard to the triple sustainability crisis: the emphases on activation and human capital development risk to enhance the possible creaming-out effects for marginalized and hardly employable people, while the work-first policy approaches risk to further boost and legitimize competitiveness and productivism, stressing the mere economistic side of employment, the steady primacy of the individual chain (unlimited) preferences/wants/aspirations–production–redistribution–satisfaction (*ibid.*), the commodification of social policies and reproductive work, and the unvarying dependence on, as well as reproduction of, growth. Finally, these strategies are called into question by the increasing ambivalence of the economic growth/employment relationship.

Post-growth transition strategies. – On the other side, the are some indications that retrenchment politics, whether they are the corollary of neoliberal or post-growth transition strategies, can have even worst counter-productive effects on both equality and sustainability (Abrahamson 2017). Indeed, they can contribute to many kinds of self-reinforcing feedback-loops and schismogenic processes, as well as to unpredictable leaps in the level of risks for poor and fragile individuals and communities. Also, weaker social welfare makes it more difficult for the poor to satisfy their basic needs. Furthermore, the combination of fading public policies and growing inequalities makes it difficult the implementation of carbon taxation systems and more sustainable housing, transportation and energy policies, for the limited capacity of public investment and the likely regressive effects (‘Weitzman paradox’). Another concern is that commodification, privatization and familization of service provision may weaken the State capability to promote more sustainable forms of service, consumption and work organization and governance, and to guarantee conditions of equal accessibility. Finally, while interesting experiences of informal and self-organized local innovative socio-economic experiments are growing, it seems hard to rely on the future development of an improbable self-service society and community-based welfare system as a viable alternative to an albeit multi-level and variously organized institutional welfare (Reyneri 2017; Williams 2007).

More context-based policies. – Some works acknowledge the idea of partly reconsidering the role of social policy with regard to the individual/social context/environment relationship, putting specific attention to the spatial dimension, the processes of rescaling and embeddedment of welfare operation, and the potentials of bottom-up non-institutional resources. That means, for instance: challenging the classical "business as usual" short-term-national modes of welfare implementation and evaluation based upon national GDP and budget indicators per year, highlighting the need for more medium- and long-term and contextual arrangements and a more robust set of valuation techniques (Kulig *et al.* 2010). Second, addressing the problem of territorial divide and risks distribution. Third, promoting new equilibria between centralized universalistic frameworks and decentralized bottom-up processes of civic associations, policy community and cooperative governance. Fourth, enhancing the processes of informalization and decommodification of work and the reduction of working time while valorizing and supporting the reproductive work and promoting new forms of work-sharing.

Accordingly to these hypotheses, welfare institutions should search for new balance between investment, compensation and ecological limits, promoting more interdependent views of personal achievement and wellbeing of collective and community-based investments, and, of organization of production and consumption in social policy goals.

Criticisms to the current debate. – As a matter of fact, a lot of work is still needed to develop/ameliorate theories, methods and practices to help these hypotheses work. In particular, there are some reasons of dissatisfaction about analysis and practice related to the ecological problem and the role of welfare systems. In particular, ongoing works on the topic and the related ideas, approaches and practices of innovation still reveal a certain separation between the social policy and sustainability writings, or they are discussed through lenses and ideas "which evolved in a previous age" (Espinosa & Walker 2011). Some limits and criticisms may be identified as follows.

Growth, green growth, degrowth. – The concept of welfare sustainability arises from the growing awareness of the contradictory role of welfare systems in a model of development that is proving ecologically incompatible. Hence, scholars observe that making sustainable and effective a Socio-Eco-Investment State strategy, a move beyond the current political economy strategies and the strict logic of SI is required, addressing the satisfaction of human needs within ecological limits (Koch & Mont 2016). Contributions, for instance, claim the "need to go beyond Keynesian and neo-classical economic theories and anchor the SI approach in a new economic model" (Morel *et al*. 2012), giving-up the emphasis on employment-first policies, market competition and consumer sovereignty and the compulsion to increase competitiveness and productivity.

