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Abstract code: 207

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Abstract

Purpose. Life cycle assessment (LCA) is used to quantify the use of land by human activities and its consequences on the environment (the ecosystem quality area of protection (AoP)). On the other hand, the impact of sea use on ecosystems appears poorly assessed by the LCA community. The purpose of this study is to address this situation by proposing operational characterization factors (CFs) for global fisheries, both regionally and globally.

Methods. The ecosystem quality impact is commonly assessed using CF = FF × EF, with the fate (FF) and effect (EF) factors. In recent work, we define CFs for AoP natural resources for fisheries, based on the fraction of the stock that is depleted. We show that these CFs correspond to the EF for the ecosystem quality AoP. FF represents the duration of the impact by specifying how long the intervention has an effect and are then defined as the inverse of the growth rate of the fish species. This leads to CFs at the ecoregion level, assessing the losses of intrinsic ecosystem functions at the regional scale. The global (and irreversible) loss is defined from the regional loss using a vulnerability score at the species level.

Results and discussion. The regional and global CFs have been calculated for 5 000 fish stocks from FAO data. CFs are provided both for ReCiPe (species.year) and LCI guideline (potential disappeared fraction of species for a year PDF.year) units. As illustration, four fisheries are presented and compared to livestock productions.

Conclusions The use of the sea by fishing activities leads to a loss of marine biodiversity. The work presented here proposes operational CFs dedicated to this, for all the global fisheries, in accordance with LCI guidelines. It allows quantifying the impacts of fisheries in LCA.

Keywords: *Fisheries, ecosystem quality, characterization factors, vulnerability score, FAO data.*

Introduction

This paper outlines the main aspects of a more detailed article (Hélias and Bach 2020). With life cycle assessment (LCA), practitioners often quantify environmental impacts, leading to three areas of protection (AoP): human health, natural resources and ecosystem quality. On the one hand, LCA makes it possible to quantify the use of land by human activities and its consequences on ecosystems (the third AoP). On the other hand, the impact of sea use on ecosystems seems to be poorly assessed by the LCA community. With the current impact assessment method, the causal effect of fishing on the quality of ecosystems cannot be represented, i.e. its impact is equal to zero. The objective of this work is to resolve this situation by proposing operational characterization factors (CFs) for global fisheries. These factors are in accordance with international guidelines that convert the inventoried mass into a unit of ecosystem quality and are in line with recent work on the depletion of fish biotic resources (Hélias et al. 2018).

Material and methods

In its guidelines, the Life Cycle Initiative (LCI), recommends CFs for the ecosystem quality AoP expressed in Potentially Disappeared Fraction of species for a year (PDF.year). For land use, CFs address the potential species loss due to the human used area per ecoregion. This leads to regional CFs (expressed in PDF/m^2 for occupation and PDF.year/m^2 for transformation) assessing loss of the intrinsic function of ecosystems at regional scale (Frischknecht and Jolliet 2016). Global CFs (expressed in global PDF/m^2 for occupation and global PDF.year/m^2 for transformation) are also provided. They assess the global (and irreversible) lost, addressing the proportion of endemic species in the ecosystem by the use of a vulnerability score (Verones et al. 2015).

In a recent work (Hélias et al. 2018) we propose an approach addressing global fisheries in terms of resource depletion. It is based on a marginal approach with a dynamic of population models, to link the inventory (the withdrawal of fish) and the impact (the depletion of the stock). The approach is briefly reported here. The often-used in fish stock dynamics Schaefer model shape (Schaefer 1954) serves as a basis of this work

$$\frac{dB}{dt} = -C + rB \times DSF \qquad (1)$$

where B is the fish biomass (ton), C the annual catch (ton.year^{-1}), r the growth rate (year^{-1}), and DSF the depleted stock fraction. The latter varies from 0 for a plentiful stock to 1 for an exhausted one. This model shows the growth where the exponential expansion (rB) is limited by the available habitat represented by DSF. In Hélias et al. (2018), eq (1) is used at steady state with a marginal approach. The CF is defined as the partial derivative of the impact (∂DSF) according to the inventory (the mass of fish removed from the biomass stock, $-\partial B$).

$$-\frac{\partial DSF}{\partial B} = \frac{C}{rB^2} \qquad (2)$$

Recently in Hélias and Heijungs (2019), consistency in modelling has been shown between this approach and the abiotic depletion potential (Guinée and Heijungs 1995) (the most used approach to assess abiotic resource depletion in LCA).

