ICES Journal of Marine Science Advance Access published July 25, 2011

ICES Journal of Marine Science; doi:10.1093/icesjms/fsr105

Lessons from the long-term management plan for northern hake: could the economic assessment have accepted it?

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Da Rocha, J-M., and Gutiérrez, M-J. Lessons from the long-term management plan for northern hake: could the economic assessment have accepted it? – ICES Journal of Marine Science, doi:10.1093/icesjms/fsr105.

Received 18 July 2010; accepted 12 May 2011.

An economic working group was convened by the EU's Scientific, Technical and Economic Committee for Fisheries (STECF) in 2007 to evaluate the potential economic consequences of the long-term management plan for the northern hake (*Merluccius merluccius*) stock. An analysis of all the scenarios proposed by the biological assessment using the Economic Interpretation of ACFM Advice (EIAA) model showed that F at the *status quo* level was the best policy for both yield and profits, in terms of net present values. This result is counter-intuitive because it seems to suggest that effort costs do not influence economic indicators, whereas it is widely accepted that including costs negatively affects economic indicators. A dynamic age-structured model is applied to northern hake and shows that the optimal fishing mortality that maximizes the net present value of profits is $<F_{max}$. The reason why the EIAA analysis was biased towards scenarios with $F > F_{max}$ is also shown.

Keywords: age-structured models, economic assessment, EIAA, fishery management optimization, northern hake.

Introduction

Economists have long participated as consultants in fishery management decisions (Wilen, 1999). However, biological and economic assessments are conducted independently. This means that the conclusions from the different models used by each discipline need to be assembled by fishery agencies to reach their objectives, which may not be possible when the analysis is based on different assumptions.

The use of unrelated methods of analysis in each area may lead to unexpected situations. For instance, a working group (STECF/SGBRE-07-03) was convened by the EU's Scientific, Technical and Economic Committee for Fisheries (STECF) in 2007 to evaluate the potential biological consequences of the long-term management plan for the northern hake (*Merluccius merluccius*) stock (STECF, 2008a). The working group found that the current rate of fishing mortality (*status quo*, F_{sq}) was close to F_{pa}= 0.25. It also concluded that F_{max}= 0.17 was a good proxy for the target reference point F_{msy}. The working group studied the impact of reducing the current fishing mortality rate, F_{pa}, to F_{max} assuming different convergence speed scenarios. Based on that analysis, STECF/SGBRE-07-03 concluded that maintaining F_{pa} as opposed to reducing F to F_{max} would in the short term lead to an increased risk of returning to an unsafe situation.

To carry out bioeconomic impact assessments for the long-term management plan, STECF also recommended scheduling an additional meeting, involving both biologists and economists. Therefore, a second working group (STECF/SGBRE-07-05) was convened later in 2007 (STECF, 2008b) to analyse the socio-economic impact of the scenarios proposed at the earlier meeting. The indicators selected for evaluating this impact were the net present values of landings (in value), crew share, gross cash flow, profits, and gross added value. These indicators were calculated using the Economic Interpretation of ACFM Advice (EIAA) model (SEC, 2004; Hoff and Frost, 2008).

Tables 1 and 2 show the results obtained by the working group for all the economic indicators associated with the French and Spanish fleets, respectively, using a 5% discount rate and considering the period 2008–2016. Regardless of which economic indicator was used, the *status quo* was the best ranked among the scenarios analysed. Therefore, the economic analysis concluded, contrary to the first working group's proposal, that fishing mortality should be kept close to the *status quo* F_{pa} rather than being reduced to F_{max}. Moreover, close inspection of Tables 1 and 2 shows that all scenarios analysed are ranked equally regardless of the economic indicator used, which is counter-intuitive. It is well known that the F associated with maximum profits is generally lower than the F associated with maximum yield (Grafton *et al.*, 2006, 2007). Consequently, when profits are considered, a scenario with $F < F_{msy}$ is expected to be ranked higher than a scenario with $F = F_{msy}$.

