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ABSTRACT

Langlois et al. (2012; 2014a) proposed characterization factors (CF) for fish biotic resource extraction impact assessment at the species level. This paper is an improvement of this approach. In the present work, the CF depends on the Maximum Sustainability Yield (MSY), weighted by the ratio of the current total fishing effort to the fishing effort at the MSY value. Because this ratio often cannot be computed from current databases, it is here obtained from the ratio of total catches to MSY and roots of the parabola linking catches to fishing effort. The new version of the CF is proposed for 125 fish stocks. This work allows assessment of fisheries in the LCA formalism. It contributes to a better representation of the depletion of biotic resources.

Keywords: Biotic resource depletion, Fisheries, Maximum sustainable yield, Characterization factor

1. Introduction

Food production is a major sector for environmental burden due to increase of foodstuff demand and food production intensification. The sea is more and more exploited for human food, and environmental assessment approaches have to take into account this use. Seafood products, coming from direct fishery activities or from aquaculture, where a part of the feeding comes from fish catches, induce a large consumption of biotic resources for human activities. An environmental assessment of these systems by Life Cycle Assessment (LCA) cannot be performed without a focus on this impact.

Langlois et al. (2014b) review the use of the sea in LCA and propose related impact pathways dedicated to the biodiversity damage potential, the ecosystem services damage potential, climate change, and the biotic resource damage potential. Recently, Emanuelsson et al. (2014) proposed new characterization factors (CFs) for fish resource depletion based on the lost potential yield (LPY). The LPY represents the average of lost catches owing to ongoing overfishing and is assessed by simplified biomass projections covering different fishing mortality scenarios. This useful approach provides CFs for 31 European fish species, but several parameters are needed: CFs are computed from (1) current biomass and fish mortality, and (2) target biomass and target fish mortality to Maximum Sustainability Yield (MSY).

The biotic resource damage potential is studied in Langlois et al. (2012; 2014a) for fishing activities at both species, for a given stock, and ecosystem levels. Proposed CF values have been used by Avadí et al. (2014). For the species level, CFs are built based on MSY and catches to deal with the biotic resource states. The present work is an improvement of CF determination at the species level.

2. Methods

2.1. Maximum Sustainability Yield.

The relation between catches and fishing effort is commonly modelled by a parabola, where the MSY is equal to the catches at the inflexion point (see Figure 1). Fish stocks are classically assessed with MSY: the highest fish catch that can be sustained in the long term (Graham 1935; Schaefer 1991). Fishery exploitation of a given stock at time t (C_t) can be increased up to a maximum level by increasing the fishing effort (E_t), because the catches are compensated by an equivalent fish production. Above the MSY and its corresponding E_{MSY}, renewal of the resource (reproduction and body growth) cannot keep pace with the removal caused by fishing and natural mortality. The MSY can be estimated either with a variety of stock-assessment methods or empirically. The most useful database for this is the RAM Legacy Stock Assessment Database (Ricard et al. 2012).

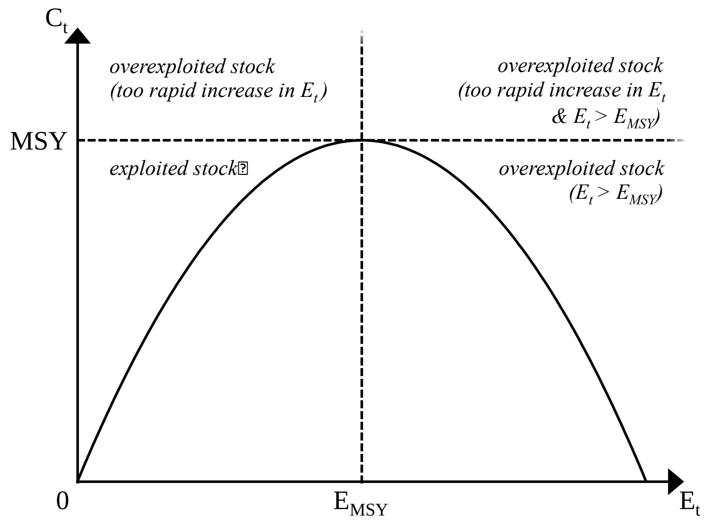

Figure 1. Fish catch (C_t) as a function of fishing effort (E_t) at the steady state

