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The Trophic Spectrum : a tool for assessing the effects of fishing on marine ecosystems at a global scale.

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1. The EcoTroph model

The present study is based on the EcoTroph model (Gascuel 2005, Gascuel *et al.* 2009), which is proposed as a plug-in module of the Ecopath with Ecosim software (EwE version 6). This model provides a simplified picture of ecosystem functioning; it allows users to represent the distribution of the ecosystem biomass as a function of trophic levels, and to analyse or simulate fishing impact in a very synthetic way.

In the EcoTroph approach, the biomass per trophic group and the catch per fishery is represented as a distribution over trophic levels, assuming that the distribution of the biomass (or production or catch) of a trophic group around its mean trophic level follows a lognormal curve. The Biomass (or production or catch) Trophic Spectrum is the curve obtained by summing all biomasses. This representation provides a very synthetic overview of an ecosystem and may help users to think at that scale. Thus, trophic ecosystem functioning can be modelled as a continuous flow of biomass surging up the food web, from lower to higher trophic levels, because of predation and ontogenetic processes (Fig.1).

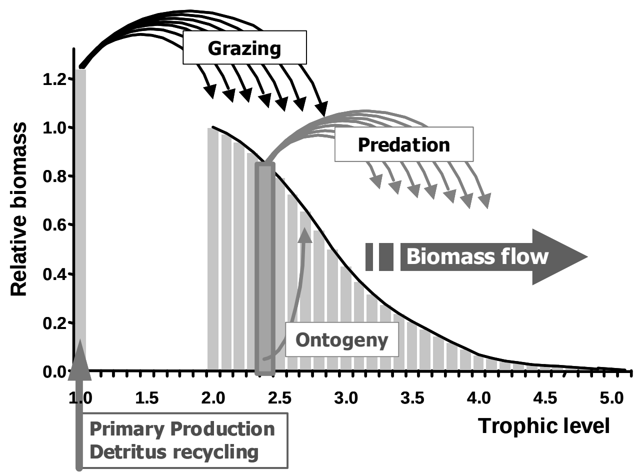

Figure 1. Diagram of the trophic functioning of an ecosystem, in EcoTroph: theoretical distribution of the biomass by trophic level and trophic transfers processes (from Gascuel et al., 2009).

2. The dataset : a global scale vision

Based on the EcoTroph approach and using the trophic spectra representations we compared various ecosystems and we conducted a meta-analysis of the impact of fishing at the worldwide scale. 57 recently published Ecopath models were considered (Fig. 2), representing various marine ecosystems in terms of size, latitude, productivity, type of ecosystem, exploitation, etc…For each of them, biomass, production, consumption and catch trophic spectra are built.

Figure 2. Map of the 57 Ecopath models used

3. Typology of marine ecosystems trophic functioning

First, two typologies of marine ecosystems trophic functioning were defined using biomass, production and consumption spectra: one using an a priori classification of ecosystem types (Fig.3a) and an other based on PCA-HAC statistical tools (Fig.3b).

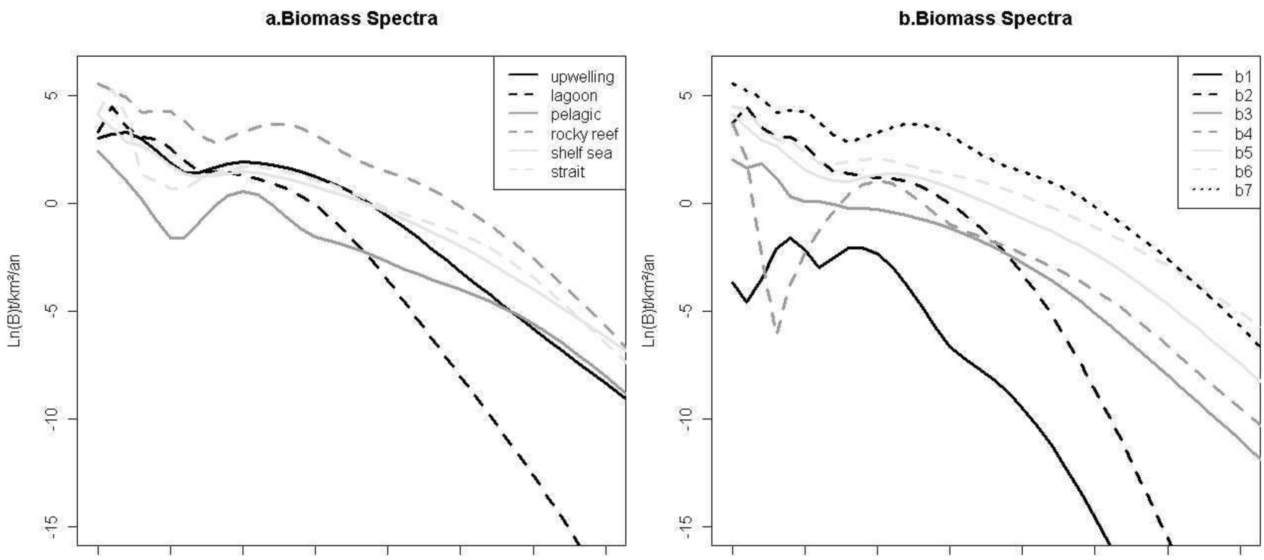

Figure 3. Typology of marine ecosystems trophic functioning : the biomass spectra view (a. a priori classification method, b. statistical method:)

This analysis points out some clear differences in ecosystems functioning. For instance, the b7 class appears to be very closed to rocky reef ecosystems, characterised by an abundant biomass for all trophic levels and high trophic efficiencies. Conversely, the b7 and lagoon classes exhibit low trophic efficiencies inducing low abundances of the highest trophic levels (Fig. 3). However, some types found by statistical analysis are not clearly identified. Two principal assumptions can be formulated in order to explain this: a priori classification could sometimes be wrong considering trophic functioning and/or Ecopath models used could represent a skewed image of the ecosystem.

4. Assessing the effects of fishing at the ecosystem scale

Three different spectra allow a view on the ecosystem exploitation (Fig. 4). The catch spectra (Y) provides an overview of the catches at the ecosystem scale. The fishing effort spectra (F = Catch/Biomass) allows identifying which trophic levels are targeted, whereas the fishing loss biomass rate (φ = Catch/Production) is a measure of the fishing impact.

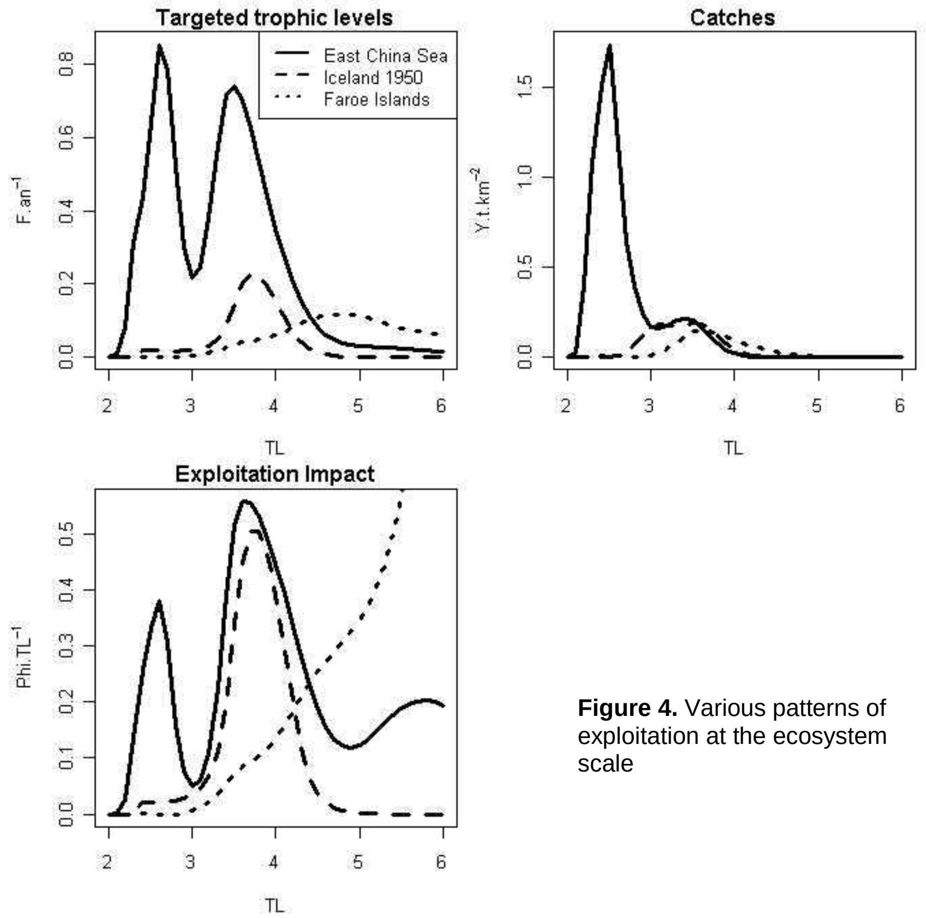

Figure 4. Various patterns of exploitation at the ecosystem scale

These spectra strongly differ among ecosystems, defining various patterns of exploitation (Fig. 4). For instance, in the East China Sea, low and intermediate trophic levels (around 2.5 due to an high exploitation of shrimps and 3.5 notably due to the exploitation of beltfish, respectively) are intensively targeted (F close to 0.8 year^{-1}); even if a large majority of catches comes from the low trophic levels, due to their high abundances, the impact is stronger for the intermediate ones (where more than 50% of the yearly production is harvested). Conversely, in Faroe islands the fishery targets the highest trophic levels (TL>4.0), with moderate fishing mortalities (F<0.2) but an high level of impact on production (and thus biomass) of top predators. The Iceland case study is characterised by a very selective fishery (mainly toward cod), in term of the trophic levels targeted (around 3.8); it also shows that moderate fishing mortalities (F around 0.2) may induce an high impact on production, in such a cold waters ecosystem.

5. Assessing the effects of fishing at the ecosystem scale

Finally, using EcoTroph, we simulated various patterns of exploitation on a theoretical ecosystem defined as the mean of all the 57 Ecopath models (Fig. 5). Three scenarios are considered: (a) the mean worldwide exploitation pattern, (b) a fisheries targeting low and intermediate trophic levels, and (c) a fisheries where high trophic levels are also targeted.

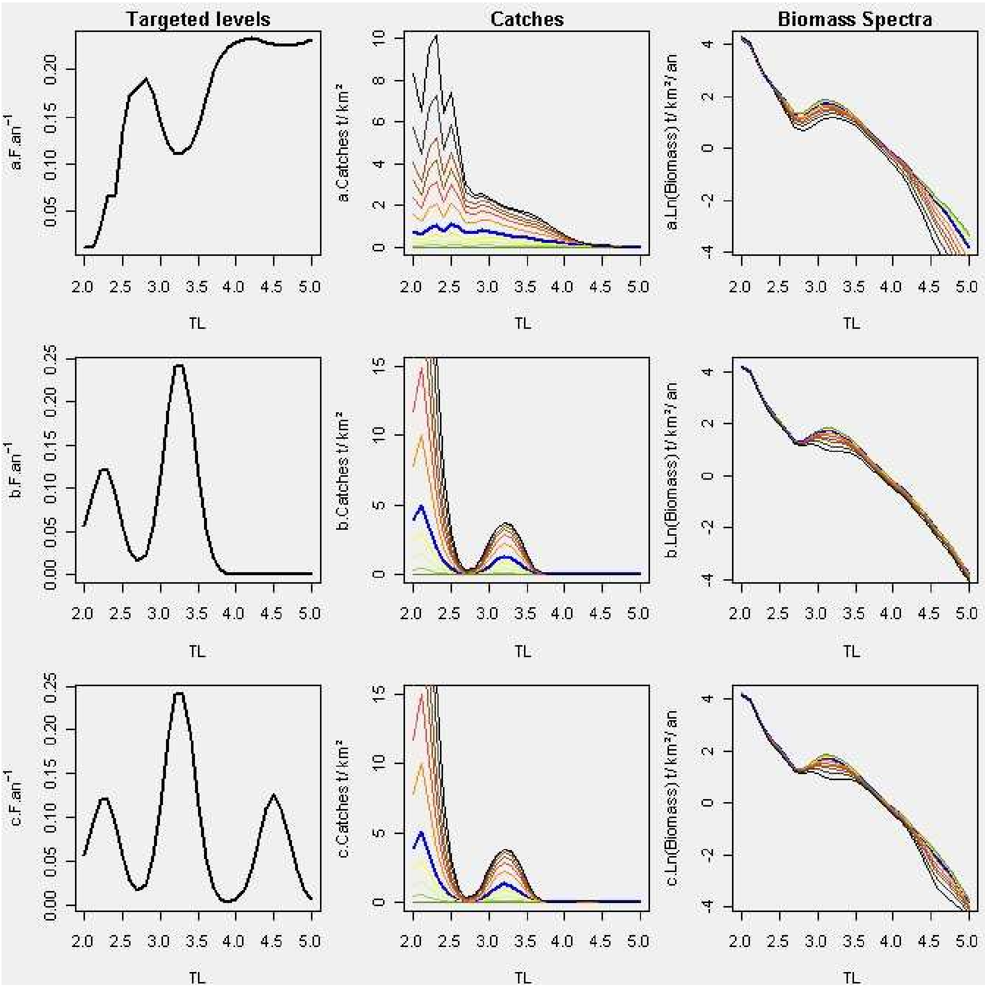

Figure 5. Effects of different patterns of exploitation (a. mean worldwilde pattern, b. and c. simulated patterns) on the mean worldwide trophic model

