Climate change and crop-pest dynamics in the Mediterranean Basin

Climate change will make assessing and managing crop-pest systems in the Mediterranean Basin more difficult than elsewhere on the globe. The Basin is in many ways a hot spot of global change – as higher as the average projected climate change threatens an extremely rich and intertwined biological and cultural diversity– and increases its vulnerability to biological invasions. As a consequence, pest problems in this hot spot will require a holistic approach to deconstruct the elusive complex interactions that are the underpinning a sound decision making at the field level

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Building on over 30 years of multidisciplinary progress inspired by pioneering work at University of California, the ENEA GlobalChangeBiology project, in collaboration with CASAS Global, is developing an interdisciplinary tool to mechanistically describe (i.e., model), analyze and manage agro-ecological problems based on the unifying paradigm that all organisms including humans acquire and allocate resources by analogous processes – the paradigm of ecological analogies that is holistic by design. Recent analyses using this approach show how the tool has provided and will continue to provide governmental agencies with the scientific basis for building eco-social resilience to climate warming into agricultural systems across the Mediterranean Basin and elsewhere.
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The Mediterranean Basin as a hot spot of global change

Climate change is expected to increase temperatures globally and al-

ter patterns of rainfall and other derivative factors that can alter species distribution, abundance and impact in natural, agricultural and medical/veterinary vector/disease systems in unknown ways [1].
The physiology and behavior of pest insects and interacting crop plants is influenced by climate change, and even modest warming can dramatically affect the energy budget of all

stages and diapause specifically via increased respiration and decreases in growth, reproduction and survival [1], and hence impact the species' geographic distributions and relative abundance. The Mediterranean Basin is a global change hot spot for a number of reasons, including expected higher than average climate change in the region, the extremely rich biodiversity it harbors, and its high vulnerability to biological invasions by serious agricultural pests.

Climate change brings additional complexity to crop-pest systems

Complexity is intrinsically high in agricultural systems, and remains the main barrier to their study and management, with climate change and invasive species being additional factors that complicate management issues further [1]. Robinet and Roques [2] point out that understanding and managing insects under climate change is vexing as contradictory results likely arise in field studies, large-scale experiments are challenging, and driving factors include interactions with other species such as host plants, competitors and natural enemies that each respond differently to climate change (see Fig. 1 in the expanded version of this paper). One way to tackle complex problems such as crop-pests interactions that lie at the interface between global change and biological systems (i.e., global change biology) is to analyze them using a mechanistic description of their biology (i.e., a model) based on the unifying paradigm that all organisms, including humans, acquire and allocate resources by analogous processes (paradigm of ecological analogies; see [3].

This approach was implemented in Europe by the project GlobalChange-Biology that framed a collaboration between ENEA and the University of California at Berkeley that continues through the non-profit scientific consortium CASAS Global (see expanded paper http://openarchive.enea.it//handle/10840/8042).

The following section identifies recent and prospective holistic analyses of climate change effects on crop-pest systems in the Mediterranean Basin performed under the joint auspices of GlobalChangeBiology project and CASAS Global, while the analyses are reviewed in the expanded version of this paper. The approach used in the analyses involves using physiologically based demographic modeling (PBDM) of crop-pest-natural enemy interactions in the context of a geographic information system (GIS) (see e.g., [3,4]). A major goal is to link the PBDM/GIS technology with increasingly available biophysical datasets from global modeling and satellite observations, and use them to bridge the gap between bottom-up (primarily physiological and population dynamics) and top-down (climatological) GIS approaches for assessing on ground ecosystem level problems, such as agricultural pests.

PBDM example of some crop-pest systems in the Mediterranean Basin

The olive/olive fruit fly (*Bactrocera oleae*) system. Olive is an ancient, ubiquitous crop of considerable ecological and socio-economic importance in the Basin, and olive fly is its major obligated pest. Climate change will impact the interactions of olive and olive fruit, and consequently alter the economics of olive culture across the Basin [5]. Combining these factors in a bioeconomic analysis enabled estimations of the economic impact of climate change on olive (see Fig. 2 in expanded paper). The same PBDM of the crop-pest system was used to assess eco-social resilience to climate warming in olive systems across the Mediterranean Basin, and was extended to include a mechanistic water balance model to explore the effects of water availability on crop-pest interactions.