The impacts leading to ecosystem quality are often addressed with $\mathrm{CF} = \mathrm{FF} \times \mathrm{EF}$. For a given intervention, the characterization of the impact is the product of the fate factor (FF) with the effect factor (EF).

For a biotic resource, we have an analogy between the depletion of the resource and the impact on biodiversity. Thus, fishing leads to a loss of biodiversity, due to the withdrawal of part of the living biomass. The *DSF* represents the disappeared fraction of the stock (a given species in its habitat) and the unit of eq (2) is therefore the species lost/kg. Eq (2) is used as EF. Most of the impacts affecting ecosystem quality (e.g. ecotoxicity, acidification, eutrophication, etc.) result from substance emissions. In this context the fate factor represents the persistence of the involved substance in the media (Cosme et al. 2018). It is usually expressed in years or days. It can be assimilated to the inverse of the sum of the removal rates (Cosme et al. 2018) or to the residence time (Rosenbaum et al. 2007). The FF for an impact on ecosystems of fisheries is reversed since it results from a resource withdrawal, but the principle remains the same: defining $\mathrm{CF} = \mathrm{FF} \times \mathrm{EF}$, the effect factor represents the impact and the fate factor defines its duration. In USEtox®, fate factors are determined as the inverses of exchange- and removal-rate constants (Bijster et al. 2018). By analogy, we defined the fate factor as $\frac{1}{r}$, the inverse of the growth rate.

The regional CF for the impact on ecosystem quality due to fish catches ($\mathrm{CF_{EQ,reg}}$, expressed in species.year/kg of fish) is therefore determined as follows

$$\mathrm{CF_{EQ,reg}} = \frac{1}{r} \times \frac{C}{rB^2} = \frac{C}{(rB)^2} \qquad (3)$$

The species.year unit corresponds to the ReCiPe method (Huijbregts et al. 2017) and the fishery impacts on ecosystems can be directly added in this method. The conversion from species.year /kg to regional PDF.year/kg can be easily done with the division of $\mathrm{CF_{EQ}}$ by the number of species in the marine region (Horton et al. 2019). Note that the reverse approach was used in the ReCiPe method to convert PDF.year into species.year.

With the LCI guidelines, global CF is also expected. From a modeling perspective, the main difference between land use and fisheries is the level of intervention. The impact of land use affects all species in the corresponding area. For fisheries, if more than one species can be caught simultaneously in an ecosystem, the corresponding impacts are additive and assessed separately through inventory flows and associated CFs in the LCA. The CF is defined for a specific species in a given ecosystem (i.e. population). In contrast to land use, human intervention through fishing a fish does not affect all communities in the ecosystem, but only one of the species in the ecosystem. However, to this must be added the direct impacts on the ecosystem related to fishing techniques such as the destruction of the seabed (Woods and Verones 2019), but this goes beyond the purpose of this study.

At the population (fish stock) level, the conversion factor to obtain the global PDF from the regional PDF should only quantify the extent to which the species concerned is endemic to the region, and only it. With the same reasoning as for the vulnerability score or the global extinction probability but at the species level, the endemic conversion factor to express global-PDF from regional-PDF is $B_j / \sum_{j^*} B_{j^*}$, the proportion of the global biomass in the ecoregion *j*.