2.2. Characterization factors previously proposed

In Langlois et al. (2012; 2014a), CFs are computed as follows

$$\mathrm{CF} = \begin{cases} \frac{1}{\mathrm{MSY}} & \text{if exploited} \\ \frac{1}{\mathrm{MSY}} \times \frac{\mathrm{MSY}}{\bar{C}_t} = \frac{1}{\bar{C}_t} & \text{elseif} \end{cases} \quad \text{Eq. 1}$$

where $\bar{C}_t$ represents mean fish catches over five years prior to impact assessment to approximate the equilibrium value (if average catches are higher than the MSY due to non-equilibrium situation, $\bar{C}_t$ is set equal to MSY). For an exploited stock, CF allows to place landings in front of renewability of the stock. When the stock is overexploited, the ratio of MSY to $\bar{C}_t$ is added. The ratio varies from 1 to infinity for catch rates ranging from MSY to zero (i.e. when the stock is overexploited close to MSY or when it is severely depleted, respectively). The ratio allows introducing the seriousness of the overexploitation based on catches only, which are common data (unfortunately, fishing efforts are often unavailable data). See Langlois et al. (2014a) for the determination of the stock status (i.e. overexploited or not).

2.3. Improvement of the characterization factors

In the present work, to determine the CF, MSY is changed in accordance with the ratio $\frac{E_t}{E_{\mathrm{MSY}}}$, which describes the extent of exploitation or overexploitation. Let the relation presented in Figure 1 be

$$\bar{C}_t = -a_1 E_t^2 + a_2 E_t \quad \text{Eq. 2}$$

The derivative is the following:

$$\frac{d\bar{C}_t}{dE_t} = -2a_1 E_t + a_2 \quad \text{Eq. 3}$$

$$\left.\frac{d\bar{C}_t}{dE_t}\right|_{E_t = E_{\mathrm{MSY}}} = 0 = -2a_1 E_{\mathrm{MSY}} + a_2 \quad \text{Eq. 4}$$

With (2) and (4), we have

$$\bar{C}_t = -a_1 E_t^2 + 2a_1 E_{\mathrm{MSY}} E_t \quad \text{Eq. 5}$$

$$\mathrm{MSY} = -a_1 E_{\mathrm{MSY}}^2 + 2a_1 E_{\mathrm{MSY}} E_{\mathrm{MSY}} \quad \text{Eq. 6}$$

$$\frac{\bar{C}_t}{\mathrm{MSY}} = -\left(\frac{E_t}{E_{\mathrm{MSY}}}\right)^2 + 2\frac{E_t}{E_{\mathrm{MSY}}} \quad \text{Eq. 7}$$

The polynomial (7) allows finding the ratio of fishing effort to fishing effort for the MSY as a function of the ratio of catches to MSY. The roots are the following:

$$r_1 = 1 + \sqrt{1 - \frac{\bar{C}_t}{\mathrm{MSY}}}, r_2 = 1 - \sqrt{1 - \frac{\bar{C}_t}{\mathrm{MSY}}} \quad \text{Eq. 8}$$

and are used in the CF to weigh MSY

$$\mathrm{CF} = \begin{cases} \dfrac{1}{\mathrm{MSY}\left(1+\sqrt{1-\frac{\bar{C}_t}{\mathrm{MSY}}}\right)} & \text{if exploited} \\ \dfrac{1}{\mathrm{MSY}\left(1-\sqrt{1-\frac{\bar{C}_t}{\mathrm{MSY}}}\right)} & \text{elseif} \end{cases} \quad \text{Eq. 9}$$

This weight varies theoretically from 2 (unexploited resource) to 0 (totally depleted resource) and introduces a relative position for the stocks according to the fishing effort only with catches and MSY values.

3. Results

The RAM Legacy database includes biological reference points for over 361 stocks, of which 138 have MSY values and 313 have catches data. The number of stocks with both values is 125. Table 1 gives CF values for overexploited (55) and exploited (70) stocks, where both catches and MSY are available in the RAM legacy database. Figure 2, left part, shows the CF weight factors according to the relative finishing effort both for previous (1 for exploited, $\frac{\mathrm{MSY}}{\bar{C}_t}$ for overexploited stock) and current CFs $\left(1 \pm \sqrt{1 - \frac{\bar{C}_t}{\mathrm{MSY}}}\right)$. Figure 2, right part, shows the total biotic resource depletion impacts (i.e. $\bar{C}_t \times \mathrm{MSY}$) for both previous and current work.

Table 1. Characterization factors (CF) for biotic-resource depletion at the species-stocks level in the RAM Legacy database.

