Ecosystem impacts of fishing the low trophic level Peruvian anchovy in the Northern Humboldt Current Ecosystem

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Prepared by: **Dr. Jorge Tam, Dr. Marc Taylor and Dr. Miguel Ñiquen.**

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Jorge Tam [1] , Marc Taylor [2] and Miguel Ñiquen [3]

[1] Instituto del Mar del Perú, Laboratorio de Modelado Oceanográfico, Ecosistémico y del Cambio Climático (LMOECC, AFIOF, DGIOCC), Lima, Perú. E-mail: jtam@imarpe.gob.pe.
[2] Institute of Sea Fisheries, Thünen Institute, Bremerhaven, Germany.
[3] Instituto del Mar del Perú, Dirección General de Investigaciones de Recursos Pelágicos (DGIRP), Lima, Perú.

Introduction

The Fishery Improvement Project Peru anchovy - industrial purse-seine (PROME) has the goal to adjust the processes of research and management of the Peruvian anchovy (Engraulis ringens) fishery from the Northern-Central stock for Indirect Human Consumption (CHI), in order to achieve certification according to the Marine Stewardship Council (MSC) standards. The standards are approved by the Global Sustainable Seafood Initiative (GSSI) and are compatible with the FAO Code Code of Conduct for Responsible Fisheries and the Guidelines for the ecolabelling of fish and fishery products from marine capture fisheries (CEDEPESCA 2017, Fishery Progress 2020).

The Marine Stewardship Council (MSC) is an international non-profit organisation. It recognises and rewards efforts to protect oceans and safeguard seafood supplies for the future so that future generations are able to enjoy seafood and oceans full of life, forever. Its vision is of the world's oceans teeming with life, and seafood supplies safeguarded for this and future generations. Its mission is to use their ecolabel and fishery certification program to contribute to the health of the world's oceans by recognising and rewarding sustainable fishing practices, influencing the choices people make when buying seafood and working with their partners to transform the seafood market to a sustainable basis (MSC 2020).

Within this context, it was necessary to demonstrate that the fishery complies with the requirement of tending to the needs of the ecosystem, as defined by the MSC standard. There is a strong concern that the level of exploitation of this fishery needs to take into account the ecosystem requirements, given the trophic importance of Peruvian anchovy as a Low-Trophic-Level (LTL) species. Therefore, the status of the fishery must be evaluated within an ecosystem context.

Thus, the objective of the present study is to assess, through the use of the updated ecosystem model of Tam et al. (2008) and Taylor et al. (2008), the ecosystem impacts of fishing the Peruvian anchovy in the Northern Humboldt Current Ecosystem.

Materials and methods

The MSC requirements for LTL species for demonstrating that the management system considers the needs of the ecosystem is outlined in the MSC Fisheries Standard Version 2.01 (MSC 2018, page 15), which states that:
"When scoring PI 1.1.1A scoring issue (b), the expectations for key LTL species shall be as given below:
a. The default biomass target level consistent with ecosystem needs shall be 75% of the spawning stock level that would be expected in the absence of fishing (B_0).
b. A higher or lower target level, down to a minimum allowed 40% of the spawning stock level that would be expected in the absence of fishing (B_0), may still achieve an 80 level score if it can be demonstrated, through the use of credible ecosystem models or robust empirical data for the UoA/ecosystem being assessed, that the level adopted:

> i. Does not impact the abundance levels of more than 15% of the other species and trophic groups by more than 40% (compared to their state in the absence of fishing on the target LTL species); and
> ii. Does not reduce the abundance level of any other species or trophic group by more than 70%."

Model

The food web model for the NHCE was constructed by updating the 1995 model previously developed by Tam et al. (2008), Taylor et al. (2008) and Tam et al. (2010), using the Ecopath with Ecosim (EwE) program (Christensen and Pauly 1993, Christensen and Walters 2000). EwE uses a mass-balance approach to estimate energy flows between pre-defined functional groups. Net production of a given group equals energy losses via predation, fishery catch rates, senescence, and net migration. The modelled area extended from 3°S to 18°S and with an offshore extent to 100 nm from the coast, covering approximately 453000 km^2. Forty five living functional groups and a detritus box were included in the model (Fig. 1). Anchovies (Northern-Central and Southern stocks), sardines and hakes were structured into 2 size groups (small and large) to account for diet changes between life stages.
The model was calibrated for the period 1995-2017 against observed catches, biomasses, fishing mortalities and effort, by adjusting the most sensitive prey-predator interactions (i.e. vulnerability parameters).