CFs are computed for 5000 FAO datasets describing fisheries as detailed Hélias et al. (2018). The reader can refer to this article for more details. As illustration, four fisheries are presented (Atlantic bluefin tuna (*Thunnus thynnus*, Scombridae) in the Eastern-Atlantic, Yellowfin tuna (*Thunnus albacares*, Scombridae) in Atlantic, Alaska pollock (*Theragra chalcogramma*, Dadidae) Northwest Pacific and European seabass (*Dicentrarchus labrax*, Moronidae) Northeast Atlantic) and compared to livestock production (chicken, pork and beef from the ecoinvent database). The purpose is not to provide an exhaust and accurate LCA, but to illustrate how CFs can be used by practitioners and to highlight some of the outcomes. For this purpose, a simple functional unit is used without considering protein content nor other nutritional aspects. All systems are assessed for one metric ton of the fresh product.

Results

Figure 1 focuses on the land (transformation and occupation) and sea (fisheries) use of the different systems. If we consider the regional PDF (Fig 1.a), bluefin tuna is then the worst-case scenario. The LCI guidelines provide confidence intervals for CFs. It is then possible to take into account all the uncertainties related to the impacts. With the confidence intervals, Alaska pollock and yellowfin tuna have a much lower impact than sea bass, but no other results can be shown. This is due to the large uncertainty in the bluefin tuna assessment and the fact that land-based productions have very wide confidence intervals, the lower limit of which is negative (i.e. a positive effect of land use on biodiversity).

The impacts assessed with the global PDF (Fig 1.b) provide different results. The impacts in global PDF are about ten times lower for terrestrial systems (beef, pork and chicken), Alaska pollock and yellowfin tuna. At the opposite, impacts decrease only slightly for seabass (from 32×10^{-11} PDF_{reg}.year to 25×10^{-11} PDF_{glo}.year) and bluefin tuna (from 47×10^{-11} PDF_{reg}.year to 40×10^{-11} PDF_{glo}.year). This leads to higher impacts for these two fish stocks than the other systems. Based on the confidence intervals, the difference is significant for seabass with respect to Alsaka pollock, yellowfin tuna and land-based productions (i.e. no overlapping of the confidence intervals), significant for bluefin tuna with respect to yellowfin tuna and chicken and almost significant between bluefin tuna and Alaska pollock, beef and pork due to the reduced overlap in the confidence intervals.

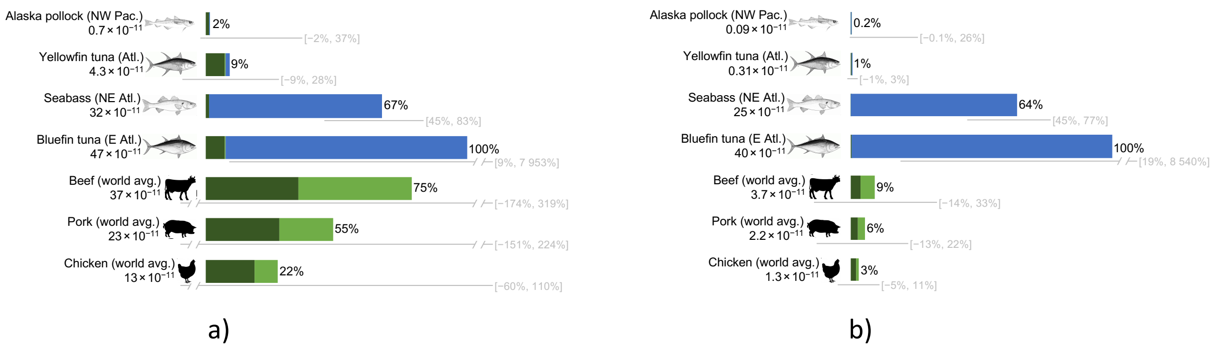

Figure 1.a) Regional and b) global impacts on ecosystems of the four fisheries and the three terrestrial meat production systems. Results are expressed in the percentage of the worst system and impact of each of them are given below the names (in pdf.year). Green: Land transformation (dark) and use light) impacts. Blue: Fishery impact on fish stocks. Grey line: uncertainty range associated with the fishery impact.

Discussion

The application case emphasizes the relevance of the evaluation to the global PDF. According to the data, Atlantic bluefin tuna is quite endemic in the eastern Atlantic, where 91% of the global biomass is found, with the remaining 9% in the western part. The status of European seabass is similar, with 81% of the biomass in the northeastern part of the Atlantic Ocean (seabass are also found in the Mediterranean Sea, rarely in the central-eastern Atlantic). As these species cannot be easily found elsewhere, their CFs expressed in global PDF are close to the regional PDF CFs. Yellowfin tuna is a global species, distributed in all temperate oceans. The Atlantic population accounts for only 11% of the global population, so its global PDF value is ten times lower than the regional PDF. The Alaskan Pollock, in the Pacific Northwest, is the main population of this species. It accounts for 66% of the global biomass (with the remaining portion in the northeast Pacific), so the variation between the regional and global PDFs is not significant. However, since the CFs are very low, the results are mainly determined by land use and the overall result of the global PDF is an order of magnitude less than the regional global PDF.

The inventories involved in this case study are not the result of a detailed description of the systems but are only generic data sets available. The conclusions of these comparisons cannot be extrapolated. However, it shows that marine production is of the same order of magnitude as land-based production and highlights large variations in impact between fish stocks. This case study illustrates how the ecosystem impact associated with fishing can be combined with the ReCiPe result and the land use of the LCI guidelines, the units being the same. This illustrates the introduction of fisheries impact into the current LCIA methods.

Conclusions

The use of the sea by fishing activities leads to a loss of marine biodiversity. The work presented here proposes operational CFs dedicated to this, for all the global fisheries, in accordance with the ICM guidelines. It allows quantifying the impacts of fisheries in LCA.

References

Bijster M, Guignard C, Hauschild M, et al (2018) USEtox® 2.0 documentation (Version 1.1). USEtox® International Center hosted at the Technical University of Denmark, Lyngby, Denmark

Cosme N, Mayorga E, Hauschild MZ (2018) Spatially explicit fate factors of waterborne nitrogen emissions at the global scale. Int J Life Cycle Assess 23:1286–1296. https://doi.org/10.1007/s11367-017-1349-0

Frischknecht R, Jolliet O (eds) (2016) Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1. UNEP/SETAC Life Cycle Initiative, Paris

Guinée JB, Heijungs R (1995) A proposal for the definition of resource equivalency factors for use in product life-cycle assessment. Environ Toxicol Chem 14:917–925. https://doi.org/10.1002/etc.5620140525

Hélias A, Bach V (2020) A New Impact Pathway towards Ecosystem Quality in Life Cycle Assessment: Characterisation Factors for Fisheries. submitted

Hélias A, Heijungs R (2019) Resource depletion potentials from bottom-up models: Population dynamics and the Hubbert peak theory. Sci Total Environ 650:1303–1308. https://doi.org/10.1016/j.scitotenv.2018.09.119

Hélias A, Langlois J, Fréon P (2018) Fisheries in life cycle assessment: Operational factors for biotic resources depletion. Fish Fish 19:951–963. https://doi.org/10.1111/faf.12299

Horton T, Kroh A, Ahyong S, et al (2019) World Register of Marine Species (WoRMS). http://www.marinespecies.org. Accessed 24 Jun 2019

Huijbregts MAJ, Steinmann ZJN, Elshout PMF, et al (2017) ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. Int J Life Cycle Assess 22:138–147. https://doi.org/10.1007/s11367-016-1246-y

Rosenbaum RK, Margni M, Jolliet O (2007) A flexible matrix algebra framework for the multimedia multipathway modeling of emission to impacts. Environ Int 33:624–634. https://doi.org/10.1016/j.envint.2007.01.004

Schaefer M (1954) Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bull Inter-American Trop Tuna Comm 1:27–56

Verones F, Huijbregts MAJ, Chaudhary A, et al (2015) Harmonizing the Assessment of Biodiversity Effects from Land and Water Use within LCA. Environ Sci Technol 49:3584–3592. https://doi.org/10.1021/es504995r

Woods JS, Verones F (2019) Ecosystem damage from anthropogenic seabed disturbance: A life cycle impact assessment characterisation model. Sci Total Environ 649:1481–1490.

https://doi.org/10.1016/j.scitotenv.2018.08.304