We show here, using a dynamic age-structured model, that the scenarios proposed by biologists for northern hake may be ranked differently depending on the economic indicator used. To that end, we solve for the optimal long-term fishing mortality and the fishing-mortality trajectories that maximize the net present values of the different indicators, using a generic basic age-structured model with constant recruitment, and specifying cost as a linear function of fishing mortality (Gröger *et al.*, 2007;

Table 1. Net present values (best scenario emboldened) for French fleet segments of the northern hake fishery for the years 2008–2016 (million €) with $\beta = 1/(1+0.05)$, for different objectives and levels of annual reduction of *F*.

		1.2 F_{max}			F_{max}			0.8 F_{max}		
Net present value parameter	***Status quo***	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**
Value of landings	**2 077**	2 054	2 057	2 059	2 032	2 027	2 029	2 026	1 994	1 989
Crew share	**699**	693	694	695	686	685	686	684	674	673
Gross cash flow	**394**	391	393	**394**	383	385	387	381	373	374
Net profit	**207**	203	205	**207**	196	197	199	194	186	187
Gross value added	**1 093**	1 084	1 087	1 089	1 069	1 070	1 073	1 065	1 047	1 047

Source: Table 7.3.1 of STECF (2008b).

Table 2. Net present values (best scenario emboldened) for Spanish fleet segments of the northern hake fishery for the years 2006–2014 (million €) with $\beta = 1/(1+0.05)$, for different objectives and levels of annual reduction of *F*.

		1.2 F_{max}			F_{max}			0.8 F_{max}		
Net present value parameter	***Status quo***	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**
Value of landings	**1 823**	1 783	1 779	1 778	1 759	1 735	1 731	1 757	1 696	1 677
Crew share	**837**	818	817	817	807	797	795	806	778	769
Gross cash flow	**372**	365	366	366	360	356	357	359	345	343
Net profit	**181**	174	174	175	168	164	165	167	154	151
Gross value added	**1 210**	1 183	1 183	1 184	1 167	1 153	1 152	1 165	1 123	1 112

Source: Table 7.4.1 of STECF (2008b).

Kulmala *et al.*, 2008; Tahvonen, 2009; Da Rocha *et al.*, 2010). The numerical simulations are intuitive from a theoretical perspective. Under reasonable prices per age, running costs per day, and discount rates, if the net present values of profits are maximized, the scenarios associated with a long-term fishing mortality $<F_{max}$ are always preferred, as in Dichmont *et al.* (2010), Grafton *et al.* (2010), and Kompas *et al.* (2010).

The dynamic management problem

An alternative to economic assessment of a fishery based on preselected fishing-mortality trajectories is to use the optimal trajectory that maximizes the net present value of a fishery's economic indicator, taking into account the dynamics described by the standard age-structured model.

Formally, assume that the fish stock is broken down into *A* cohorts. The net present value of a fishery economic indicator can be expressed as

$$\sum_{t=0}^{\infty} \beta^t \left(\sum_{a=1}^{A} \mathrm{pr}^a Y_t^a - C(F_t) \right), \tag{1}$$

where pr^a, Y_t^a, $C(F_t)$, and β are the price at age *a*, the yield at age *a* in year *t*, the total cost function (which depends positively on fishing mortality at time *t*, F_t), and the discount factor, $0 \le \beta \le 1$, respectively. Discount is frequently introduced in fisheries economics by using the discount rate, *r*, rather than the discount factor, β (Grafton *et al.*, 2006). The former is applied in continuous time frameworks and the latter more commonly in discrete setups. The inverse relationship between the two terms is given by $\beta = (1+r)^{-1}$.

Notice that the objective function represents different economic indicators depending on the prices and costs considered. For instance, if pr^a has a value of 1 and the cost is zero, the objective function represents the discounted yield in weight. When the cost is zero and pr^a is not equal to 1, the objective function coincides with the discounted yield in value. When pr^a is not 1 and the total cost is the cost of fuel plus other running costs, the objective function is equal to the added discounted value. Finally, if the total cost also includes labour, then the objective function is the fishery's discounted profits.

