Fiche sujet de thèse 2/ Doctoral project 2

Towards forecasting the impact of climate and anthropogenic disturbances on jellyfish blooms in the Mediterranean Sea. Implications for ecosystems and human health

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Context. - The Mediterranean Sea is one of the most threatened hotspots of marine biodiversity exposed to growing anthropogenic pressures, which together with climate shifts, challenge the sustainable use of resources. In recent decades, the proliferation of massive jellyfish blooms has portended dramatic impacts on the ecosystem functioning, thereby warning ecosystem services for human welfare. The current general understanding of increases in jellyfish abundance point towards modifications of the marine habitat, via the proliferation of artificial substrates in coastal areas, overfishing and ocean warming (Lynam *et al*. 2011; Duarte *et al*. 2013; Marques *et al*. 2015), however thus far a simultaneous multifactorial assessment of potential driving factors of jellyfish blooms and the ecological processes involved has been overlooked. Massive proliferations of jellyfish have gained attention due to their direct impacts on Mediterranean fisheries and tourist industries. The awareness of this phenomenon has triggered large-scale surveys, including the basin-scale JellyWatch, headed by the Mediterranean Science Commission (www.ciesm.org), and the EU-funded Med-Jellyrisk (http://jellyrisk.eu). Scenarios of global change, however, forewarn large uncertainties and threats for this marine ecosystem, i.e. enhanced water temperatures, coastal habitat modification, increase of invasive species and potentially harmful blooms, i.e. jellyfish. Hence, jellyfish hazards may profoundly affect not only economic activities and welfare in the region (Molinero *et al*. 2008; Coll *et al*. 2010; Lejeusne *et al*. 2010), but also threat human health due to the enhanced records of harmful species (Lee et al. 2023). Understanding the foundations of jellyfish blooms and their implications on the Mediterranean ecosystem health is therefore of crucial importance for achieving resilience management in this biodiversity hotspot.

Objectives.- Our goals are to (i) quantitatively assess the jellyfish long-term dynamics in the Mediterranean Sea over the period 1960 to 2020; (ii) disentangle the drivers of their increase, namely the compound effects of rising temperature, overfishing, eutrophication, and the increase of artificial substrates in coastal waters; (iii) build a comprehensive framework to use jellyfish bloom dynamics as indicators of the Mediterranean ecosystem health; and (iv) to forecast the potential impact of warming on the spread or shrinkage distribution of native and invasive Mediterranean jellyfish species and their implications for human health.

Methodology. - We will use a data set created in the framework of the EU project Ocean-Certain which mainly covers the northern coast of the Mediterranean basin. This comprehensive data span from 1960 to 2020 and appears ideal to test isolated effects and their synergies of temperature, fishing, eutrophication, and habitat modification on jellyfish changes. The rational of using these factors stems on their potential role favouring jellyfish population growth. That is, rising temperatures enhance temperature-stable water masses and yield favourable conditions for jellyfish (Molinero *et al*. 2008), while fishing amplifies the effect of warming on jellyfish dynamics by removing competitors and predators (Lynam *et al*. 2011). Similarly, eutrophication promotes conditions known to favour jellyfish over fish populations by boosting turbidity and small phytoplankton and zooplankton taxa, as well as hypoxic conditions (Haraldsson *et al*. 2012). Coastal habitat modification enhances the availability of artificial substrates providing habitat for polyps, thereby promoting favourable conditions for population growth (Duarte *et al*. 2013).

Changes in the Mediterranean climate over the past century will be assessed by using a climate proxy based on monthly anomaly fields of ocean-atmosphere variability (NCEP/NCAR Reanalysis dataset). In addition, historic (HadISST) and forecast (HadGEM1) sea surface temperature for the Mediterranean Sea will be used to assess the potential impact of warming on the thermal niches of the main species of Mediterranean jellyfish, e.g., *Pelagia noctiluca*, *Aurelia* sp., *Rhizostoma pulmo*, *Cotylorhiza tuberculata*, and the invasive species *Rhopilema nomadica* and *Mnemiopsis leidyi*.

As proxy for eutrophication we will use chlorophyll concentration (SeaWiFS derived) and long term records of primary production from the central Adriatic Sea covering the period 1962 to 2005 (Data from the Institute of Oceanography and Fisheries, Croatia), whereas fishing data and fish biomass (small pelagics and demersal fish) derived from long term scientific surveys will be used to test the relationship between fishing pressure and jellyfish biomass (Data from FAO, SeaAroundUs, and the Institute of Oceanography and Fisheries, Croatia). In addition, long term data of coastal modification derived from UNEP will be used to assess the link between increase of coastal artificial substrates and jellyfish proliferations.

To disentangle individual effects of each factor and their interactions we will use a framework for understanding causal processes based on fuzzy cognitive maps and structural equation modelling (SEM). These results will let building a comprehensive framework to quantify the strength of the link between jellyfish bloom dynamics and ecosystem degradation and to use jellyfish bloom dynamics as indicators of the Mediterranean ecosystem health that will be chronologically mapped to assess decadal changes. Lastly, we will assess the thermal niche of native and invasive species. Thermal niches will be confronted with projected Mediterranean warming scenarios to assess potential changes (spread/contraction) in their spatial distribution and to build risk maps of jellyfish species threatening human health.

Expected results. - The proposed research combines a multi-scale framework to develop sound modelling approaches to tackle fundamental questions in global change ecology and current challenges in sustainability science. Failure to incorporate an ecosystem-based perspective of jellyfish bloom dynamics and their socio-ecological implications will yield a misleading picture on how the Mediterranean marine ecosystem will respond to global ocean threats, thus compromising a long-term sustainable use of ecosystem services. These activities will provide a mechanistic understanding of jellyfish' responses to global changes by incorporating population dynamics and ecological niches. The responses will be parameterized and incorporated to network interactions models, including zooplankton-fish links. In addition, these results will provide a thorough understanding of both fundamental ecological questions (e.g., jellyfish bloom dynamics, invasion ecology), human health risks, and resources dynamics directly affecting fish under future scenarios. The output of these activities will contribute to the Marine Strategy Framework Directive (MSFD) to reduce uncertainties of ocean threats and overfishing on pelagic food webs and exploited fish in the Mediterranean basin.

Feasibility. - The above activities have no risks involved in completing the proposed research. The PIs have long experience working in the Mediterranean Sea and have built a solid network of experts interested in the same ecological challenges. In addition, the singular situation to have the long-term data sets required for the proposed research, as well as a large body of experimental results of warming effects on plankton communities provides an excellent framework to achieve the project.

References

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