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How does fishing alter marine populations' and ecosystems' sensitivity to climate? – An introduction

The effects of climate and fishing on marine populations and ecosystems have conventionally been considered separately and it has often been suggested that they should be disentangled from each other. However, exploitation not only modifies the abundance of targeted or by-catch species but can also affects demographic structure, stock structure, geographical and migration patterns, species composition and trophic pathways. As a result, climate and exploitation interact in their effects and evidence has accumulated to demonstrate that fishing pressure can have direct consequences on the way in which climate signal propagates through populations and ecosystems.

In September 2006, a workshop was hosted in the Berlin Museum of Natural History under the auspices of the international program Globec. A specific topic of this workshop was to examine the sensitivity of marine ecosystems to climate and human exploitation. Theme Session F on ICES 2009 Annual Science Conference follows some of the ideas presented in the original Globec workshop. In the present contribution, we summarise the conclusion from that Globec workshop and review some of the recent findings obtained since then, as an introduction to the state of the art of research related to this Theme Session, and to promote debate within the Session.

We conclude that the understanding of climate-fishing interactions is still in its infancy. This calls for increasing efforts in studying the interactions between the effects climate and fishing, in particular in a context of global climate change and globalised fisheries.

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Effects of climate and fishing

The state of marine populations, communities and ecosystem is well known to fluctuate over temporal scales ranging from seasonal to millennial. Investigating the cause behind these variations has been central to marine ecology in general and fisheries ecology in particular. These causes are obviously multiple, complex and often combined, and despite more than a century of investigation, their study is far from being achieved. In practice, the causes for fluctuations in marine ecosystems have been investigated as three types of processes. First, processes that are internal to the biological system studied, such as density dependence or multi-species interactions. Second, processes that are driven by variations in abiotic conditions, ultimately controlled by climate. Third, processes which result from the intensive mortality inflicted by human activities, mostly fishing exploitation. It has been and is still conventional to study these effects separately, due to lack of interdisciplinary knowledge and data, as a way to reduce the complexity of the analysis and/or due to requirements to try to separate and measure human impact alone. However, as the interaction between different drivers becomes more evident, there is a current tendency to conduct more comprehensive studies in which the different types of causes are integrated in the same analysis. The purpose of the current ICES session is specifically to examine such kind of studies in which biological, climatic and fishing processes are jointly studied with a view to understand the complex drivers behind the fluctuations in marine systems over time.

September 2006, the Globec workshop

In September 2006, a workshop entitled "impact of climate variability on marine ecosystems: a comparative approach" was hosted in the Berlin Museum of Natural History under the auspices of the international program Globec (Global Ocean Ecosystem Dynamics). The workshop was structured in four working groups. One of these groups specifically focused on the sensitivity of marine ecosystems to the combined influence of climate and human exploitation.

The main results for the workshop are summarised in a series of articles soon to be published in Journal of Marine Systems (with most articles already available electronically from the Journal's website). Some of the main conclusions are outlined below.

The evidence for high variability in marine systems at centennial to millennial scale can be demonstrated from sedimentary records. To a large extent, this variability can be attributed to

past climate variability (Finney et al. in press). The nature of ecosystem response to climate variations can emerge in three main fashions: directly driven responses, transient responses and nonlinear feedback responses (Overland et al, in press) and the mechanisms leading from the climate signal to the biological response are still to a large extent obscure (Drinkwater et al, in press). Human exploitation on marine systems brings another level of complexity to already complex investigations of climate-biological interactions in the oceans. Planque et al (in press) argue that it is unrealistic to try to separate climate-induced from fishing-induced effects, and they investigate how fishing can change the way exploited marine populations and ecosystems respond to climate. They provide a number of examples to demonstrate that fishing pressure can reduce diversity at the population and ecosystem level by (i) reduction of age/size composition, (ii) depletion/removal of metapopulation units, (iii) alteration of life-history traits, and (iv) increase in population/ecosystem turnover rates. This is expected to lead to a reduction of the resilience of populations/ecosystems to climate impacts. Of particular interest is that ecosystems under intense exploitation which suffer a decrease of their top predators seem to evolve towards stronger bottom–up control, at the expense of top–down control, leading to greater vulnerability of the respective ecosystem to climate forcing. Perry et al. (2009, in press) conclude by pointing out that, whereas exploitation increases the sensitivity of marine systems to climate variability, climate change accumulates sufficiently slowly that it is unlikely to have as immediate an impact on marine systems as climate variability or exploitation.