The maximization problem consists of solving the objective function (1) taking into account the stock dynamics, which are given by $N_{t+1}^{a+1} = \mathrm{e}^{-z_t^a} N_t^a$, where N_t^a and z_t^a are the size in numbers and the total annual mortality rate of age group *a* during year *t*, respectively. The total mortality rate is decomposed into fishing mortality *F* and natural mortality *M*, which is assumed to be constant across ages. Formally, $z_t^a = p^a F_t^a + M^a$, where p^a represents the selectivity parameters for age *a*. We also assume that recruitment follows an Ockham rule and that yield is determined by Baranov's (1918) equation. Further, we restrict the solution to satisfying the precautionary restriction given by $\mathrm{SSB}_t \ge B_{pa}\ \forall t$, where SSB refers to spawning-stock biomass. This implies that recruitment is constant; i.e. $N_t^1 = N^1\ \forall t$.

Notice that $N_t^a = \phi_t^a N_{t-(a-1)}^1 = \phi_t^a N^1, \quad \forall a = 1, \ldots, A$, where ϕ_t^a can be interpreted as the survival function that shows the probability of a recruit born in year $t-(a-1)$ reaching age *a*, for a given *F* path $\{F_t, F_{t-1}, F_{t-2}, \ldots F_{t-(a-1)}\}$. It is given by

$$\phi_t^a = \begin{cases} \Pi_{i=1}^{a-1} \mathrm{e}^{-z_{t-i}^{a-1}(F_{t-i})} & \text{if} \quad a > 1, \\ 1 & \text{if} \quad a = 1. \end{cases} \tag{2}$$

With no loss of generality, it is assumed that $A = 3$. In this context, the function to be maximized can be expressed as

$$L = \sum_{t=0}^{\infty} \beta^t \Big\{ \mathrm{pr}^3 y^3(F_t)\phi_t^3 N^1 + \mathrm{pr}^2 y^2(F_t)\phi_t^2 N^1 + \mathrm{pr}^1 y^1(F_t)\phi_t^1 N^1 - C(F_t) \Big\}, \tag{3}$$

where $y^i(F_t)$ is the yield per unit of fish at age *a* in year *t*. Therefore, the first-order condition of the maximization problem is given by

$$\begin{aligned}\frac{\mathrm{d}L}{\mathrm{d}F_t} &= \beta^t\left\{\mathrm{pr}^3\frac{\mathrm{d}y^3(F_t)}{\mathrm{d}F_t}\mathrm{e}^{-p^2F_{t-1}-M^2}\mathrm{e}^{-p^1F_{t-2}-M^1}N^1\right.\\ &\quad+\mathrm{pr}^2\frac{\mathrm{d}y^2(F_t)}{\mathrm{d}F_t}\mathrm{e}^{-p^1F_{t-1}-M^1}N^1+\mathrm{pr}^1\frac{\mathrm{d}y^1(F_t)}{\mathrm{d}F_t})N^1\\ &\quad\left.-\frac{\mathrm{d}C(F_t)}{\mathrm{d}F_t}\right\}\\ &\quad+\beta^{t+1}\left\{\mathrm{pr}^3y^3(F_{t+1})(-p^2)\mathrm{e}^{-p^2F_t-M^2}\mathrm{e}^{-p^1F_{t-1}-M^1}N^1\right.\\ &\quad\left.+\mathrm{pr}^2y^2(F_{t+1})(-p^1)\mathrm{e}^{-p^1F_t-M^1}N^1\right\}\\ &\quad+\beta^{t+2}\left\{\mathrm{pr}^3y^3(F_{t+2})(-p^1)\mathrm{e}^{-p^2F_{t+1}-M^2}\mathrm{e}^{-p^1F_t-M^1}N^1\right\}\\ &= 0. \end{aligned} \tag{4}$$

Using the survival function definition, Equation (2), this first-order condition can be expressed as

$$\begin{aligned}&\left\{\mathrm{pr}^3\frac{\mathrm{d}y^3(F_t)}{\mathrm{d}F_t}\phi_t^3N^1+\mathrm{pr}^2\frac{\mathrm{d}y^2(F_t)}{\mathrm{d}F_t}\phi_t^2N^1+\mathrm{pr}^1\frac{\mathrm{d}y^1(F_t)}{\mathrm{d}F_t})\phi_t^1N^1\right.\\ &\left.-\frac{\mathrm{d}C(F_t)}{\mathrm{d}F_t}\right\}\\ &+\beta\left\{\mathrm{pr}^3y^3(F_{t+1})(-p^2)\phi_{t+1}^3N^1+\mathrm{pr}^2y^2(F_{t+1})(-p^1)\phi_{t+1}^2N^1\right\}\\ &+\beta^2\left\{\mathrm{pr}^3y^3(F_{t+2})(-p^1)\phi_{t+2}^3N^1\right\}=0.\end{aligned} \tag{5}$$

