

INVITED LETTER TO THE EDITOR

Present and future of ecological and evolutionary research in Mediterranean-type ecosystems: Conclusions from the last International Mediterranean Ecosystems Conference¹

The XIV MEDECOS and XIII AEET Consortium^{2–7}

Mediterranean-type ecosystems (MTEs) have long attracted the attention of biologists worldwide. One of the main reasons is the tremendous vascular plant diversity within the five MTEs, including the Mediterranean Basin, southwestern and southern Australia, coastal and southern regions of California, central Chile and the Cape Region in South Africa. Mediterranean-type ecosystems harbor almost 20%, i.e., about 50,000 species, of the world's known vascular plant species on less than 5% of the Earth's surface (Cowling et al., 1996). A combination of geological stability, climatic oscillations, fire frequency, and summer droughts created unique plant communities and floras with characteristic, unmistakable names, such as matorral, chaparral, maquis, fynbos and kwongan. Such a great interest in MTEs by the international scientific community was given concrete expression in 1971, when the International Society for Mediterranean Ecology (ISOMED) was established to promote research, conservation, and public awareness of the biological diversity of the world's Mediterranean-type climate regions. Since then, the International Mediterranean Ecosystems Conference (MEDECOS) has periodically been held, rotating among Mediterranean-type climate countries every 3–4 yr, to bring together scientists and natural resource managers with a strong interest in MTEs.

The XIV MEDECOS was held in Seville, Spain (1–4 February 2017). The conference was co-organized by the University of Seville, the Doñana Biological Station (EBD-CSIC), and the Spanish Association for Terrestrial Ecology (AEET). Given that many AEET members develop their research or professional activities in Mediterranean-type climate regions, the XIV MEDECOS was jointly held with the XIII AEET general meeting (see <http://www.mede-cos-aeet-meeting2017.es/>). Overall, the conference gathered 538 participants from 23 nations. The number of participants from countries harboring MTEs was quite biased toward the largest MTE area, i.e., the Mediterranean Basin, and the organizing country (Fig. 1). Overall, 424 participants came from seven countries across the Mediterranean Basin, 72 from the other four countries with MTEs, and 42 from non-MTE countries. Spain was particularly well represented with 351 participants, which was understandable as the AEET, a Spanish association established in 1989 with more than 700 members, held its XIII general meeting concurrently.

Human-induced habitat transformation and degradation have increasingly been posing serious threats to the conservation of biodiversity in MTEs (Rundel et al., 1998; Underwood et al., 2009). For this reason, the theme of the conference was “Human driven scenarios for evolutionary and ecological changes” with the aim of highlighting the impact of human activities on MTEs. This concern was reflected in the important diffusion of the conference in the media, i.e., 20 general press notes and 31 specific articles in local and national media, in some cases with interviews with journalists during the conference on various topics of general interest. These included the effects of global climate change on increasing aridity and extreme meteorological events in Mediterranean countries, the lack of solid policies and efficient conservation measures for Mediterranean ecosystems, the relationship between fire effects and inefficient management plans of natural resources in the Mediterranean, and the perennial problem of the inadequate low funding of basic research in ecology.