Many of the above conclusions are still based on a limited number of empirical evidences, theoretical models or robust statistical analyses and this situation calls for thorough studies of the interacting effects of forcing by climate and fishing when trying to mitigate their negative consequences.

Approaches and state of the art since the Workshop

In the last three years, an increasing body of literature on climate and human effects on fisheries have appeared in the mainstream journals. Although references to the importance of "disentangling climate and human effects" still exist in some ongoing research projects (e.g. EU project RECLAIM - REsolving CLimAtic IMpacts on fish stocks), some recent works claiming the inability to separate those drivers and the importance to study their combined effect start to appear (e.g. Rolland et al., 2008; Rouyer et al., 2008). Among this last group, recent developments on coupled biophysical ecosystem models have provided a tool which is regarded as one of the most promising in investigating combined effects of climate and

fishing (e.g. Travers et al., 2007). Examples of expert groups dedicated to analyse combined effects of fisheries and climate or use integrated ecosystem models to analyse these effects also exist, such as CLIMAFISH (http://climafish.wikispaces.com/) or the recent workshop on "*Applying IPCC-class Models of Global Warming to Fisheries Prediction*" (http://www.gfdl.gov/fisheries-and-climate-workshop).

Pressing issues

Understanding the interplay between climate, fishing and the internal dynamics of marine systems is becoming critical in a context of global climate change, globalised fisheries and possible major shifts in marine ecosystem states.

The managers way of approaching the issue is often by investigating how climate variability and change may modify marine systems biological and economic productivity in the future and find ways to mitigate possible negative outcomes (Beaugrand et al, 2008, Brander, in press). The tight connection between climate-biology and fishing is on the other hand often overlooked and so the indirect consequences of fishing on marine systems are poorly anticipated. What controls the resilience of marine systems in the face of climate variability and change, and how this can be altered by fishing requires in-depth investigation, for fisheries practices and management strategies adapted to future climate conditions to be developed.

Since the September 2006 Globec workshop, evidence has continued to accumulate that in many ocean regions, climate and fisheries are acting in a synergistic manner (e.g. Kirby et al, 2009) and that this may lead to dramatic shifts in ecosystem states (e.g. Richardson et al, 2009). Such synergy is also visible at the level of fish populations. In 2006, Hsieh et al demonstrated that high levels of fishing can lead to increase in fish abundance variability. In a following work by the same group, Anderson et al (2008) investigated the possible causes behind the increase in variability. They argued that it was fishing-induced changes in population dynamics characteristics (density-dependence) which was most likely responsible for increased variability rather than closer tracking of climate signals, as argued above (Planque et al in press, Perry et al in press). This is still a very open question, since not all fish populations may display over-compensatory density dependence, a necessary condition for the mechanism described by Anderson and his colleagues to happen.

Where to go from there?

It is clear from existing evidence that fluctuations in fish abundance and in marine ecosystem states result from the combined effects of climate, fishing and internal biological processes but what is less clear is how these processes have interacted in the past, and more importantly how they can interact in the future. Current knowledge is still parsimonious and most models (either conceptual on numerical) remain simple when not simplistic. Marine ecosystems are complex adaptive systems (sensu Levin 1998) and while they dynamically respond to forcing from climate and human pressure, they are modified in such way that their future responses to similar forcing will likely be different. The challenge is now to reveal how the interactions between climate, fishing and the internal dynamics of marine systems are articulated and how such knowledge can be applied for the management of living marine resources (Mahon et al, 2008). The purpose of session F of the ICES Annual Science conference is to contribute to the increasing body of knowledge and evidence on this question by providing empirical evidence for how (and not just 'if') fishing may influence the sensitivity of marine populations and ecosystems to climate.

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