Ecosystem-based and evolutionary approach to the exploitation of species

for a sustainable management of fished socio-ecosystems

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Project summary:

Given the present biodiversity crisis, sustainable management of populations directly exploited by humans is essential. In the context of fisheries, management is done by modulating the fishing effort, in space or time, in the form of regulations or incentives (eg, definition of quotas, marine protected areas). The vast majority of these regulations are made on a species-by-species basis and ignore ecosystem (eg, change in the interaction network) and evolutionary (variation in age at maturity, adult size) aspects. This PhD project proposes to study these two aspects and their implications for the socio-ecological sustainability of these systems. The aim is to understand how different fishing scenarios affect the propagation of indirect effects within the ecological network, but also how these fishing pressures can affect the co-evolution of species. Finally, the establishment of marine protected areas being an important tool of current fisheries management, we propose to explicitly consider these spatial aspects taking into account the heterogeneity of selection pressures (exploited vs fished areas) at the scale of the region.

Project background:

The massive development of fisheries over the last century, on a global scale, has profoundly affected marine ecosystems. In 2016, the FAO estimated that 30% of exploited stocks were overexploited. A study covering 118 years of UK trawling offers an even more worrying assessment, estimating that 88% of species are overexploited and that biomass losses can reach 94%[1]. At the scale of the network, these declines empty ecological niches, favoring the shift of these systems towards alternative states. Still at the scale of the network, large species, generally predators at the top of the trophic chain, are often more heavily exploited. More than 90% of large fish individuals have thus disappeared from the oceans over the past 50 years[2]. This decrease in the abundance of top predators is likely to alter the abundances of lower trophic level species in cascades (trophic cascades)[3,4].

Because fishing exerts a significant excess mortality on the population, individuals reproducing early can pass their genes to the next generation, the others being counter-selected. Due to growth constraints, these individuals are smaller on average at the time of reproduction. These rapid evolutionary phenomena have been well described over the last decades[5,6]. An evolution towards smaller sizes ultimately constrains the economic sustainability of the activity (large individuals playing a major role in the reproduction of the stock[7]) and its ecological effects (size constrains many ecological interactions). Such evolutionary phenomena for instance accompanied the collapse of cod populations off Newfoundland and altered their recovery[5].

These aspects are generally ignored in current fisheries management. The models used are based on single-species criteria (eg, MSY (maximum sustainable productivity) in Europe, and MEY (maximum economic productivity) in Australia). The thesis project presented here is therefore interested in this network/evolution interface and aims to better understand how it affects the sustainability of fisheries, both on the ecological side (maintenance of the diversity and structures of ecological networks) and on the economic size (maintenance of the productivity and yield of fisheries).

Research questions and proposed methodologies

The proposed work is divided into three independent but complementary axes. Each axis can lead to independent results and publications.

Axis 1: Effects of fisheries on the dynamics of the interaction network

In this first axis, we propose to study how the distribution of the fishing effort between the different species of the network affects its dynamics and the sustainability of the activity. The dynamical models used will be based on the average size of the individuals present within the food web. This phenotypic trait (body size) is indeed ideal for linking ecological and evolutionary effects: (1) body size largely defines the position of different species within the food web (large species at the top of the chain); (2) fishing effort policies are often based on body size (eg, size quotas or due to technical constraints, eg mesh size). Many size-based ecological models can be used, both from the point of view of ecological dynamics[8] and from an eco-evolutionary point of view[9]. Using these models, we will test the following predictions: (i) a balanced fishery between the different sizes allows better socio-ecological sustainability of the system by minimizing the indirect effects of fishing (the so-called “balanced harvesting” hypothesis[10]); (ii) the evolution towards smaller sizes enables the resilience of certain exploited populations (so-called “Evolutionary rescue” hypothesis) but reduces the potential future yield of the activity.

Axis 2: Adaptation of fishing efforts and exploitation sustainability

Fishing effort can also respond to and adapt to variations in the different species present, at different spatio-temporal scales. At the level of the fishing company, effort can be redistributed from one fishing area to another, depending on catches. On larger scales (national or international), regulations and quotas can change according to abundance, for example for the purposes of species conservation and/or maintaining fishing yields. A simplified approach to this question[11], based on a prey-predator couple, shows that, surprisingly, the adaptation of the fishing effort can lead to abrupt shifts. The application of such results in a more complex context (many species, several trophic levels), however, remains unclear. We predict that the abrupt changes should be more reduced in this network context, the effort then varying more continuously. We will study how the sustainability of the system depends on these adaptation processes.

Axis 3: Spatial management of fishing effort (eg, Marine Protected Areas)

Given the current precarious management of fisheries, the establishment of Marine Protected Areas is currently seen as a viable alternative. It could allow good sustainability, the areas left in reserve supplying fish to the adjacent exploited areas. An important question then concerns the optimal design of such protected areas (eg, proportion of the space to be protected, one large protected area or several small ones, etc.)[12]. Work on this question generally ignores network and evolutionary aspects. However, the establishment of reserves actually creates heterogeneous selection in space. Depending on the dispersal rates of species (and therefore gene flows between different areas), the effects of such marine protected areas can therefore be very different, and influence the eco-evolutionary dynamics linked to fishing. The effect of this heterogeneity will be different for large-bodied species for which the spatial scale of foraging is larger. We will study these questions and predictions, by developing spatially explicit models within which we will spatially vary the fishing effort (eg, discrete models with different patches). These spatially explicit models being more complex to set up, this axis will first be considered from a simplified angle (eg, using not a network, but two or three species in a trophic chain), then developed at the scale of the network.

Approach, supervision and candidate:

For each of the three axes, starting models are clearly identified, most often in connection with past work of the supervisors. In addition to the proposed network simulations, simpler situations (eg, limited number of species, simplified fishing scenarios) will also be sought in order to be able to analyze the associated dynamics more completely (mathematically). The comparison with empirical cases will make it possible to discuss the relevance of the models. The collaboration envisaged in this thesis with Eric Tromeur (biodiversity and resources office) will make it possible to develop this interface. The subject, at the interface between the sustainability of socio-ecosystems, eco-evolutionary dynamics and their application to global changes, may interest many journals in the field (eg, Ecology Letters, American Naturalist, Global Change Biology).

Supervision will be led by Nicolas Loeuille and Jean Christophe Poggiale. The two supervisors have been working side by side for many years and have already started collaborations and co-supervisions. N. Loeuille has developed many ecosystem and eco-evolutionary models. JC Poggiale is a specialist in mathematical modeling applied to ecology. Their previous work[3,4,9,11] on the size structure of networks and populations will facilitate the implementation of the project. The two co-supervisors have significant experience in supervising PhD students. Eric Tromeur, non-supervisor, will take part in the collaboration. His participation will allow us to discuss certain empirical aspects and thus to deepen the discussion concerning the validation of the models.

This project is particularly suited to BEE (Biodiversity Ecology Evolution) type master profiles oriented towards theoretical aspects and modeling or to master profiles in modeling or applied mathematics.

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