Nowadays, at the ecosystem scale, almost all the tropic levels are targeted with catches more important toward low ones whereas high ones are the most impacted (Fig.5, upper line). Low trophic levels appear to be easier to exploit (providing higher catches) and more resilient than the higher ones (Fig.5, middle and lower lines).

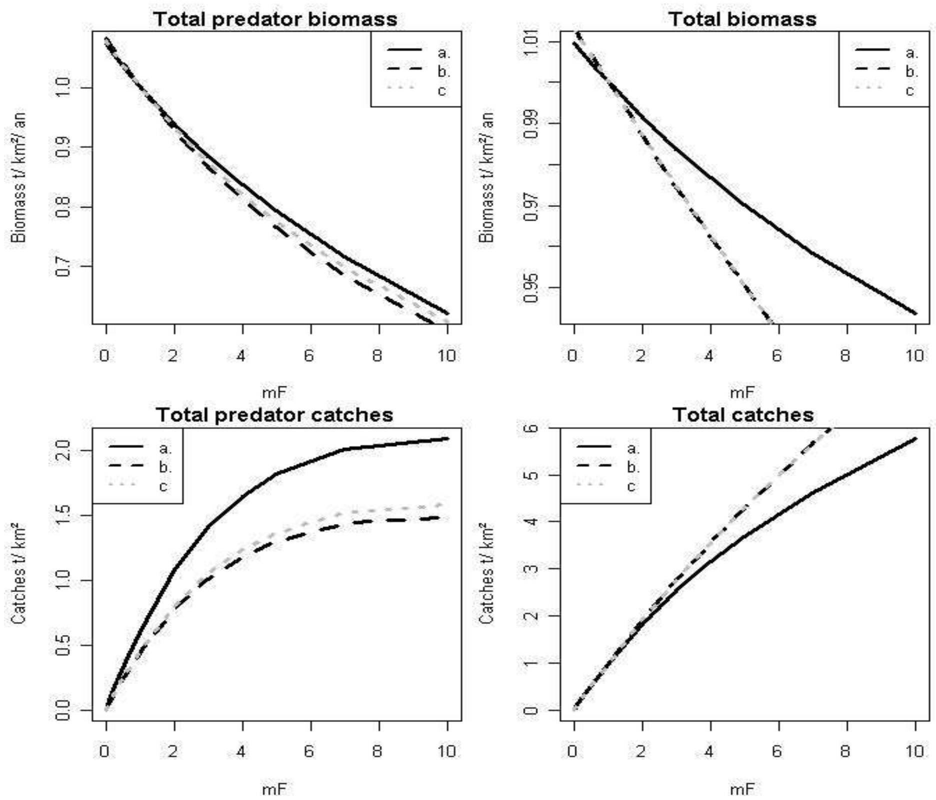

Figure 6. Impact of increasing fishing effort on biomass and catches, regarding: the total ecosystem biomass and catches (right) and the predator biomass or catches (left)

The high exploitation rate produce a faster decrease in the total biomass for the (b) and (c) patterns than for the (a) one. The biomass of predators (TL>3.5) is very sensitive to fishing and decrease fast with an increasing effort for all the simulated scenarios (Fig.6).

The higher and more distributed fishing effort applied on high trophic levels in scenario (a) allows higher catches on top predators than in patterns (b) and (c). Nevertheless an over-exploitation of the top predators can be simulated for the three cases and strengthen the current state of over-exploited ecosystems (Fig.6). However, the total catches figure shows that it is still possible to catch more, targeting low trophic levels which are very abundant (mullets, shrimps, molluscs, juveniles…).

In conclusion, the Trophic Spectrum is a synthetic tool which permits to compare various marine ecosystems, to characterise the main parameters of their trophic functioning, and to define patterns of exploitation at the ecosystem scale. In an ecosystem-based management perspective, the use of Trophic Spectra and EcoTroph simulations appears a promising way.

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