Unfortunately, there are still few social policy works that are addressing this issue while for the big part the researches still move within a paradigm that does not conceive, for example, any idea of limit in availability of resources and growth of work, production, reproduction, redistribution, or any understanding of the environmental unsustainability and the dissipative properties of the same welfare organization. On the other hand, the literature on sustainability and degrowth has only to a limited extent addressed the issue of welfare and its possible role in the awaited transitions towards more sustainable systems (*e.g.*, a steady state economy).

The different types of social risks that the environmental crisis and the contrasting strategies put in place, constitute an important example of how a paradigm shift is needed. Apart the distributional effects, as Johansson *et al.* (2016: 98ss.) underline, social risks emerging from the environmental crisis "are far less observable, are much more complex and have a much more ambiguous effect on the 'population'". Furthermore, they are different also because "the time is running out", while a central authority to address the problem appears weak if not entirely missing. Finally, while social policy mainly regards the management of social risks that are usually *individually unpredictable but collectively predictable*, climate change is a "systemic risk", global and long-term, unprecedented and uncertain in its dynamics and overall effects, and therefore *collectively unpredictable* (Gough 2017). In brief, they are very different from the risks associated with industrial and post-industrial welfare systems, but strongly overlap and intertwine with them and the current policies.

Hence, the current discussion about possible models of *green-growth*, *a-growth*, *de-growth* and the most recent political emphasis on the so-called *green new deal*, risks to end up being excessively abstract and decontextualized, compared to the current modes of welfare organization and governance, while research on the latter risks to become more and more outdated compared to the ongoing transformations.

Context-and organization-based issues. – Social policy analysis seems to struggle in grasping the contextual and organizational variables and dynamics, the interactions that involve feedback loops and cumulative change (Room 2011), and how these may concur both to create sustainability issues and to promote transformative opportunities. Indeed, there is little discussion on potentials – and limits – of more *context-based and organization-change social policies* (Villa 2016), as well as a little shared knowledge on what it is possible to learn from practices of this kind.

At the same time, practicability of such models is far from obvious, owing to many problems of costs/investments, complexity, timing, indeterminable outcomes and possible biases in targeting and involving people and territories. First, they hardly can be seen as alternatives to the universalistic- or category-based social policy system, without the risk of further enhancing inequalities and undermining the legitimacy and enforceability of both universal basic needs and/or equal social rights for all. Second, in the short run they probably require further social and economic investments that risk to boost the tensions at the base of the mentioned dilemmas. Third, they certainly involve high levels of methodological complexity and require high management skills for supporting very complex governance and metagovernance processes and changes, while experimenting differentiated forms of power distribution, modes of inclusion and economic exchange, resource ownership (*ibid.*) As such, increased research investment at this level is desirable.

The problem of transition. – Sustainability – and above all the social policy – literatures, still deploys a limited involvement and little shared knowledge about the modes of *transition* towards the possible new scenarios. Grand narratives such as those mentioned above (*e.g.*, degrowth, steady state economy) state important principles and many economic and political insights. Unfortunately, the ways in which behavioral and organizational patterns and learning and co-evolutionary processes give form to transitions, probably counts more than any theoretical design and representation of future scenarios (Room 2011; Tsoukas 2005). The latter easily risk losing their strengths if they are strictly interpreted in normative, static, sector-specific and purely dimensional terms and cease to be thought as *stories*, namely thinking in terms of *changing patterns through time*, where complexity, non-linearity and recursion are probably the key properties to be considered (Bateson 1979; Harries-

Jones 1995). Therefore, social policy and sustainability research should invest more effort in understanding what it means to deal with these properties, crossing analyses and methods with different literatures related to governance and organization processes, knowledge and action, collaborative problem solving and transformative change, communication, learning and evolution science.