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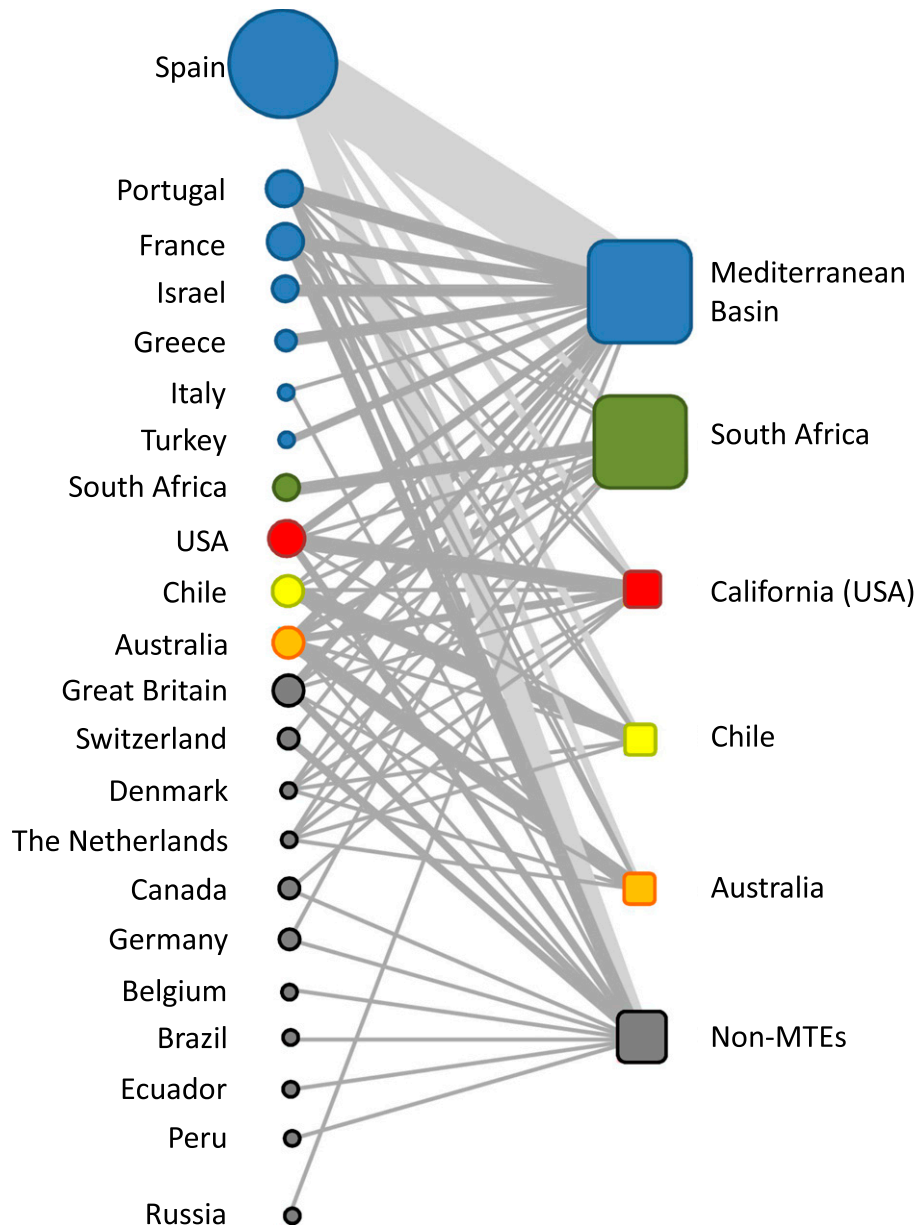


FIGURE 1 Plot of interactions between the first author's affiliation and the Mediterranean-type ecosystem (MTE) where the study was conducted. Country vertex size (circles) is proportional to the total number of contributions of each country as given by the first author's affiliation. The MTE vertex size (quadrats) is proportional to the number of contributions with research undertaken in each MTE. Contributions conducted in non-MTE countries are also indicated. Linkage thickness is proportional to the number of contributions from each country studying each MTE. Spain's linkages are plotted in light gray for better visualization. Countries from each MTE share the same color. Analysis was performed with the igraph R package (Csárdi and Nepusz, 2006).

Here we report on the conference outcomes to identify the major topics, trends, and issues of interest for the international community working in MTEs worldwide. We particularly focus on the way that ecological and evolutionary research in MTEs is coordinated and conducted by the international scientific community. We also propose a number of specific actions for enhancing ecological and evolutionary research in MTEs in a context of a rapidly changing world, in which MTEs have been predicted to be seriously

affected by global warming and land-use changes in the 21st century (Sala et al., 2000; Klausmeyer and Shaw, 2009; Gómez-Navarro et al., 2010; Jacobeit et al., 2014). Finally, we stress the need to reconsider some important aspects beyond science for future meetings on MTEs, such as the achievement of gender parity at all levels of the organization and development of the conference, as well as active participation of North African Mediterranean countries in MTEs meetings.

CURRENT MAJOR RESEARCH THEMES IN MTEs

The conference was structured in eight sessions and 21 symposia, with a total of three sessions and 15 symposia specifically focused on an extensive array of topics related to the ecology, evolution, and conservation in MTEs (Fig. 2). Overall, the XIV MEDECOS and XIII AEET general meeting proved to be an excellent meeting point for the scientific community interested in multiple biological aspects of MTEs. Next, we summarize some of the scientific major topics and outcomes of the conference.

