Using Species Sensitivity Distribution to capture ecosystem scale fisheries impacts on biodiversity

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1. Introduction

The impact of fishing on ecosystem quality is a newly established endpoint impact pathway that uses individual stock modelling to quantify the direct removal of biomass from a target population (Hélias et al. 2023; Stanford-Clark et al. submitted). However, the whole impact of fishing reaches far beyond target stocks. Removing often-significant portions of certain populations indirectly affects other species present in the ecosystem, primarily through the alteration of trophic interactions.

This new approach aims to improve the assessment by accounting for both direct and indirect impacts of biomass removal by fishing at an ecosystem scale, providing a more holistic representation of fishing impacts on biodiversity in Life Cycle Impact Assessment (LCIA).

Besides the challenge of capturing the complex dynamics of the marine system within the impact-modelling phase of Characterisation Factor (CF) development, the final impact must be compliant with the available LCIA framework. For this, and based on the effect factor (EF) modelling in toxicity and ecotoxicity (Rosenbaum et al. 2008; Verones et al. 2020), Species Sensitivity Distributions (SSD) to fisheries pressure are used to capture ecosystem-scale impacts of fishing in a single CF value per target catch.

2. Materials and Methods

The EF in relation to contaminants is generally defined by species-specific effect-concentration curves, and then, from these curves at a given threshold point, (such as the EC20), SSD curves are constructed. Based on this framework, concentration-effect curves are replaced here by the catch-depletion relationship of fish species. The time-dynamic ecosystem model Ecopath with Ecosim (EWE) is used to model cause-effects between pressure (fishing and trophic interactions) and the proportion of each fish population present.

The Adriatic Sea (FAO Area 37.2.1) is used as a proof of concept to consolidate this new methodological approach, based on FAO reported catches (individuals/tonnes of species), as a precursor of a regionalised, globally applicable method.

3. Results and Discussion

Effect-mortality curves are compiled for biomass depletion of fish stocks (effect) due to increasing target catch (impact “concentration” equivalent) as follows:

- Fishing pressure on a given target species$_i$ is individually adjusted in the EWE model between 0 and a max value that yields 100% mortality, whilst maintaining all other species occurring in the system at their current exploitation rate. This allows CFs to be obtained at the end of the process.
- Depletion curves are computed from the corresponding steady states obtained by the increasing fishing pressure, this pressure is expressed relative to a reference state: the carrying capacity of the stock- representing a hypothetical pristine state against which damage to biodiversity can be quantified.
- The point where each stock depletion curve crosses the reference threshold is plotted on a single SSD curve per target species, in order to then generate ecosystem scale impact values of fishing in Potentially Affected Fraction of species (PAF) units.

For the latter, unlike increasingly lethal ecotoxicity effects, biotic resources can have non-linear responses to combined fishing and predation pressures, where the depletion of a target species can provoke an increase in others. Positive abundance change is often considered beneficial, however the unchecked proliferation of a certain species can create uneven distribution of the ecosystems biomass and become detrimental to biodiversity. To deal with both overexploitation and overexpansion effects in populations, two impact thresholds are defined (Figure 1), using 20% (+/-) change in biomass relative to the reference state (B0). A species is considered affected when its biomass crosses first one or other of these thresholds. Stock carrying capacity, available as an output of the CMSY algorithm (Froese et al. 2017), represents the maximum ecologically sustainable biomass of a stock; and is therefore considered an interesting departure point from which to quantify and communicate impacts on biodiversity.

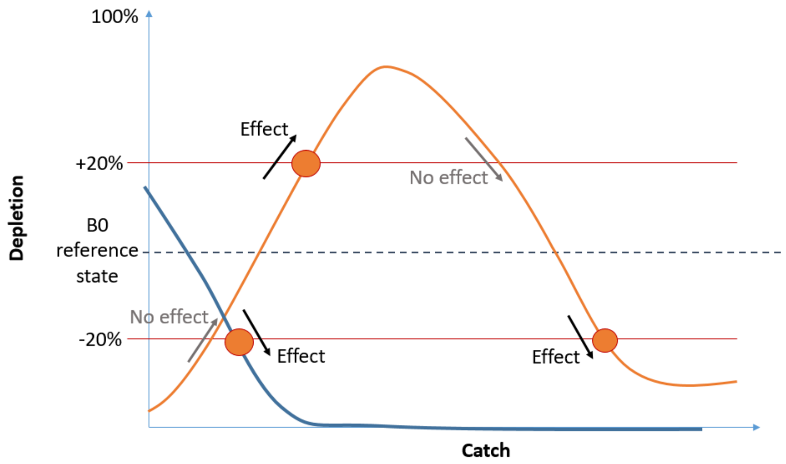

Figure 1: Dual impact threshold to define PAF based on positive and negative population changes.

CFs are derived from the PAF curve using the marginal and average approach, following the effect-based PAF approach (Henderson et al. 2011) but according to the current catch pressure in place of a HC50 value.

To exemplify the approach, novel midpoint CFs are computed for 41 Functional Groups containing 194 marine species reported as exploited in the Adriatic Sea, according to FAO fishing data (FAO Fisheries Division 2020). This initial categorisation by Functional Groups also provides the potential to inform on the additional facet of functional biodiversity.

4. Conclusions

This proof of concept presents a novel approach to fisheries CF computation, that improves the existing approach (Hélias et al. 2023) by taking into account both direct and indirect impacts based on an established impact assessment formulism. The assessment is elevated from population to ecosystem-scale and takes account of both over-exploitation and over-expansion of populations, in order to provide a more holistic impact quantification.

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