A model of fish and jellyfish competition
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Introduction

Jellyfish ecology attracts increasing attention in marine research, sparked by a number of spectacular cases where jellyfish have proliferated to the apparent detriment of fish stocks, most famously in the Black Sea. Some researchers have suggested that the frequency and magnitude of jellyfish blooms are increasing worldwide, and that anthropogenic impacts are responsible, but detailed studies of jellyfish ecology are difficult to conduct, because of the lack of good time series on jellyfish populations, as well as the difficulties involved in sampling, collecting and processing them both in field studies and in the lab.

Model studies are therefore an attractive approach to increasing our understanding of these systems, but in spite of this, jellyfish are underrepresented in ecosystem models.

Whether globally increasing or not, jellyfish outbreaks could potentially have huge economic impacts, due to losses in fisheries, tourism, and through obstruction of important infra-structure, and mechanistic models provide an opportunity to explore the causality behind the observed patterns.

Methods

• We present a general mechanistic model of fish-jellyfish interactions.
• Jellyfish are generally considered to be trophic ‘dead ends’, so we assume a ‘killing the winner’ type food web (Figure 1), containing a resource specialist (fish) and a defence specialist (jellyfish).
• We link key characteristics of organisms with the behaviour of the ecosystem through mechanistic descriptions of processes at the individual level, such as the clearance rate of fish (β): 

\[ \beta = \alpha \beta_0 \sin \theta \left( \frac{v_{fish}}{v_{pred}} \right) \]

Where \(\alpha\) is the capture probability, \(\theta\) the visual half angle, and \(v_{fish}\) and \(v_{pred}\) denote the swimming velocity of the predator and prey. Visual range \(R\) is a function of light and prey size, and is calculated according to the model of Akçua & Utne (1997, see Figure 2).

• Because of parameter uncertainties, we compare the predicted clearance rates to observations from Akçua et al. (2011), in order to verify that they fall within realistic boundaries (Figure 3).
• The food web system was modelled as a system of 5 coupled differential equations and solved analytically to yield equilibrium biomasses for a range of primary productivities and fishing mortalities.

Results

Main results are shown in Figures 4, 5 and 6, respectively. Some notable features are:
• For increasing system productivity (Figure 4), the model predicts a series of invasions of species and staggered control of alternate trophic levels. Jellyfish are the last to invade, and continue to increase with primary production.
• There is a large region of coexistence of jellyfish and fish (Figure 4), during which forage fish increase and predators decline with both primary production. Fishing mortality on forage fish initially only affects predator fish biomass (Figure 5).
• At threshold values of primary production and fishing mortality, predator fish go extinct. Forage fish thereafter rapidly decline in biomass, followed by extinction (Figure 4 & 5).
• The entry of jellyfish in the system is robust to fishing mortality on forage fish, but the region of coexistence gets narrower with both increasing fishing and primary production (Figure 6). The combined effects of fishing pressure and primary production may thus push the system out of the region of coexistence, where change in either alone might not.

Discussion & Conclusion

We compare the findings of this study with the case of the Black Sea, a relatively simple and heavily impacted ecosystem, with a well-documented case of jellyfish proliferation.

• The model produce biomasses which are within observed values for e.g. the Black Sea (see e.g. Oguz & Gilbert, 2007)
• A key model feature is the control of forage fish by predator fish, which allows jellyfish to invade the system. This staggered control has been heavily implicated in the Black Sea (e.g. Daskalov, 2002).
• Trophic cascades and control is rarely as pronounced as for this relatively simple model (Heath et al., 2014), but sudden shifts in community structure similar to what is predicted here and related to overfishing and eutrophication have been documented previously by Oguz & Gilbert (2007) and by Daskalov (2008).
• There is some debate as to whether overfishing or eutrophication is the primary driver of jellyfish regime shifts, but these results indicate that fishing may well erode the resilience of the system towards eutrophication, and vice versa.
• This stresses the importance of ecosystem-based management.

References: