ESTIMATING MSY AND MEY IN MULTI-SPECIES AND MULTI-FLEET FISHERIES: THE CASE OF THE BAY OF BISCAY MIXED FISHERIES

Jordi GUILLEN, IFREMER, UMR AMURE, jordi.guillen.garcia@ifremer.fr
Claire MACHER, IFREMER, UMR AMURE, claire.macher@ifremer.fr
Mathieu MERZEREAUD, IFREMER, UMR AMURE, mathieu.merzereaud@ifremer.fr
Michel BERTIGNAC, IFREMER, michel.bertignac@ifremer.fr
Spyros FIFAS, IFREMER, spyros.fifas@ifremer.fr
Olivier GUYADER, IFREMER, UMR AMURE, Olivier.Guyader@ifremer.fr

ABSTRACT

Most fish stocks worldwide are not optimally exploited and are therefore are producing less in biologic and economic terms that what it could be obtained. MSY objective for all the stocks by 2015 is put forward by several countries as management target to be achieved, while other countries such as Australia have moved towards MEY as target. In multi-species and multi-fleet fisheries however single species assessments and MSY and MEY reference points are often not valid. In this paper, we analyze the calculation of MSY and MEY in multi-species and multi-fleet fisheries, applied to the Bay of Biscay demersal fisheries. Estimations of MSY and MEY performed in this paper show that increases of the overall landings and economic performances can be obtained by fishing effort reductions and global selectivity improvements in the Bay of Biscay demersal fishery. In this paper we have also shown the importance of accounting for the multi-fleet nature of the fisheries, and so the capacity to allocate fishing effort between fleets to obtain better yields taking into account joint production processes, various métiers and reallocation of effort (both in production and economic terms). Estimating profitability changes when fishing at MEY and in the current situation of overcapacity and overexploitation offers an estimation of the costs of not fishing at MSY and MEY.

INTRODUCTION

Most of the worldwide assessed fish stocks are overexploited, and so not optimally exploited. Worm et al., (2009) estimated that 63% of assessed fish stocks worldwide require rebuilding; while in the EU, 88% of assessed stocks are being fished beyond the maximum sustainable yield (MSY), being 30% of these stocks outside safe biological limits (EC 2009). Estimations of current exploitation levels compared to maximum economic yields (MEY), and thus, estimation of fleet overcapacities are more scarce (Dichmont et al. 2010).

Both, the MSY and the MEY were originally based on models designed for single-species fisheries. The MSY concept has been largely criticized. One of these criticisms is the impossibility of maximizing sustainable yields for all species simultaneously in multispecies fisheries. Despite the fact that, in reality, most species are caught together with other species by multiple fleets (multi-species and multi-fleet fisheries), only the multi-species consequences have started to be considered in the analysis (Mace 2001, Matshuda and Abrams 2006).

In this study we incorporate the presence of multiple fleets in the analysis of the estimation of MEY on multi-species fisheries. Given the large biological and technical interactions on most worldwide fisheries, an adequate management system based on single-species and single-fleet reference points is unrealistic and not appropriate. Indeed, ICES (2008) stated that on a multi-species context the biomass at MSY level has to be established following multi-species criteria, since the optimal fishing effort for one species would be directed to harvest different species, to which different MSYs and MEYs levels of optimal effort might need to be applied. In parallel, in a multi-fleet context the optimal fishing effort needs to be established by fleet, which are harvesting different sets of species and with different exploitation patterns for each of them.

The exploitation of fish stocks by different fleets can lead to changes on the MSY and MEY yield-effort curves depending on the effort allocation among fleets and therefore on global selectivity. This has implications on whether to consider technical and economic efficiency on the definition of MSY and MEY (i.e. by choosing the overall fleet composition), but also political decisions on favoring certain fleets, and consequently rent transfers among fleets and its social impacts.

The Bay of Biscay demersal fishery gives an example of multi-specific context with management objectives of MSY. This mixed fishery is one of the most important fisheries in the Bay of Biscay. More than 550 vessels from France, Spain and Belgium operate on this fishery, targeting mainly *nephrops* (Norway lobster, *Nephrops norvegicus*), hake (*Merluccius merluccius*) and sole (*Solea solea*) with trawl and gillnets.

This paper explores the calculation of MSY and MEY in multi-species (*nephrops*, hake and sole) and multi-fleet (trawlers, trawlers targeting *nephrops*, gillnetters, gillnetters targeting sole, and other vessels) fisheries, applied to the Bay of Biscay demersal fisheries.

MATERIALS AND METHODS

Bio-economic model

For this analysis we used the bio-economic model IAM (Impact Assessment Model for fisheries management). This model was developed to assess impacts of management scenarios or scenarios of changes in the economic or/and environmental context of the fishery. The model is developed in R/C++. It is an integrated model coupling the biological dynamics of fish stocks with the economic dynamics to perform impact assessment taking into account the biological impacts and the economic impacts for fleets. The IAM is multi-species, multi-fleets and multi-*métiers*. It is age structured, spatially aggregated and has an annual time step. The bio economic model calculates at each time step fishing mortality, spawning biomass, biomass, total catches, catches by fleet, fleet and individual economic performances, the total number of vessels by fleet, employment and crew salaries. The model can assess the impacts of various management scenarios: fishing gear selectivity improvement, decrease in time fishing per vessel, decrease in the number of vessels, quota constraints. The model was used to explore bio-economic impacts of several pathways to MSY for decision support within STECF working groups on management plan for sole in the Bay of Biscay (STECF 2011a). Other applications of the model deal with bio-economic impacts of selectivity improvements (Raveau et al. 2012). Main equations of the model are described in more detail in Macher et al. (2008).

The revenues (Gross value of landings) per fleet are obtained by adding the revenues from the modeled species (s) and the ones from other species not modeled ($oths$):

$$GVL_f = \sum_s (P_{s,f} \times L_{s,f}) + GVLoths_f \qquad \text{(equation 4)}$$

Where P is the price by species and fleet, L is the weight of landings by species and fleet, and GVL is the gross value of landings. The revenues from other species rather than the three modeled species (*nephrops*, hake and sole) have been estimated assuming that the other species revenues remain constant.

Economic performance indicators are calculated following the methodology established on the Annual Economic Report (STECF 2011b). Therefore, the Gross Value Added by fleet is estimated:

$$GVA_f = GVLav_f - fuec_f - ovc_f - rep_f - Fixc_f \quad \text{(equation 5)}$$

Where *fuec* is fuel costs, *ovc* is other variable costs, *rep* is reparations and maintenance and *Fixc* is fix costs.

Profitability is estimated by the Gross Cash Flow (*GCF*).

$$GCF_f = GVLav_f - fuec_f - ovc_f - rep_f - Fixc_f - ccw_f \quad \text{(equation 6)}$$

Where *ccw* is the crew costs, calculated assuming that wages are constant.

Effort adjustments (increases or decreases) by fleet are done through the number of vessels that participate in the fishery. Fishing effort (fishing days) by vessel and season is assumed to be constant for the analysis. Thus, variations of effort simulated in this paper correspond to capacity adjustments. Costs (variable costs and fixed costs) by fleet are assumed here to be proportional to the number of vessels in the fleet (i.e. to the effort).

The IAM model operates under several assumptions for this particular Bay of Biscay case study: constant price by commercial grades, constant catchability and strategies of effort allocation by métier and Hockey stick stock-recruitment relationships for sole, hake and *nephrops*.

Data

The bio-economic model was parameterized with the outputs from the stock assessments performed by the ICES for year 2009 for the stocks of *nephrops* in the Bay of Biscay and Northern hake (ICES 2010) and performed during the benchmark on flat fish for the stock of sole in the Bay of Biscay (ICES 2011). Hockey-stick stock-recruitment relationships were adjusted based on the 1990-2006 data for hake, on 1987-2009 data for *nephrops* and on 1993-2006 data for sole. Fleets data on fleets structure, productions and costs were parameterized from the IFREMER's Fisheries Information System that gathers data from Ifremer and from the French administration collected notably within the DCF regulation framework (Berthou et al. 2008; Daurès et al. 2008, Van Iseghem et al. 2011).

Vessels catching *nephrops*, hake or sole in the Bay of Biscay were classified into 5 different fleet segments according to their strategies: trawlers targeting *nephrops* all year long and depending on *nephrops* for more than 40% of their gross revenue, mixed trawlers, gillnetters targeting sole and for which sole represents more than 30% of the gross revenue or mixed gillnetters. The fleet "others" includes the vessels that could not be classified into the previous fleets but contributes to the fishing mortality of these species and for which all the data were not available. This fleet "others" could therefore not be fully modeled but only for its impacts on stocks.

Figure 1: Map of the Bay of Biscay[1]

Table 1 shows the number of vessels, fishing mortality per species (F), quantities (Q), landings (L) and value of landings (V) for each species and in totals, total costs and economic performance detailed by fleet.

Table 1: Main data for the fleets involved in the demersal mixed fishery (2009)

Variables/Fleets	Trawler *Nephrops*	Mixed Trawler	Mixed Gillnetter	Gillnetter Sole	Other Fleets	TOTAL
Number of Vessels	116	241	86	105	NA	NA
F *nephrops*	0.32	0.10	0.00	0.00	0.02	0.43
F hake	0.01	0.02	0.04	0.00	0.49	0.57
F sole	0.02	0.05	0.01	0.21	0.06	0.35
Q *nephrops* (Tonnes)	4,642	1,437	0	0	279	6,358
Q hake (Tonnes)	866	1,819	4,320	344	48,943	56,291
Q sole (Tonnes)	253	845	123	2,273	717	4,210
L *nephrops* (Tonnes)	2,993	926	0	0	180	4,099
L hake (Tonnes)	463	1,367	4,320	344	46,423	52,917
L sole (Tonnes)	253	845	123	2,273	717	4,210
L Total (Tonnes)	6,817	22,054	8,468	5,926	NA	NA
V *nephrops* (000 Euros)	29,386	9,094	0	0	NA	NA
V hake (000 Euros)	1,023	3,161	11,433	909	NA	NA
V sole (000 Euros)	2,744	9,134	1,503	27,840	NA	NA
V Total (000 Euros)	37,093	84,954	37,199	45,005	NA	NA
GVL vessel (000 Euros)	319.8	352.5	432.5	428.6	NA	NA
Costs vessel (000 Euros)	290.8	330.2	343.6	357.3	NA	NA
GVA vessel (000 Euros)	159.5	154.4	277.3	256.9	NA	NA
GCF Pr vessel (000 Euros)	29.0	22.4	88.9	71.3	NA	NA

In 2009, the Bay of Biscay demersal mixed fishery produced[2] a turnover (gross landings value) of more than 200 million Euros, a Gross Value Added of more than 100 million Euros and profits of almost 24 million Euros.

RESULTS

Single species MSY estimation

In the Bay of Biscay demersal mixed fishery, the main three species targeted are *nephrops*, hake and sole. For each of the three species, the optimal fishing mortality and effort (E_{MSY}) corresponding to the maximum sustainable yield is estimated. In the current study, yields will refer to landings that are the utilized part from the removed stock, and so the amount contributing to economic or social activity.

For this MSY estimation we initially assume that increases (decreases) in the global fishing mortality will lead to proportional increases (decreases) in the fishing mortality for each of the fleets, and so in their fishing effort. Thus, the global exploitation pattern (selectivity) of the fishery remains constant.

As it can be seen from table 2, all 3 fish stocks are overexploited, because current exploitation levels (effort multipliers equal to 1) are higher than the optimal effort (E_{MSY}). So, more landings could be obtained on a sustainable way if an effort lower than current effort was applied.

Table 2: Summary results from the MSY estimations

	Single-species simulations			Multi-species simulation		
	Nephrops	Hake	Sole	*Nephrops*	Hake	Sole
Effort Multiplier (E)	0.66	0.46	0.77	0.48	0.48	0.48
Catches (Tonnes)	6,308	69,500	4,860	5,846	69,533	4,706
Landings (Tonnes)	4,631	67,728	4,860	4,514	67,701	4,706
Discards (Tonnes)	1,677	1,772	0	1,332	1,832	0
Biomass (Tonnes)	28,393	309,333	24,418	34,855	300,962	34,376

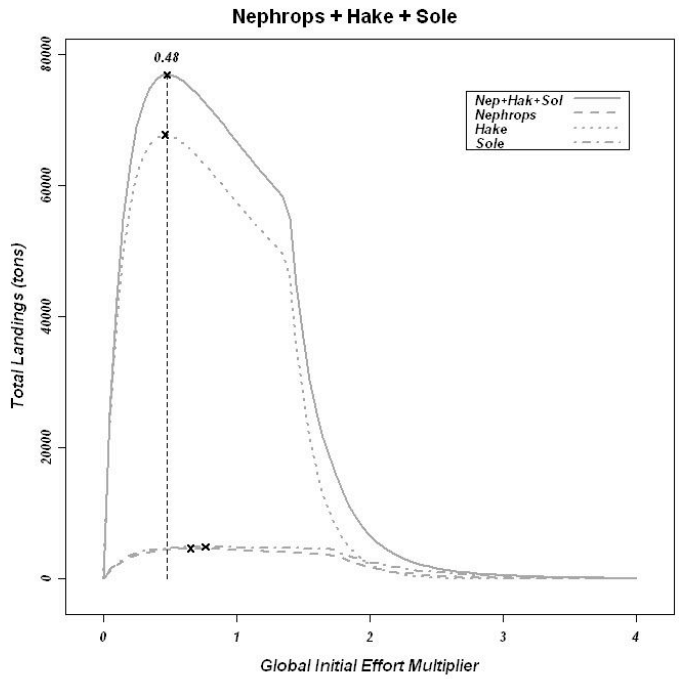
In fact, with single species simulations, the maximum sustainable landings that can be obtained are 4,631 tons of *nephrops* landings with a fishing effort 34% lower than current effort, 67,728 tons of hake with an effort 54% lower and 4,860 tons of sole with an effort 23% lower, as can be seen from table 2. While landings for *nephrops*, hake and sole in the initial period (on 2009 from table 1) accounted for 26% less. This implies that all stocks will benefit from effort reductions.

Multi-species fisheries: effects of technical interactions

Optimal fishing effort levels for *nephrops*, hake and sole are respectively 34%, 54% and 23% lower than the current effort level. However, effort reduction should take into account that these species are in technical interactions through fleets.

We then estimate an MSY on the aggregate catches by summing up the sustainable production curves for all 3 species (Figure 2).

Figure 2: Landings at MSY considering the multi-species characteristics of the fishery



The effort level that maximizes together the landings of *nephrops*, hake and sole is a 52% lower than current effort, as can be seen on figure 2. The optimal fishing effort that maximizes landings is close to the optimal effort that maximizes hake catches due to the large landings that can be obtained from this stock, in comparison to the *nephrops* and sole ones. Total landings obtained by maximizing *nephrops*, hake and sole individually (single-species simulations) are 2.6%, 0.0% and 3.3% higher than the landings obtained at the effort level that maximizes the sum of all 3 (see table 2).

MEY estimation

The MSY concept only takes into consideration the biological dynamics. It is moreover a single species notion. From an economic perspective, the objective is not to provide the maximum amount of fish that can be harvested from a stock on a sustainable way as MSY do but to provide the maximum of rent from catches. MEY objective is to optimize the profits that can be obtained from the fishery. From this point of view, MEY is a multispecies notion that considers economic dynamics of the fisheries activity and includes fishing costs in addition to the biological dynamics (Kompas 2005, Grafton et al. 2007, Dichmont et al. 2010).

MEY estimation considering proportional effort allocation by fleet

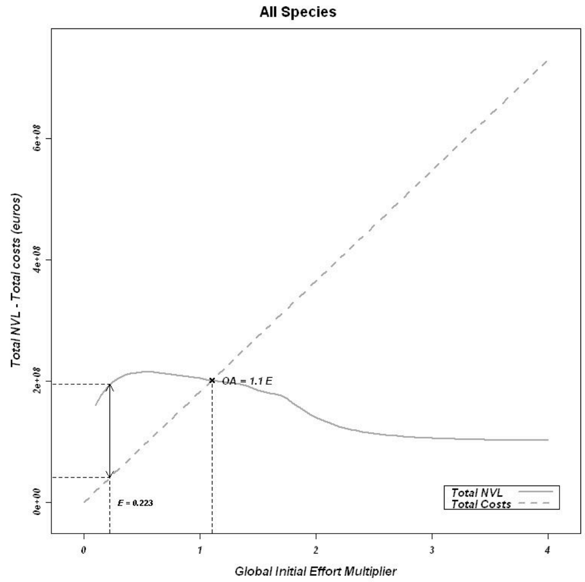
The MEY is estimated assuming that other species landings and consequently their revenues[3] remain constant. MEY is estimated here as the profit from the fishery at equilibrium.

The MEY value is found to be positioned on the left and below the MSY as expected by the fishery economics theory. Therefore, the fishing effort and the landings are lower at the MEY level compared to the MSY level (Clark 1990, Kompas 2005). Optimal effort that maximizes profits from the fishery would be 0.22 (assuming other species revenues constant). Optimal effort is therefore lower than the 0.48 that was estimated when it is aimed at maximizing landings.

Nephrops, hake and sole represent 48% of total revenues from the fleets analyzed, depending whether other species are considered constant or proportional.