Fire ecology—Mediterranean-type ecosystems are highly fire-prone. For this reason, fire always represents a major focus where several basic and applied research lines converge. Two symposia focused specifically on the effects of fire, *Fire-Driven Evolution of MTE Floras* and *Fire and Plant–Animal Interactions*, from which two ideas emerged. First, the appearance of fire-adapted lineages with novel fire-related traits, e.g., fire-stimulated flowering, seed dispersal and/or germination, over different geologic eras, chiefly accounted for the evolution of land plants in MTEs. Furthermore, adaptations to other environmental conditions that characterize MTEs, such as drought, occurred either concurrently with fire or after adaptation to fire, suggesting a paradigm shift to reassess ecological and evolutionary theories for MTEs that exclude fire. And second, fire significantly disrupts plant–animal interactions in MTEs. Nonetheless, the effects may not all be detrimental, as fire may benefit plants, insects, and vertebrates by disrupting antagonistic interactions.

Moreover, fire creates habitat mosaics at different spatiotemporal scales, eventually promoting biodiversity and buffering plant and animal communities against drought. Obviously, fire frequency and intensity eventually determine the viability of fire-prone environments, a topic that continuously feeds into basic research and policy-making in MTEs.

Indeed, many contributions from other sessions and symposia also dealt with the causes and consequences of fire, reinforcing the

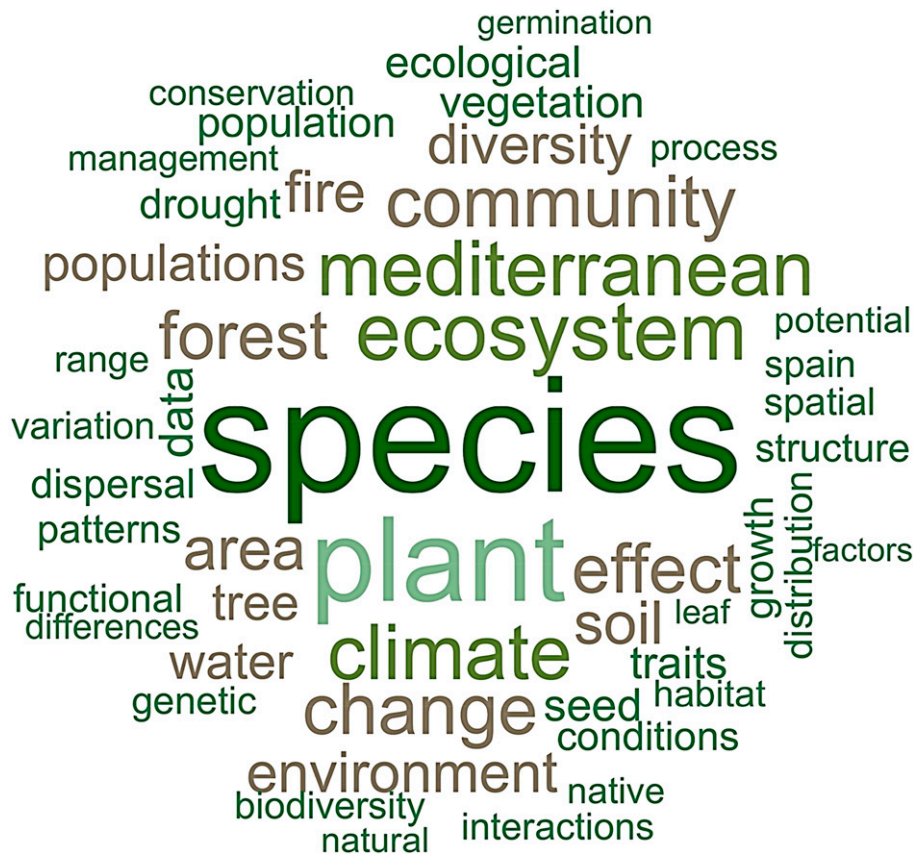


FIGURE 2 Word cloud resulting from the analysis of word frequencies among all abstracts submitted to the XIV MEDECOS & XIII AEET Meeting. Only words appearing more than 100 times with a meaningful biological sense were taken into account. Word size and color correspond to different frequency categories.

cross-cutting nature and importance of fire in MTE research. It is worth emphasizing the wide array of approaches and methodologies used to study the effects of fire on Mediterranean-type natural systems, highlighting territorial analysis combined with sophisticated spatially explicit modeling techniques. For example, GIS-based methodologies are being used to generate fire scenarios by combining data from various sources, e.g., land use/land cover, landscape structure, fuel load, and fire history. The final goal is to develop effective tools to reduce territorial vulnerability to wildfires for both human societies and natural systems.