Overexploited			**Exploited**		
Stock ID	**Common name**	**CF ($kg^{-1}.y$)**	**Stock ID**	**Common name**	**CF ($kg^{-1}.y$)**
ACADREDGOMGB	Acadian redfish	2.76×10^{-09}	ALBASPAC	Albacore tuna	1.48×10^{-11}
ALBANATL	Albacore tuna	4.80×10^{-11}	ARFLOUNDPCOAST	Arrowtooth flounder	1.00×10^{-10}
AMPL5YZ	American Plaice	9.77×10^{-10}	ARGANCHONARG	Argentine anchoita	1.20×10^{-12}
ANCHOVYKILKACS	Anchovy kilka	4.87×10^{-10}	ARGANCHOSARG	Argentine anchoita	1.73×10^{-12}
ARGHAKENARG	Argentine hake	2.09×10^{-11}	ATOOTHFISHRS	Antarctic toothfish	2.32×10^{-10}
ARGHAKESARG	Argentine hake	3.60×10^{-12}	AUSSALMONNZ	Australian salmon	1.98×10^{-10}
ATBTUNAEATL	Atlantic bluefin tuna	2.03×10^{-11}	BGROCKPCOAST	Blackgill rockfish	2.80×10^{-09}
ATBTUNAWATL	Atlantic bluefin tuna	8.03×10^{-10}	BHEADSHARATL	Bonnethead shark	8.79×10^{-13}
ATHAL5YZ	Atlantic Halibut	3.63×10^{-08}	BIGEYEIO	Bigeye tuna	8.99×10^{-12}
BIGEYEATL	Bigeye tuna	1.53×10^{-11}	BIGEYEWPO	Bigeye tuna	1.55×10^{-11}
BLACKOREOWECR	Black oreo	7.95×10^{-10}	BLACKROCKNPCOAST	Black rockfish	8.05×10^{-10}
BLUEROCKCAL	Blue rockfish	5.81×10^{-09}	BLACKROCKSPCOAST	Black rockfish	6.11×10^{-10}
BOCACCSPCOAST	Bocaccio	2.59×10^{-08}	BLUEFISHATLC	Bluefish	4.55×10^{-11}
BSBASSMATLC	Black sea bass	4.88×10^{-10}	BTIPSHARATL	Blacktip shark	3.36×10^{-11}
BUTTERGOMCHATT	Atlantic butterfish	8.21×10^{-08}	BTIPSHARGM	Blacktip shark	2.07×10^{-11}
CABEZSCAL	Cabezon	7.54×10^{-08}	CABEZNCAL	Cabezon	5.43×10^{-09}
CODGB	Atlantic cod	3.87×10^{-10}	CHAKESA	Shallow-water cape hake	6.37×10^{-12}
CODGOM	Atlantic cod	5.18×10^{-10}	CHILISPCOAST	Chilipepper	2.36×10^{-10}
CROCKPCOAST	Canary rockfish	3.83×10^{-08}	CMACKPCOAST	Pacific chub mackerel	2.65×10^{-11}
DEEPCHAKESA	Deep-water cape hake	9.38×10^{-12}	DSOLEPCOAST	Dover sole	3.50×10^{-11}
DKROCKPCOAST	Darkblotched rockfish	1.59×10^{-08}	ESOLEPCOAST	English sole	1.28×10^{-10}
GAGGM	Gag	4.46×10^{-10}	FLSOLEBSAI	Flathead sole	4.27×10^{-12}
GRAMBERGM	Greater amberjack	1.03×10^{-09}	GEMFISHNZ	common gemfish	3.86×10^{-10}

Overexploited			**Exploited**		
Stock ID	**Common name**	**CF ($kg^{-1}.y$)**	**Stock ID**	**Common name**	**CF ($kg^{-1}.y$)**
HAD5Y	Haddock	7.35×10^{-10}	GOPHERSPCOAST	Gopher rockfish	9.90×10^{-09}
KMACKGM	King Mackerel	3.91×10^{-10}	HADGB	Haddock	1.69×10^{-11}
NZSNAPNZ8	New Zealand snapper	6.48×10^{-10}	HERRNWATLC	Herring	3.14×10^{-12}
POLL5YZ	Pollock	1.94×10^{-10}	KELPGREENLINGORECOAST	Kelp greenling	7.98×10^{-09}
POPERCHPCOAST	Pacific ocean perch	1.54×10^{-08}	KINGKLIPSA	Kingklip	7.57×10^{-12}
PTOOTHFISHMI	Patagonian toothfish	5.42×10^{-09}	KMACKSATLC	King Mackerel	3.88×10^{-10}
RGROUPGM	Red grouper	2.86×10^{-10}	LNOSESKAPCOAST	Longnose skate	5.35×10^{-10}
RPORGYSATLC	Red porgy	3.20×10^{-08}	LSTHORNHPCOAST	Longspine thornyhead	1.56×10^{-10}
RSNAPEGM	Red snapper	1.08×10^{-09}	MACKGOMCHATT	Mackerel	7.85×10^{-12}
RSNAPWGM	Red snapper	8.77×10^{-10}	MONKGOMNGB	Monkfish	2.86×10^{-10}
SBARSHARATL	Sandbar shark	2.91×10^{-08}	NRSOLEEBSAI	Northern rock sole	1.72×10^{-12}
SNOWGROUPSATLC	Snowy grouper	7.04×10^{-09}	NZLINGLIN3-4	Ling	5.89×10^{-11}
SPANMACKSATLC	Spanish mackerel	7.27×10^{-10}	NZLINGLIN5-6	Ling	2.75×10^{-11}
STMARLINSWPO	Striped marlin	6.56×10^{-10}	NZLINGLIN6b	Ling	7.00×10^{-10}
STRIPEDBASSGOMCHATT	Striped bass	9.89×10^{-11}	NZLINGLIN72	Ling	1.41×10^{-09}
SWORDMED	Swordfish	8.24×10^{-11}	NZLINGLIN7WC	Ling	9.32×10^{-11}
SWORDNATL	Swordfish	1.16×10^{-10}	OROUGHYNZMEC	Orange roughy	2.37×10^{-10}
TAUTOGRI	Tautog	7.44×10^{-09}	PATGRENADIERSARG	Patagonian grenadier	7.57×10^{-12}
TILESATLC	Tilefish	6.55×10^{-09}	PHAKEPCOAST	Pacific hake	1.32×10^{-12}
VSNAPSATLC	Vermilion snapper	3.83×10^{-09}	POPERCHGA	Pacific ocean perch	3.11×10^{-11}
WHAKEGBGOM	White hake	4.87×10^{-10}	PSOLENPCOAST	Petrale sole	3.90×10^{-10}
	Windowpane	1.79×10^{-09}	PSOLESPCOAST	Petrale sole	4.06×10^{-10}
WINDOWSNEMATL	Windowpane	3.63×10^{-09}	PTOOTHFISHPEI	Patagonian toothfish	2.43×10^{-10}
WINFLOUN5Z	Winter Flounder	8.03×10^{-10}	REDFISHSPP3LN	Redfish species	2.07×10^{-11}
WINFLOUNSNEMATL	Winter Flounder	9.25×10^{-10}	SABLEFEBSAIGA	Sablefish	3.73×10^{-11}
WITFLOUN5Y	Witch Flounder	4.25×10^{-10}	SABLEFPCOAST	Sablefish	1.16×10^{-10}
WPOLLEBS	Walleye pollock	1.02×10^{-12}	SBWHITACIR	Southern blue whiting	5.19×10^{-11}
WPOLLGA	Walleye pollock	2.80×10^{-11}	SKJCWPAC	Skipjack tuna	6.43×10^{-13}
YELLCCODGOM	Yellowtail flounder	1.49×10^{-09}	SKJEATL	Skipjack tuna	2.63×10^{-12}
YELLGB	Yellowtail flounder	4.11×10^{-10}	SKJWATL	Skipjack tuna	9.91×10^{-12}
YELLSNEMATL	Yellowtail Flounder	4.17×10^{-09}	SMOOTHOREOCR	Smooth oreo	1.95×10^{-10}
YEYEROCKPCOAST	Yelloweye rockfish	1.48×10^{-07}	SMOOTHOREOWECR	Smooth oreo	2.93×10^{-10}
			SNOSESHARATL	Atlantic sharpnose shark	3.94×10^{-13}
			SOUTHHAKECR	Southern hake	2.07×10^{-10}
			SOUTHHAKESA	Southern hake	9.87×10^{-11}
			SSTHORNHPCOAST	Shortspine thornyhead	3.32×10^{-10}
			STFLOUNNPCOAST	Starry flounder	6.20×10^{-10}
			STFLOUNSPCOAST	Starry flounder	1.31×10^{-09}
			SWORDSATL	Swordfish	4.18×10^{-11}
			TREVALLYTRE7	Trevally	4.61×10^{-10}
			VSNAPGM	Vermilion snapper	1.63×10^{-10}
			WPOLLNSO	Walleye pollock	3.29×10^{-13}
			YELL3LNO	Yellowtail Flounder	3.11×10^{-11}
			YFINATL	Yellowfin tuna	6.07×10^{-12}
			YFINCWPAC	Yellowfin tuna	2.50×10^{-12}
			YTROCKNPCOAST	Yellowtail rockfish	1.22×10^{-10}
			YTSNAPSATLC	Yellowtail snapper	4.35×10^{-10}

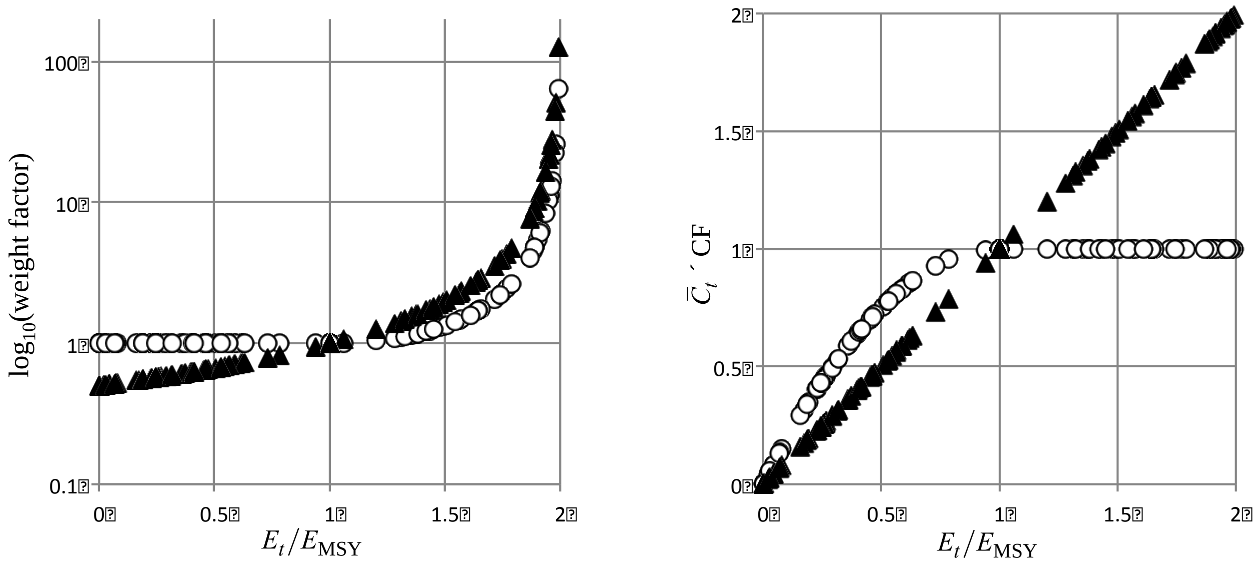

Figure 2. Weight factors (left part) and total impact (right part) according to relative fishing effort. White circle: approach proposed in Langlois et al. (2014a); black triangle: this study.

4. Discussion

This work is an improvement of the previous CF calculations in two respects:

- The CF value increases now continuously according to the total fishing effort for exploited species. The CF for a species where the current total catches is close to the MSY (i.e. close to overexploitation) is now higher than the CF for a species where catches are low, as it is shown in Figure 2, left part, when the relative fishing effort is lower than 1.
- The total impact (total catches by CF) increases continuously from low exploited species to depleted resources, whereas in the previous equations, the total impact was identical for all overexploited species (Figure 2, right part, when the relative fishing effort exceeds 1).

As already expressed in Langlois et al. (2014a), the use of MSY and steady state assumption present some limitations. The transition periods for a given stock are not properly taken into account, being it the result of a drastic increase in effort leading to overexploitation, or to a fast decrease in effort, resulting from the implementation of a low quota aimed at the rapid restoration of the stock biomass. In order to limit this inconvenient and to approximate the equilibrium state, a five-year catches average has been used.

5. Conclusion

While many impacts are now consensual in LCA and standard frameworks are starting to be available (JRC-EIS 2011), no guidelines exist for biotic impact assessment (Emanuelsson et al. 2014). This work proposes CFs at midpoint level for fishing activities, where the use of the biotic resource is taken into account in front of the resource recovery capacity (expressed by the MSY). This work allows assessment of fisheries in the LCA formalism. It contributes to a better representation of the depletion of biotic resources.

6. Acknowledgments

This work benefited from the support of the French National Research Agency (WinSeaFuel ANR-09-BIOE-05). J. Langlois, P. Fréon and A. Hélias are members of the ELSA research group (Environmental Life Cycle and Sustainability Assessment, http:// www.elsa-lca.org); they thank all the members of ELSA for their precious advice.

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This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

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It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6