When assuming that other species are constant, with an effort of 0.22 of the current effort, then profits would be 154 million Euros (value of landings would be 195 million Euros and costs 41 million Euros). The profitability is 6.4 times higher than in the current situation (Effort equal to 1), where profits are almost 24 million Euros (table 1). The difference of profits at MEY and current profit gives an estimation of the costs of overcapacity and overexploitation.

Figure 3: MEY with other species constant



MEY estimation considering the optimal effort allocation by fleet (multi-fleet nature)

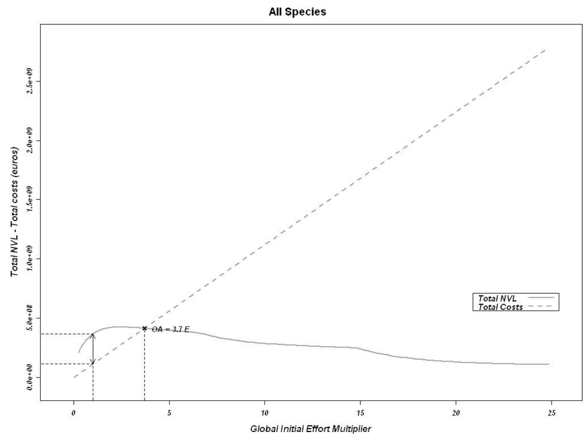
The assumption of a constant proportion of the fleets in the total fishing fleet is then relaxed and we assume that effort can be allocated independently by fleet. This results in determining the effort allocation by fleet that maximizes profit.

When considering the multi-species and multi-fleet character of the fishery (and according to assumptions on species dynamics included in the model), the optimal allocation of effort by fleet that maximizes profits is obtained when:

- Mixed trawlers and “other” fleet do not participate in the fishery
- mixed gillnetters increase their effort,
- trawlers targeting *nephrops* reduce their effort,
- gillnetters targeting sole reduce their effort with the assumption of constant other species,

It should be noted that *nephrops*, hake and sole represent 72% of the total revenues from the fleets analyzed. When comparing these results to the MEY calculations considering that different efforts could not be allocated between the fleets, the landings for all three modeled species are higher when effort can be optimally allocated between species and profits are 67% higher.

Figure 4: MEY with other species constant



In this case, the economic equilibrium is also more stable since the open access point would be situated 3.7 times the optimal effort.

CONCLUSIONS

Estimations of MSY and MEY performed in this paper show that increases of the overall landings and economic performances can be obtained by fishing effort reductions and global selectivity improvements in the Bay of Biscay demersal fishery. In this paper we have also shown the importance of accounting for the multi-fleet nature of the fisheries, and so the capacity to allocate fishing effort between fleets to obtain better yields taking into account joint production processes, various métiers and reallocation of effort (both in production and economic terms).

In output managed fisheries, quota recommendations consistent with MSY and MEY estimations should also help preventing discards, illegal landings and loss of fishing opportunities created by fleets reaching single species quotas at different rates as highlighted by Vinther et al., (2004) and Pascoe et al., (2007). Estimating profitability changes when fishing at MEY and in the current situation of overcapacity and overexploitation offers an estimation of the costs of not fishing at MSY and MEY.

ACKNOWLEDGEMENTS

This work has been carried out with the support of the French Research Agency, ANR, (Agence National pour la Recherche) through the research program entitled Adhoc; and with support of the French Directorate of Sea Fisheries and Aquaculture of the French Ministry of Ecology, sustainable development and ecology through the partnership on the bioeconomic working group project.

REFERENCES

Worm B., R. Hilborn, J.K. Baum, T.A. Branch, J.S. Collie, C. Costello, M.J. Fogarty, E.A. Fulton, J.A. Hutchings, S. Jennings, O.P. Jensen, H.K. Lotze, P.M. Mace, T.R. McClanahan, C. Minto, S.R. Palumbi, A.M. Parma, D. Ricard, A.A. Rosenberg, R. Watson and D. Zeller, 2009, Rebuilding global fisheries. *Science*, 325, pp. 578-585.

United Nations, 2002, Report of the World Summit on Sustainable Development, Johannesburg, South Africa.

Commission of the European Communities (EC), 2009, *Green Paper on the Reform of the Common Fisheries Policy*. Brussels, 22.4.2009, COM(2009) 163 final.

Dichmont C.M., S. Pascoe, T. Kompas, A. Punt and R. Deng, 2010, On implementing maximum economic yield in commercial fisheries. In: Proceedings of the National Academy of Sciences 2010; 107: 16–21.