Two simulations were carried out: (i) simulation without forcings and (ii) simulation using the Peruvian Coastal Thermal Index (PCTI, Quispe et al. 2015) as an environmental forcing. The incorporation of the PCTI, which is a strong proxy for the depth of the thermocline and the upper boundary and extent of the oxygen minimum zone (OMZ), was used as an environmental forcing function on the vulnerability parameters of anchovy to diving predators (*i.e*. trophic groups Sea lions, Fur seals, Boobies, Cormorants, Pelicans, Penguins). Specifically, the OMZ is known to limit the vertical distribution of many pelagic species like anchovy, and it has been hypothesized that periods of deepening may allow anchovy to escape predation to some degree. Conveniently, PCTI anomaly was close to zero for the model's base year, 1995. The inverse of the index was used, given that positive anomalies (higher coastal temperatures and deeper OMZ) are likely related to lower vulnerabilities, followed by the addition of one (PCTI*-1 + 1) to scale it relative to the 100 %, i.e. normal status in EwE. The addition of the PCTI forcing function was justified by through an improvement in fit to historical time series (*i.e*. via sum of squares, SS) and via a lower Akaike Information Criterion (AIC).

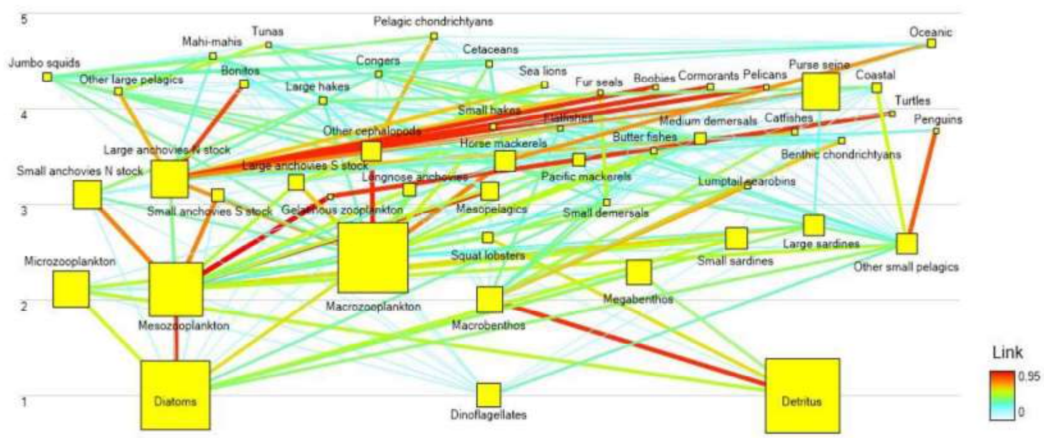

Figure 1. Flow diagram and trophic levels of the 46 functional groups included in the Northern Humboldt Ecosystem model. Trophic levels of each functional group (vertical axis) were estimated by the model. The area of each rectangle is proportional to the biomass of each functional group. Color and width of lines are scaled to the amount of energy flow between functional groups.

Depletion experiments

Depletion experiments followed the general procedures in Smith et al. (2010), the model was run for 24 years during the period 1995 to 2018 using historical time series, followed by 10 years of constant status quo fishing mortality, and then projecting 21 years under varying levels of fishing mortality applied to adult Peruvian anchovy Northern-Central stock up to 2049 to determine equilibrium biomasses in the model, under the specified fishing mortality level on anchovy. During the depletion experiments all fishing mortalities, except that for anchovy, were fixed at 2018 levels.

Results

Simulation without environmental forcing

Depletion experiments varying levels of fishing mortality of adult Peruvian anchovy Northern-Central stock, using the model without environmental forcing, resulted in a status quo fishing mortality under Fmsy and a level of anchovy depletion of 19.1 % (Fig. 2).

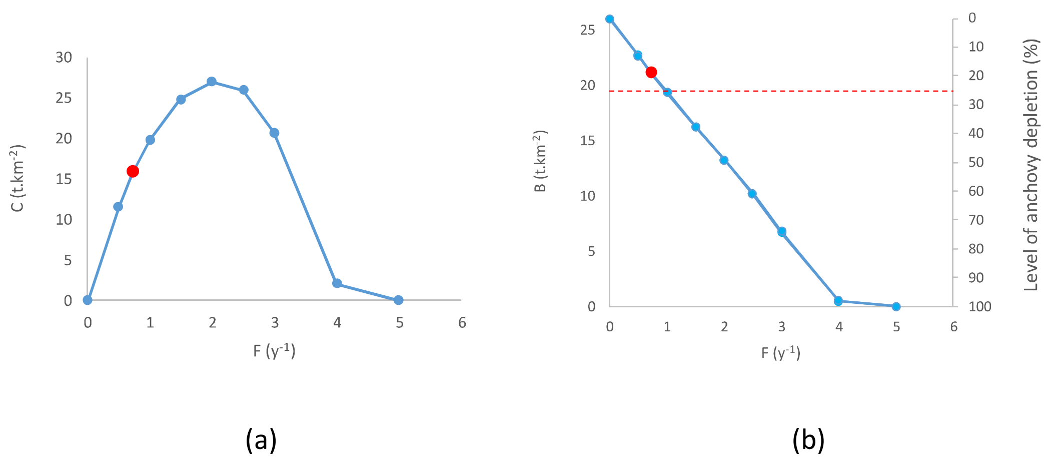

Figure 2. (a) Catch vs. Fishing mortality; (b) Biomass vs. Fishing mortality of Peruvian anchovy Northern-Central stock. The red point indicates status quo fishing mortality. Dashed line indicates 25 % limit for anchovy depletion.

At the status quo level of anchovy depletion (19.1 %) the ecosystem impact was 4.5 % (Fig. 3), that is, the anchovy fishery does not impact the abundance levels more than 15 % of the other species and trophic groups by more than 40%. In addition, the status quo level does not reduce the abundance level of any other species or trophic group by more than 70 %.

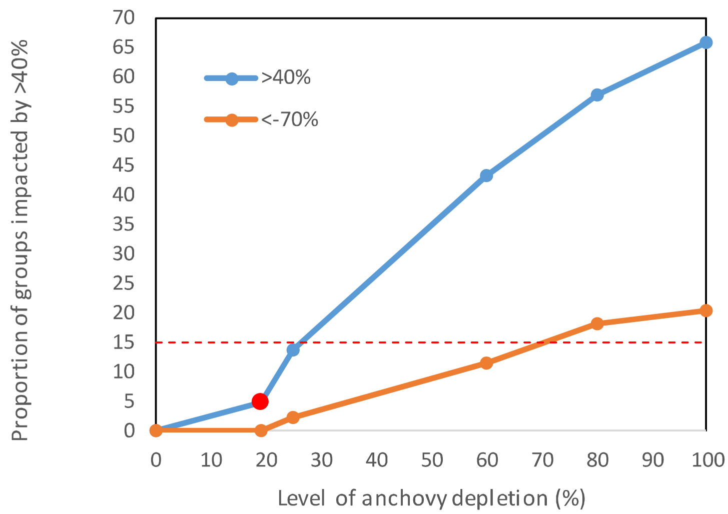

Figure 3. Ecosystem impacts of fishing the low trophic level Peruvian anchovy Northern-Central stock (blue line) and proportion of groups reduced by more than 70 % (red line). The red point indicates status quo fishing mortality. Dashed line indicates 15 % limit for ecosystem impact.

Simulation with environmental forcing

Depletion experiments varying levels of fishing mortality of adult Peruvian anchovy Northern-Central stock, using the model with environmental forcing, resulted in a status quo fishing mortality under Fmsy and a level of anchovy depletion of 19.3 % (Fig. 4).