Anthropocentrism. – Finally, social policy research follows different perspectives but share a very little interest for the understanding of the living. It rarely claims inquiries in the world of things that in nature live, that is, grow, learn, evolve: the creaturely world of mental processes (Bateson 1979). Human nature is commonly distilled in separate, disembodied and disembedded parts (variables, individuals, restricted spatial-temporal sequences of lineal actions) that even if helpful, equate life to abstract mechanisms (Thompson 2007). Hence social policy research hardly includes any consideration of the ecological properties and implications of the relationships man-nature, body-mind-environment and reason-emotion, of life forms and trajectories, of the learning and evolution processes on which welfare measures and organizations produce huge impacts of many kinds. Rather, there is a steady commitment to simplification/reductionism in the operations of distinctions, mapping, comprehension and management of cognitive and social processes and environmental feedbacks, still based on a dualistic-Cartesian view of the relationship with nature as domination. The risk is keep making the policy analysis unable to identify limits to the current mechanisms of development and protection of social rights, well-being and forms of livelihood, as well as viable alternatives in a scenario of dramatic change.

Taking a step forward. – To take a step forward, we try to move between the folds of some of the above mentioned grand narratives with the aim of identifying some specific processes that make welfare systems more or less ecologically parasitical or, on the contrary, more or less capable of promoting better conditions for sustainability. The idea is to argue around the dynamic, organizational and contextual configurations of welfare systems, their changing strategies and their precarious equilibria in turbulent contexts. While taking the policy instruments into account, our research mainly focuses on how they contribute to the ecological properties of the citizens-institutions-environment interactions, looking at the modes of self-organization and sense-making, the structures of interdependence, embodiment and embeddedness, the types of learning, the non-linear dynamics of adaptation and co-evolution.

In particular, we try to explore the bottom-up and top-down dynamics that affect/create specific socio-ecological conditions, and their modes of dissipating/preserving/increasing the systems' economics of flexibility, that is their social, cognitive, informational and bio-energetic uncommitted potentialities for change, learning, adaptation and development (Bateson 1972; Room 2011). First, with regard to the modes of welfare organization, we critically analyze the prevailing economistic and administrative rationales of managerial *modus operandi* (Bonetti & Villa 2014) and their attitudes to rigidly program the policy implementation upon a few over-simplified assumptions. Second, with regard to the modes of social policy implementation, we examine some counter-intuitive effects of individualized and pre-structured – universalistic or category-based – policy measures (Sabatinelli & Villa 2015; Villa & Johansen 2019), particularly in relation to the poor/fragile contexts and communities and among the people "who would benefit the greatest" (Villa 2015, 2016).

To this aim, we try to outline and test an *ecological perspective* and *style* (Tsoukas 2005) in social policy analysis which primarily adopts some non-reductionist basic assumptions drawing inspiration from cybernetics, economic and formal sociology, mind science, ecological psychology, ecological economics. While disregarding both anthropocentric and biocentric positions on the matter, this perspective looks at a better and integrated understanding of interaction, organization, institutional and co-evolutionary processes at the basis of welfare systems operation and its main outcomes.

The methodology is mainly based on *action-research* (AR). The latter is an approach that fits well with the aim of promoting both research- and action-driven fieldworks based on the collaboration between researchers and social and political actors. It is actualized by blending *pragmatist* observations, learning and change instruments with *systemic* analysis, with a particular regard for the role of *abduction* as a legitimate part of the investigation processes and a useful analytical and change strategy to deal with emergent properties of organizations, policies and social systems (Lewin 1951; Harries-Jones 1995; Swedberg 2014). Abduction reflects the process of forming/selecting analytical and explanatory hypotheses in situations in which the previous ones fail, appear obsolete or are simply lacking, enabling recognizing, reconstructing and comparing patterns of interactions, rules and regularities in complex systems.