At present, one of the issues of major current concern is the increasing number and frequency of large fires in MTEs due to rapid changes in both land use and climate. Special attention was paid to species and community responses to the interaction between drought and fire, which is expected to be intensified by climate change. Current studies indicate that increased drought events will hamper vegetation recovery after fire events, which will largely depend on the structure of plant communities. The impact of this phenomenon is being studied from practically all viewpoints and disciplines, which is particularly relevant for the development of long-term conservation planning of MTEs. For example, although plant and soil fungal communities are obviously affected by fire recurrence in multiple ways, the major threat for long-term plant population persistence comes from physical factors, such as increasing soil losses through repeated fires. Thus, fire risk reduction

and biodiversity conservation have to be fine-tuned through adequate land-use planning, which needs to be specific to the particularities of each MTE and regions within MTEs.

Global climate change—Another important topic that is already a central framework in ecological and evolutionary research is the predicted effects of global climate change on MTEs. Climate models have consistently forecast a substantial increase of temperatures in MTEs within this century. In fact, temperature trends continue to break records in several Mediterranean countries almost every year. Three sessions and seven symposia were framed in a context of global climate change, stressing the enormous interest and concern of the scientific community for this topic. We noted a great interest in gathering geographically explicit data on climatic adaptation at all levels, from intraspecific genetic and phenotypic variation associated with climatic gradients across distribution ranges, to physiological and functional responses of species and communities to climatic conditions. Numerous contributions showed how climate change can affect plant phenology, biotic interactions, and seed dispersal. However, their long-term implications for communities and ecosystems are difficult to predict. In addition, the effects of climate change on plant-soil interactions occupied a relevant place in MEDECOS. Particularly enlightening were the contributions focusing on cascade

effects on defoliation, decomposition of leaf litter, soil microbial communities, and nutrient availability.

Regardless of the topic, contributions focused broadly on many aspects of global change, including not only changes in weather conditions, but also in drought severity, aridity, land use, fire frequency, and their interaction. In other words, researchers are more interested in the multiple consequences that warming may have on Mediterranean-type biological systems than in the effects of increasing temperatures per se. Generally, researchers clearly struggle to understand and predict organismal responses to global change in MTEs. The reasons are the multiple dimensions and heterogeneity of Mediterranean-type environments as well as uncertainties about the so-called "dark niche" (*sensu* D. Ackerly, University of California Berkeley), that is, the tolerance of organisms under non-analog environmental conditions that are not yet observed in the present day. Clearly, the complexity of the problem is forcing researchers to adopt multidisciplinary approaches in collaborative networks because they require knowledge and skills from a broad range of disciplines.

Evolutionary approaches—The evolutionary approaches to MTE research were an important part of the conference, with one session entitled Evolutionary and Ecological Drivers of Mediterranean Ecosystems as Biodiversity Hotspots, a fundamental topic in MTE research. Other symposia, addressing multiple evolutionary topics,

included Eco-evolutionary Dynamics in a Changing World: Integrating Genes, Traits and Ecosystems; Local Adaptation in the Mediterranean; and Evolutionary Responses to Climate Change: Evidence from Mediterranean Plant Populations; among others. The contributions clearly indicated that understanding the evolutionary consequences of global climate change is becoming a goal of paramount importance in MTE research. We are moving away from studies solely reporting on climate-mediated phenological shifts or variation in species' distribution ranges. After accumulating evidence that organisms have rapidly responded to sharp environmental changes in just a few decades, we now need to understand the mechanisms and processes by which such changes are taking place. This shift in focus may be essential to better predict the long-term effects of global climate change on biodiversity. Given the huge biological value of MTEs as biodiversity hotspots and the fact that they may become seriously affected by increasing warming and aridity, MTEs are extraordinary study systems for the investigation of the ecological and evolutionary consequences of global climate change.