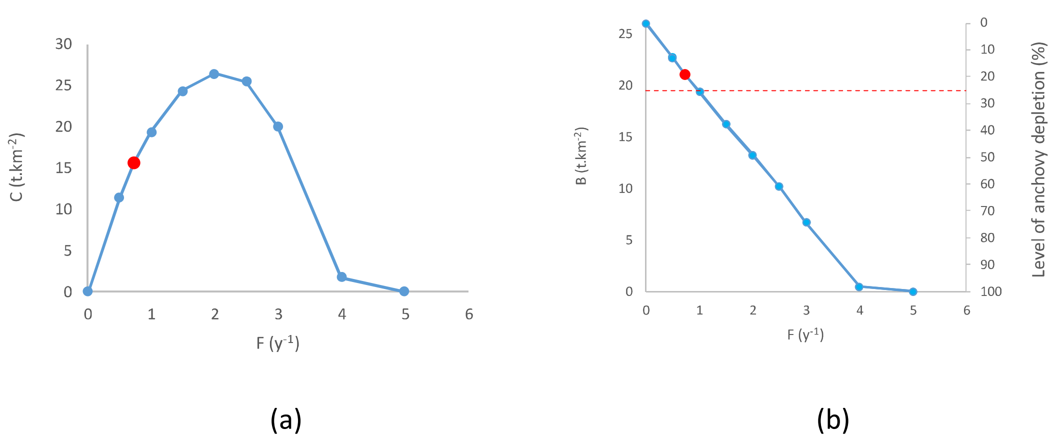

Figure 4. (a) Catch vs. Fishing mortality; (b) Biomass vs. Fishing mortality of Peruvian anchovy Northern-Central stock. The red point indicates status quo fishing mortality. Dashed line indicates 25 % limit for anchovy depletion.

At the status quo level of anchovy depletion (19.3 %) the ecosystem impact was 4.5 % (Fig. 5), that is, the anchovy fishery does not impact the abundance levels more than 15 % of the other species and trophic groups by more than 40%. In addition, the status quo level does not reduce the abundance level of any other species or trophic group by more than 70 %.

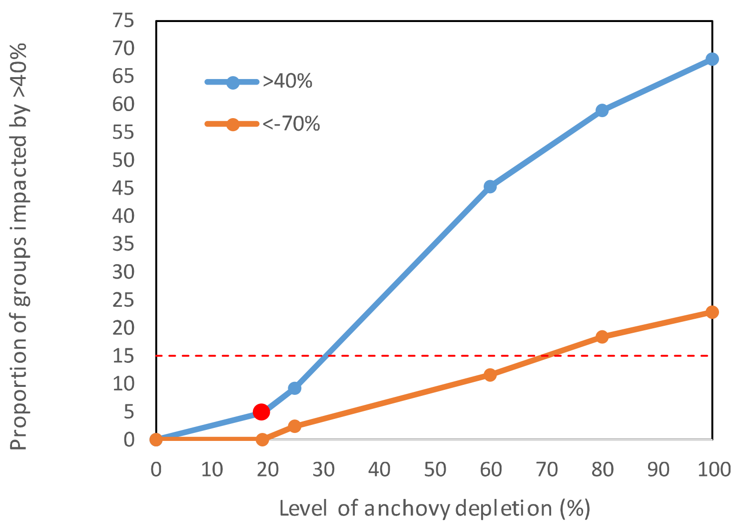

Figure 5. Ecosystem impacts of fishing the low trophic level Peruvian anchovy Northern-Central stock (blue line) and proportion of groups reduced by more than 70 % (red line). The red point indicates status quo fishing mortality. Dashed line indicates 15 % limit for ecosystem impact.

Discussion

In order to understand the processes affecting the ecosystem impacts of fishing the low trophic level Peruvian anchovy in the Northern Humboldt Current Ecosystem, the percentage of anchovy in predators diets (Fig. 6), as well as the anchovy consumption of anchovy predators (Fig. 7) were analysed. The predators with more than 50 % of anchovy in their diets were boobies, cormorants, pelicans, bonitos, other large pelagics, sea lions, catfishes and fur seals. Predators with more than 2 $t.km^{-2}.y^{-1}$ of anchovy consumption were bonito, medium demersals, horse mackerels, other large pelagics and pacific mackerels.

To assess which "key" prey species perform as forage fish, upon which upper trophic level predators depend, the SURF index (SUpportive Role to Fishery ecosystems) for each prey species was calculated; this index weights food web connectance by the importance of trophic connections, so that higher scores indicate a greater potential for indirect foodweb effects of forage fish fisheries (Plagány and Essington 2014). Species with B/Bcons (where Bcons is the summed biomass of all species with a trophic level greater than 2) and SURF values over thresholds of common key forage fish were (Fig. 8): macrozooplankton, diatoms, mesozooplankton and large anchovies (Northern-Central stock).

To validate this result the keystoneness index, which attributes high values of keystoneness to functional groups that have both low biomass proportion and high overall effect, was plotted against the relative total impact index, which estimates the total impact of one functional group on the ecosystem through the mixed trophic impact (Libralato et al. 2006). The same five species had higher relative total impact and high keystoneness index (Fig. 9): large anchovies (Northern-Central stock), macrozooplankton, diatoms, mesozooplankton and other small pelagics, indicating that these species have high impact on the different groups of the ecosystem resulting from a small change to the biomass of these species.

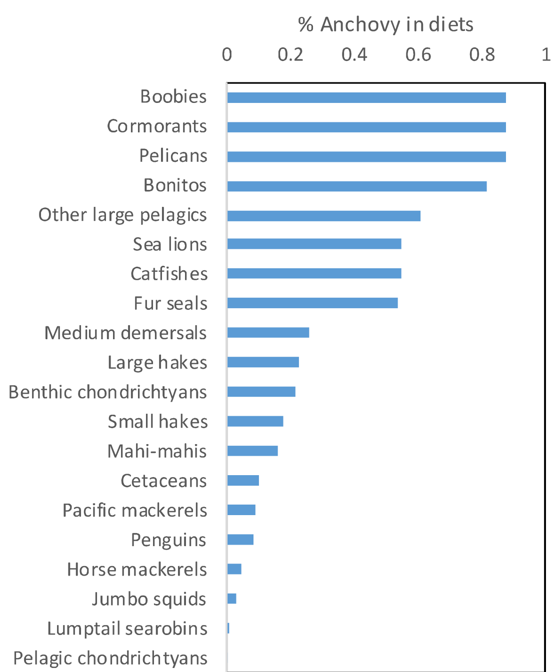

Figure 6. Percentage of anchovy in diets of anchovy predators.

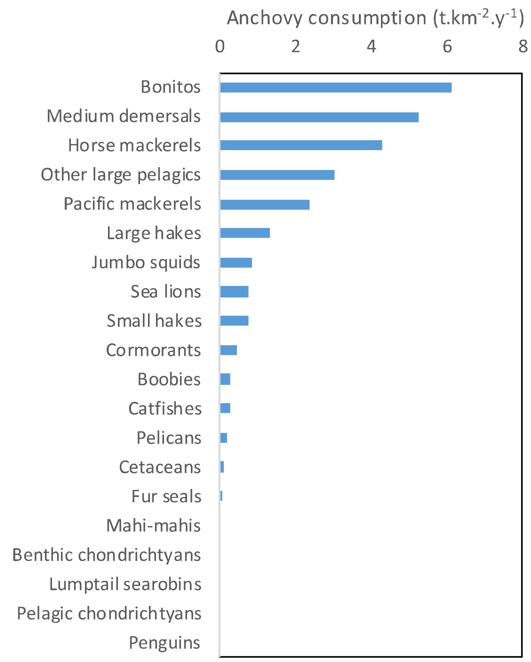

Figure 7. Anchovy consumption of anchovy predators.

