Ecological thresholds and trophic cascades: implications for the recovery of an open marine ecosystem

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Excessive fishing pressure in overexploited and low diverse pelagic ecosystems may have a large impact in the functioning of marine food webs. This has long been a running subject of debate and is of central importance for the management of marine ecosystems. In pelagic marine ecosystems, food webs are characterized by complex interactions that make identifying trophic cascades, from top-predators to primary producers, in open marine ecosystems difficult. Similarly, evidences of temporal shifts in food web dynamics are not common, and usually have been related to changes in climate. At present, understanding how and under which circumstances marine ecosystems respond to anthropogenic and climate forces bear vast management implications. Without a food web perspective it is difficult to understand why in some cases there is a lack of recovery of overharvested fish species in some parts of the world, despite thoughtful management controls of the fishery. Analysis of field observations through the years 1974 to 2005 in the central Baltic Sea has provided evidence for a reorganization of the ecosystem caused by cascading effects of the top predator collapse, the cod, and has allowed identifying some of the causal mechanisms that have inhibited the recovery of cod in recent years.

In the Baltic Sea, after the decline of seals and other populations of marine mammals principally due of hunting, cod has been the top predator. However, from the early 1980s, cod sharply declined mainly because of high fishing pressure that came along with unfavorable environmental conditions for its recruitment; that is, the lack of salt- and oxygen-rich water inflows from the North Sea into the Baltic basin. In fact, higher salinity of the mid-deep waters not only enhances the buoyancy of cod eggs and prevents them from sinking into hypoxic water layers it also favors the development of the main food sources for cod larvae. Since the late 1980s, the cod stock has been low, and it has not shown any tendency to recover. The low abundance of cod has allowed a substantial increase in the sprat population, a small pelagic fish that mainly feeds on zooplankton. As a consequence, zooplankton, mainly herbivorous crustaceans, declined markedly and phytoplankton increased.
The removal of cod has percolated down through the food web leading to a shift in the structure and functioning of the pelagic food web of the central Baltic Sea. In fact, in recent decades, increased blooms of possibly harmful phytoplankton that may be toxic to people, fish and other wildlife have been observed, and it is thought that the decrease of zooplankton is one of the causes of such phenomena (Casini et al. 2008). In addition, the cod collapse has altered the food web links in the central Baltic Sea during the last three decades. Food web links appeared sensitive to an ecological threshold defined by a total sprat abundance of 17×10^{10} individuals that separates two alternative ecosystem scenarios in which the food web links change drastically. Below such an ecological limit, cod controlled the sprat population which does not affect significantly zooplankton biomass, as statistical analyses suggest. In contrast, and more importantly, when

Baltic Cod. Photo: B. Ueberschär, IFM-GEOMAR

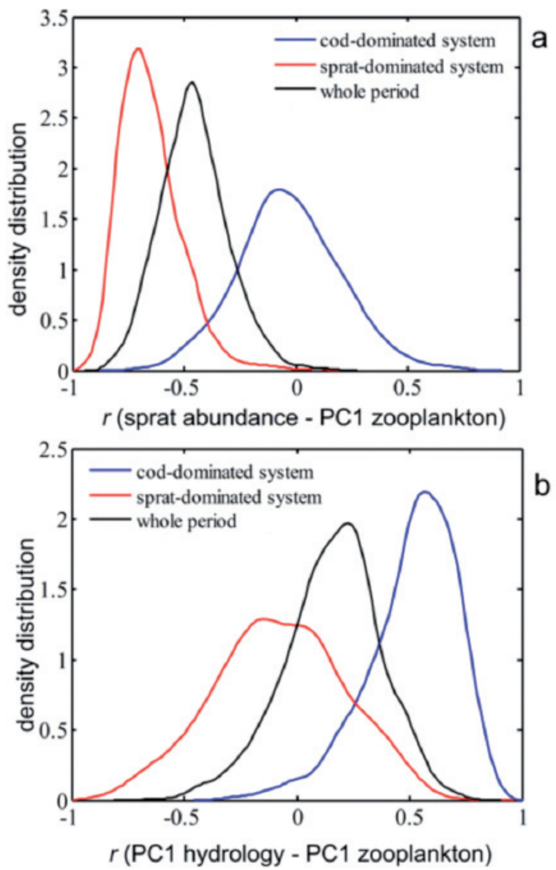

Figure 1: Alternative scenarios of the central Baltic Sea ecosystem related to the dominance and crash of the cod. (a) The two configurations are illustrated by the changes in the relationship between sprat abundance and zooplankton biomass. When cod dominates the system it controls the sprat population, which does not affect significantly zooplankton biomass. This drastically changes in the absence of cod, as sprat heavily controls zooplankton biomass. (b) Changes in the relationship between hydrological factors and zooplankton in the ecological scenarios of dominance and crash of the cod. The cod-dominated scenario prevents the heavy sprat control on zooplankton. In such a case, hydrological conditions are more relevant for zooplankton growth. Conversely, when cod crash and sprat dominates the system, its heavy influence on zooplankton emerges even more relevant for zooplankton growth than the influence of hydrological factors.

sprat abundance was higher than the threshold, sprat controlled not only zooplankton biomass but also their spatial localization. In fact, zooplankton organisms were concentrated in deeper waters. The strength of the sprat control emerged even stronger than the effect of hydrological conditions on zooplankton. In figure 1 the alternative scenarios of the central Baltic Sea ecosystem are shown. These two scenarios are illustrated as the relationship between sprat abundance and zooplankton biomass (Fig. 1a), and the link between zooplankton and hydrological factors (Fig. 1b). These changes in food web links highlight the role top predators may have as ecological buffers in marine ecosystems. In this particular case, it is clear that cod acts as a regulator of sprat abundance being able to buffer high-sprat recruitment events and their severe consequences in lower levels of the food chain (Casini et al. 2009).

In recent years, hydrological conditions for cod recruitment have improved not only in terms of favorable conditions for eggs and larval survival, but also potentially favoring the development of one of the key zooplankton prey for cod larvae, the copepod *Pseudocalanus*. The cod recruitment, however, has failed and the population stock remains low, probably because of the high sprat abundance that continue to be higher than the ecological threshold driving the pelagic food web in the central Baltic Sea (Casini et al. 2009).

This study shows that empirical food web data can provide relevant information for disentangling the combined effects of human-induced disturbances (e.g., overfishing) and climate change on marine ecosystems. It should be noted that harvested species may be seen as part of a large, dynamic, trophic network, with a high probability of being susceptible to top-down control, generating cascading effects through the food web. This stresses that changes in ecosystem functioning, potentially difficult to reverse, can be a result of variations at the higher trophic levels directly affected by human exploitation, and not only the consequence of climate change.

References

Casini M., J. Hjelm, J.C. Molinero, J. Lövgren, G. Kornilovs, M. Cardinale, V. Bartolino, and A. Belgrano, 2009: Trophic cascades promote threshold-like sudden shifts in the functioning of a pelagic marine ecosystem. *Proceedings of the National Academy of Sciences*, **106**, 197-202. doi:10.1073/pnas.0806649105.

Casini M., Lövgren J., Hjelm J, Cardinale M., Molinero J.C., and Kornilovs G., 2008: Multi-level trophic cascades in a heavily exploited open marine Ecosystem. *Proceedings Royal Society B*. doi: 10.1098/rspb.2007.1752.