This approach also helps to build-up comparative (national and international) investigation processes overcoming the supposed limited usability of case-studies findings to the research field, and to move between the extremes of the widespread (in social policy analysis) universalistic totally context-free methods and the less common strictly contextually-bounded ones (Villa & Johansen 2019; Bonetti *et al.* 2019). First, by producing multiple descriptions; second identifying hypotheses on regularities that can lead to the formation of plausible patterns; third comparing similarities and differences in series of fieldworks.

We also collaborate since many years in education, training and consulting activities in the field of social and ecological welfare, work and social exclusion policies, organization, participation and governance processes, community development and sustainability. Research and change/innovation of socio-economic and organizational processes are in some cases integrated thanks to the adoption of the AR and its ability to accompany field experiments aimed at promoting sustainable transitions. Activities are mainly developed in collaboration with public and non-profit institutions, social enterprises and local social actors. One important goal is to develop more interdisciplinary collaborations.

REFERENCES

Abrahamson P. (2017). *Future welfare. An uneven race to the top and/or a polarized world?* In: Aspalter C. (Ed.), The Routledge International Handbook to Welfare State Systems. Routledge, London.

Bailey D. (2015). The Environmental Paradox of the Welfare State: The Dynamics of Sustainability. *New Political Economy* 20: 793-811.

Bateson G. (1972). *Steps to an Ecology of Mind*. Chandler Publishing Co, New York.

Bateson G. (1979). *Mind and Nature. A Necessary Unity*. Bantam Books, Toronto.

Büchs M., Koch M. (2017). *Postgrowth and Wellbeing. Challenges to Sustainable Welfare*. Palgrave MacMillan, London.

Espinosa A., Walker J. (2011). *A Complexity Approach to Sustainability. Theory and Application*. Imperial College Press, London.

Fitzpatrick T. Ed. (2011). *Understanding the Environment and Social Policy*. Policy Press, Bristol.

Gough I. (2017). *Heat, Greed and Human Need. Climate Change, Capitalism and Sustainable Wellbeing*. Eward Elgar, Cheltenham.

Harries-Jones P. (1995). *A recursive vision. Ecological understanding and Gregory Bateson*. University of Toronto Press, Toronto.

Johansson. H. Khan, J. Hildingson R. (2016). Climate change and the welfare state: do we see a new generation of social risk emerging? In: Koch M., Mont O. (Eds), *op. cit*.

Koch M., Buch-Hansen H. (2016). Human Needs, Steady-State sconomies and sustainable welfare. In: Koch M., Mont O. (Eds), *op. cit.*

Koch M., Mont O. (2016). *Sustainability and the Political Economy of Welfare*. Routledge, London.

Kulig A. Kolfoort, H. and Hoekstra, R. (2010). The Case for the Hybrid Capital Approach for the Measurement of the Welfare and Sustainability. *Ecological Indicators* 10: 118-128.

Lewin K. (1951). *Field Theory in Social Science*. Harper & Row, New York.

Matthies A-L., Narhi K. (2017). *The ecosocial transition of society. The contribution of social work and social policy*. Routledge, New York.
Morgan G. (2007). *Images of organizations.* Sage, Thousand Oaks.
Polanyi K. (1977). *The Livelihood of Man*. Academic Press, New York.
Room G. (2011). *Complexity, Institutions and Public Policy. Agile Decision-making in a Turbulent World*. Edward Elgar, Cheltenam.
Ruser A. (2018). *Climate Politics and the Impact of Think Tanks. Scientific Expertise in Germany and the US*. Palgrave MacMillan, London.
Spash C.L. (Ed.) (2017). *Routledge Handbook of Ecological Economics. Nature and Society*. Routledge, London.
Swedberg R. (2014). *The Art of Social Theory*. Princeton University Press, Princeton.
Thompson E. (2007). *Mind in Life. Biology, Phenomenology, and the Science of Mind*. Harvard University Press, Harvard.
Tsoukas H. (2005). *Complex Knowledge Studies in Organizational Epistemology*. Oxford University Press, Oxford.