The evolution of plant reproductive strategies and functional traits putatively linked to Mediterranean-type climates was also addressed by a substantial number of contributions from different sessions and symposia, e.g., Plant Reproductive Ecology and Evolution in a Changing Mediterranean Climate, and Contrasting Worldwide Functional Trait Trends in Mediterranean-Type Ecosystems. In place of mechanistic studies devoted to specific lineages, where generalization is only achieved after the accumulation of study cases, researchers are increasingly interested in applying modern techniques of phylogenetic reconstruction and comparative analysis to study functional trait evolution and patterns of plant diversification. These macroevolutionary approaches make use of floristic databases and supermatrix analyses, which use all available character data simultaneously and enable the incorporation of diverse kinds of data, including characters from fossils (de Queiroz and Gatesy, 2007). As a result, some old biological questions that remained elusive due to the lack of appropriate tools are now successfully being addressed for MTEs. A noteworthy example concerns the old idea of convergence between geographically far-flung MTEs. In particular, phylogenetic inertia with origins in pre-Mediterranean lineages, rather than evolutionary convergence driven by a Mediterranean climate, seems to account for the trait similarities among Mediterranean vegetations. Clearly, the success of macroevolutionary approaches in MTEs strongly depends on knowledge of the flora, which is well advanced in practically all MTEs. The Mediterranean Basin represents an exception, as a comprehensive flora is still lacking due to its large geographical area and political division.

Invasion ecology—Finally, it is well known that MTEs have long exchanged many plant species and that some of them became invasive. In short, European species were first introduced several centuries ago in other MTEs mostly for livestock grazing, while at present the flow of introduced species goes the other way around, mainly due to the transport of ornamental plants to Europe. The concern of the MTE research community with combating this problem was tackled in the specific symposium Plant Invasions in Mediterranean-type Ecosystems. In addition, contributions in other sessions also dealt with invasive plants as study cases to address the major questions developed in their respective sessions and symposia. For example, topics of major concern are N-fixing species spreading in

nutrient-poor ecosystems, which are quite common in MTEs, the potential hybridization between closely related native and non-native species and its implications for biodiversity conservation, and the assessment of plant competitive ability between native and invasive populations as one of the main mechanisms accounting for plant invasion. Overall, it was clear that biologists have adopted invasive plants as study systems for the exciting and challenging questions that they pose. Nevertheless, examples of successful long-term eradication of invasive plants in MTEs are still rare, which strongly call for action on the part of the research community.

NEW DIRECTIONS FOR RESEARCH IN MTEs

We analyzed the conference contributions to detect some shortcomings that are worth pointing out, as they might have consequences for the development and impact of biological research in MTEs in the future. First of all, we assessed how the international community is currently developing research in MTEs. Clearly, researchers from MTE countries mainly work in their own MTEs (Fig. 1), which is expected as it is cost-effective. Nonetheless, and because multiple biological patterns converge in all MTEs, we expected more contributions on coordinated research encompassing more than one MTE. In fact, fewer than 20 studies, merely 4% of the contributions, were done in more than one MTE. We believe that the impact, but also the visibility of ecological and evolutionary research in MTEs would be enhanced by increasing the number of studies addressing the same questions in several MTEs. Obviously, our conclusion is highly conditioned by the MEDECOS participants and their contributions, but it is likely to mirror the current situation in MTE research. Further joint projects should be encouraged and supported by scientific societies interested in MTEs to coordinate international research teams pursuing ambitious common research goals in all MTEs.

We detected a strong bias toward basic research (73% of contributions) and terrestrial ecosystems (95% of contributions) in MEDECOS. Although the plant biology community interested in MTEs is large and active, in terms of variety of research lines, development and incorporation of novel technologies, and high scientific productivity, an international conference on MTEs should also raise the visibility of other disciplines and approaches of primary importance for the conservation of MTE biodiversity. For instance, water shortage due to overexploitation, particularly in a scenario of increasing warming and aridity, is always an issue in MTEs as well as the brutal pressure of human activities along Mediterranean coastal lines. These two factors strongly jeopardize the long-term conservation of Mediterranean biodiversity because their progression over time seems to be unstoppable. For this reason, marine and aquatic ecologists, and applied-oriented professionals at the interface between the natural environment and human societies, i.e., geographers and wildlife managers, would be particularly welcome in MEDECOS. Finally, it is worth emphasizing that MEDECOS has always been a plant ecology meeting. In this conference, 81% of the contributions dealt with plants, whereas about 12% of the contributions focused on animals as study organisms. The picture was even worse for contributions dealing with fungi and microorganisms, which represented about 2% of the contributions. Overall, we believe that all these biases may be narrowing the scope of the potential participants in MEDECOS, an aspect that should radically change in the future.