Mace P.M., 2001, A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries*, 2, pp. 2-32.

Matsuda H. and P. Abrams, 2006; Maximum yields from multispecies fisheries systems: rules for systems with multiple trophic levels. *Ecological Application*, 16, pp. 225-37.

ICES, 2008, *Report of the Working Group on Multispecies Assessment Methods (WGSAM)*, 6-10 October 2008, Copenhagen, Denmark, ICES CM 2008/RMC:06.

Commission of the European Communities (EC), 2006, *Council regulation (EC) No 388/2006 of 23 February 2006 establishing a multiannual plan for the sustainable exploitation of the stock of sole in the Bay of Biscay*. Luxemburg.

Commission of the European Communities (EC), 2004, *Council regulation (EC) No 811/2004 of 21.4.2004 establishing measures for the recovery of the Northern hake stock*. Luxemburg.

STECF, 2011a, *Impact Assessment of Bay of Biscay sole (STECF-11-01)*. Simmonds J., G. Biais, M. Bertignac, C. Macher, M. Merzereaud, R. Scott and W. Vanhee (ed.). Copenhaguen, Denmark. pp. 41.

Raveau A., C. Macher, S. Méhault, M. Merzéréaud, C. Le Grand, O. Guyader, M. Bertignac, S. Fifas and J. Guillen, 2012, A bio-economic analysis of experimental selective devices to improve bottom trawlers selectivity in the Nephrops-hake fishery of the Bay of Biscay. *Aquatic Living Resources*, in press.

Macher C, O. Guyader, C. Talidec, and M. Bertignac, 2008, A Cost-benefit Analysis of Improving Trawl Selectivity in the Case of Discards: The Nephrops norvegicus Fishery in the Bay of Biscay. *Fisheries Research*, 92, pp. 76–89.

STECF (Scientific, Technical and Economic Committee for Fisheries), 2011b, *The 2011 Annual Economic Report on the EU fishing fleet.* Publications Office of the European Union. Luxembourg. ISBN 978-92-79-22326-6. ISSN 1018-5593. pp. 233

ICES, 2010, *Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM)*, 5 - 11 May 2010, Bilbao, Spain. ICES CM 2010/ACOM:11. pp. 599.

ICES, 2011, *Report of the Benchmark Workshop on Flatfish (WKFLAT)*, 1–8 February 2011, Copenhagen, Denmark. ICES CM 2011/ACOM:39. pp. 257.

Berthou P., O. Guyader, E. Leblond, S. Demanèche, F. Daurès, C. Merrien and P. Lespagnol, 2008, From fleet census to sampling schemes: an original collection of data on fishing activity for the assessment of the French fisheries. ICES CM 2008/ K: 12, Halifax.

Daurès F, Van Iseghem S, Demanèche S, Leblond E, Brigaudeau C, Guyader O, Berthou P. Re-assessing the French small-scale coastal fisheries: from fleet activity to economic performance. ICES CM 2008 / K:10, Halifax.

Van Iseghem S., E. Quillerou, C. Brigaudeau, C. Macher, O. Guyader, F. Daures, 2011, Ensuring representative economic data: survey data-collection methods in France for implementing the Common Fisheries Policy. *ICES Journal of Marine Science*, 68, pp. 1792-1799.

Kompas T. 2005, Fisheries management: economic efficiency and the concept of 'Maximum Economic Yield'. *Australian Commodities*, 12, pp. 152-160.

Grafton RQ, Kompas T, Hilborn RW. Economics of overexploitation revisited. Science 2007; 318:1601.

Clark C.W. 1990. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*. Wiley, New York.

Vinther M., S. Reeves and K. Patterson, 2004, From single-species advice to mixed-species management: taking the next step. *ICES Journal of Marine Science*, 61, pp. 1398-1409.

Pascoe S., P. Koundouri and T. Bjorndal, 2007, Estimating targeting ability in multi-species fisheries: A primal multi-output distance function approach RID D-9710-2011. *Land Economics*, 83, pp. 382-397.

---

[1] The Bay of Biscay lies along the western coast of France, from Brest south to the Spanish border, and the northern coast of Spain west to Cape Ortegal in A Coruña.
[2] For the fleets were economic data is available, so excluding the "*other*" fleet.
[3] Assuming other species revenues proportional to effort, the effort for some fleets would increase on an unrealistic way.