The olive/insect vector/*Xylella fastidiosa* system. Insects can also cause indirect damage to crops, as is the case when they act as vectors of pathogens. The bacterial pathogen *Xylella fastidiosa* is simply one of the growing number of exotic invasive species that challenge the Mediterranean Basin [6]. A holistic analysis based on the ecological requirements for growth, survival and reproduction of olive, *X. fastidiosa*, its identified insect vectors and their natural enemies is required to determine the potential geographic distribution, abundance, and impact of this disease. These methods can be used to develop sustainable management strategies and tactics to address the disease on a regional basis. The PBDM approach provides a basis for making such assessments (see [3]), and a good example is the PBDM model developed for grape and the invasive polyphagous glassy-winged sharpshooter (GWSS; *Homalodisca vitripennis*), that is a vector of *X. fastidiosa* that causes Pierce's disease in grape in California, and for two egg parasitoids (*Gonatocerus ashmeadi* and *G. triguttatus*) introduced for biological control of GWSS. PBDM analysis was able to separate and quantify the biotic and abiotic factors that affect the distribution and abundance of *X. fastidiosa* in grape at the geographic scale of California, and similar analyses are expected to achieve comparable results for the pathogen in olive at the Mediterranean Basin's scale. Recent projections of the potential geographic distribution of *Xylella*, with no consideration of vector biology, have been obtained using the correlative ecological niche modeling tool Maxent, and are discussed in the expanded version of this paper (see Fig. 3 in expanded paper).

The citrus/Asian citrus psyllid (*Diaphorina citri*)/*Candidatus* Liberibacter asiaticus system. Asian citrus psyllid is considered the most important pest of citrus worldwide since, in addition to being a destructive invasive species causing direct feeding damage to species of citrus and other species in 25 genera of Rutaceae, it is a vector of the phloem-limited bacterium *Candidatus* Liberibacter asiaticus and other species of the genus (*Candidatus* L. africanus and *Candidatus* L. americanus), that cause greening disease (huanglongbing, HLB) in citrus. HLB is one of the most serious diseases of citrus in many countries across Asia, Africa, and North and South America, and is considered a threat to the survival of the citrus industry in the Mediterranean Basin, where the disease is not yet present (see Fig. 4 in expanded paper). A PBDM of the citrus/Asian citrus psyllid /*Candidatus* L. asiaticus system has been developed to summarize the available data in the literature, and used to assess prospectively the geographic distribution and relative yield of citrus, the relative densities of the psyllid, its parasitoid (*Tamarixia radiata*, currently used in classical biological control programs), and the potential severity of HLB in North America and the Mediterranean Basin. Prospectively, the joint favorability suggests the eastern Mediterranean region is at greatest risk, with only Sicily and small areas of southern Spain included in the upper half of the range (see Fig. 5 in expanded version of this paper).

Other PBDM assessments

Other recent prospective PBDM assessments of crop-pest systems relevant to the Mediterranean Basin include: fruit tree hosts/Mediterranean fruit fly (*Ceratitis capitata*), grapevine/European grapevine moth (*Lobesia botrana*), tomato/tomato leaf miner (*Tuta absoluta*), alfalfa/interacting pests, cotton/pink bollworm (*Pectinophora gossypiella*), and spotted wing Drosophila (*Drosophila suzukii*). Only in the case of *D. suzukii* was the host plant not modeled as it attacks more than 80 hosts and some are widely available for *D. suzukii* reproduction when temperatures are in the favorable range.

Conclusions

The Mediterranean Basin is a global change hot spot since, in addition to being a repository of bio-cultural diversity of global relevance, it is also being particularly challenged by climate change and biological invasions. This makes assessing and managing crop-pest dynamics in the region extremely complex and difficult relative to other areas globally. ENEA's GlobalGhangeBiology project in collaboration with CASAS Global has begun to tackle panoply of global change multifaceted pest problems, using physiologically-based weather-driven geospatial modeling tools that enable mechanistic description of their biology (i.e., modeling), analysis of their dynamics and impact, and the development of environmentally sound management options. The success story for olive and olive fly is a template for analyses that provide governmental agencies with the scientific basis for developing sound policy required to adjust to global change including climate change in Europe and elsewhere.

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