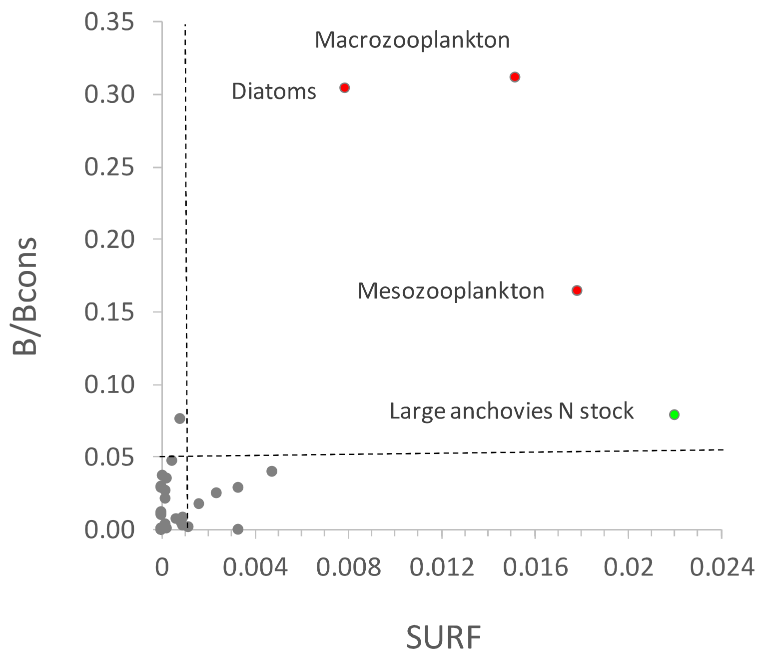

Figure 8. Biplots of consumer biomass proportion and SURF for the northern Humboldt Current Ecosystem model. Gray points are species not considered to be forage fish. Horizontal and vertical dashed lines indicate threshold values above which a species would be indicated as "key".

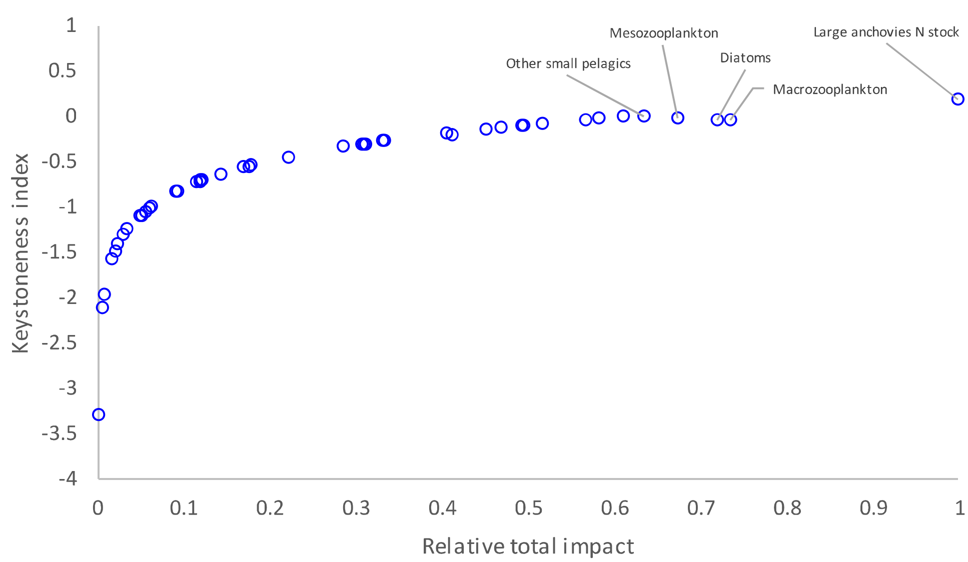

Figure 9. Keystonennes index (KSi) for the groups in the Northern Humboldt Current Ecosystem model. For each group, KSi is reported against relative total impact (ei).

Conclusions and recommendations

Depletion experiments varying levels of fishing mortality of adult Peruvian anchovy Northern-Central stock, using both ecosystem models (without and with environmental forcing), indicated that at the status quo fishing mortality (F = 0.784) and level of anchovy depletion (around 19 % B_0), does not impact the abundance levels of more than 15 % of the other species and trophic groups by more than 40%, and also does not reduce the abundance level of any other species or trophic group by more than 70 %.

We recommend to continue gathering information about *in situ* data to improve model fitting with longterm time series, as well as to include more complex processes through environmental forcings at different timescales (e.g. regime shifts and climate change) and mediations based on ecosystem dynamics (e.g. responses of different stanzas).

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