As mentioned earlier, MTEs harbor impressive vascular plant diversity in a relatively small portion of the Earth's land area. Surprisingly, Mediterranean plant systematics was totally absent at the conference. It is difficult to extract the causes of that, perhaps it is attributable to the general decline of taxonomic expertise and interest in biological sciences, but it would be extremely beneficial for MTE research to attract plant systematists interested in Mediterranean-type taxa and bring them to MEDECOS. The timing would be perfect because plant systematics has been experiencing a rapid transformation incorporating state-of-the-art genomic and bioinformatic tools, which is opening new venues for the conceptual and methodological advance of the discipline (Sauquet and Graham, 2016).

OTHER CONSIDERATIONS

The number of participants coming from countries with MTEs outside of the Mediterranean Basin was rather limited, ranging from a low of 10 participants from South Africa to a high of 25 participants from the United States of America. The predominance of participants from Mediterranean Basin countries was expected, as the Mediterranean Basin is the largest MTE and because traditional biological schools from Mediterranean countries in botany, ecology and zoology have been working in their Mediterranean environments since they were established. Although it is difficult to quantify the size of the scientific community working in every MTE, a specific conference on ecology, evolution and conservation in MTEs, such as MEDECOS, seems not to be attracting the attention of MTE specialists.

One of the reasons could be that MEDECOS has to compete with well-established meetings from scientific societies gathering hundreds and thousands of professionals every year, where basic and applied research on MTEs fit perfectly, such as the Botanical Society of America, the Ecological Society of America, the European Society for Evolutionary Biology, the Society for the Study of Evolution, and even the International Botanical Congress also held in 2017. In addition, MEDECOS also has the particularity that the five MTEs are spread throughout all the continents, representing important traveling costs for attendees who may consider MEDECOS as a conference too focused on Mediterranean botanical and ecological issues, which represent the historical and scientific background of the conference. However, this is not the case, as the conference is now highly diverse in topics, approaches and methodologies, enabling a global vision of Mediterranean ecosystems and providing opportunities for interdisciplinary approaches and comparative studies among the five MTEs worldwide. Clearly, imaginative actions ought to be developed to make MEDECOS an engaging and unique periodic event for researchers and wildlife resource managers interested in MTEs.

A recurrent shortcoming in practically all scientific meetings is the underrepresentation of participants from developing countries. We all know that socioeconomic and geopolitical reasons chiefly account for that, particularly in the current Mediterranean migration crisis provoked by overpopulation, deadly conflicts and extreme poverty across some North and sub-Saharan African and Middle East countries. However, in the case of an international conference on MTEs, the complete absence of North African countries was striking. It is widely accepted that the evolution, phylogeography, and in many cases the origin of the Mediterranean Basin flora cannot be understood without the Mediterranean and Saharan Africa (Quézel, 1978; Médail and Quézel, 1999; Lavergne et al., 2013).

Thus, further efforts should be made to build bridges with Mediterranean African countries, e.g., Morocco, Algeria, and Tunisia, to increase their visibility and participation in international scientific meetings. Such points of encounter among botanical, ecological, and evolutionary communities should create opportunities for partnerships and collaborations to develop joint biological research in African MTEs. The need to incorporate African countries into MEDECOS links up with the role of science in social and economic development that should be spurred, promoted and led by scientific societies even beyond the borders of their own countries.

Finally, we are pleased to say that the participation of women in the conference was rather balanced with women representing 44% of the participants. However, we still detected important deficiencies with regard to gender balance in the conference: about one-third of oral communications, one-fourth of invited talks, and one-third of conveners of sessions and symposia featured women. We admit that it is difficult to forecast the attendance and participation of women to scientific meetings to achieve gender parity. In contrast, it is possible to raise the visibility of women scientists by increasing their participation as invited speakers, conveners, and/or organizers until setting gender parity at all levels. With no exception, scientific societies and associations ought to illustrate and promote the basic values, attitudes and behaviors with the sole aim to enhance and enrich human societies beyond scientific advance.

Overall, we stress the value of the accomplishments of the joint XIV MEDECOS and XIII AEET general meeting and its role to disseminate the ecological and evolutionary plant research undertaken in MTEs. However, MEDECOS should widen its scope and goals in the issues outlined here, which can represent long-term scientific, social, and economic assets in MTE countries. The adoption of an advanced strategic planning of the next MEDECOS, to be held in South Africa in 2020, identifying specific goals and targets to be accomplished during and after the conference would provide the means to continue consolidating the biological research in MTEs in a rapidly changing world.

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