More compactly,

$$\sum_{a=1}^{3}\mathrm{pr}^a\frac{\mathrm{d}y^a(F_t)}{\mathrm{d}F_t}\phi_t^aN^1-\frac{\mathrm{d}C(F_t)}{\mathrm{d}F_t} = \sum_{a=1}^{2}p^a\left[\sum_{j=1}^{3-a}\beta^j\mathrm{pr}^{a+j}y^{a+j}(F_{t+j})\phi_{t+j}^{a+j}N^1\right]. \tag{6}$$

A generalization of this example for any value of A implies

$$\sum_{a=1}^{A}\mathrm{pr}^a\frac{\mathrm{d}y^a(F_t)}{\mathrm{d}F_t}\phi_t^aN^1-\frac{\mathrm{d}C(F_t)}{\mathrm{d}F_t} = \sum_{a=1}^{A-1}p^a\left[\sum_{j=1}^{A-a}\beta^j\mathrm{pr}^{a+j}y^{a+j}(F_{t+j})\phi_{t+j}^{a+j}N^1\right]. \tag{7}$$

Equation (7) reveals that the fishing mortality trajectory that maximizes the net present value of the economic indicator for any value of β is the balance between two effects: (i) the instantaneous effect of changes in the fishing mortality in year t, when the population's age distribution is constant across time (left side), and (ii) the effect of changes in the population's future age distribution induced by changes in F_t. Note that β affects the future net present value (right side). Note that making $\beta = 1$ implies caring about future changes as much as if they occurred in the current year. In contrast, considering $\beta = 0$ implies not caring about the future at all.

When $F = F_t = F_{t+1}$, Equation (7) collapses to a steady-state solution that can be understood as the steady-state value of F that is reached in the long term by the optimal trajectory. For the steady-state solution $F = F_t = F_{t+1}$, Equation (7) becomes

$$\left[\sum_{a=1}^{A}\mathrm{pr}^a\frac{\mathrm{d}y^a(F)}{\mathrm{d}F}\phi^a(F)N^1-\frac{\mathrm{d}C(F)}{\mathrm{d}F}\right] = \sum_{a=1}^{A-1}p^a\left[\sum_{j=1}^{A-a}\beta^j\mathrm{pr}^{a+j}y^{a+j}(F)\phi^{a+j}(F)N^1\right], \tag{8}$$

where

$$\phi^a = \begin{cases} 1 & \text{if} \quad a=1 \\ \exp\left(\sum_{j=1}^{a-1}p^jF+M^j\right) & \text{if} \quad a>1 \end{cases} \tag{9}$$

is the stationary survival function.

Observe that if $\beta = 1$, $\mathrm{pr}^a = 1$, and $\mathrm{d}C(F)/\mathrm{d}F = 0$, the stationary optimal condition (8) can be written, after manipulation, as

$$\sum_{a=1}^{A}\frac{\mathrm{d}y^a(F)}{\mathrm{d}F}\phi^a(F)+\sum_{a=1}^{A}y^a(F)\frac{\mathrm{d}\phi^a(F)}{\mathrm{d}F}=0. \tag{10}$$

This equation represents the first-order condition of an optimization problem that maximizes $L=\sum_{a=1}^{A}y^a(F)\phi^a(F)N^1$, which characterizes $F_{\max}$. Therefore, when $\mathrm{pr}^a = 1$, the marginal cost is zero $[\mathrm{d}C(F)/\mathrm{d}F = 0]$, and $\beta = 1$, the steady-state solution is $F_{\max}$. In contrast, if $\beta = 0$, the steady-state solution is the immediate maximum economic yield (Lleonart and Merino, 2009). In some frameworks, the optimal trajectory does not necessarily reach a constant steady state in the long term, but consists of pulse fishing (Tahvonen, 2009).

Results

Here, we find the optimal long-term fishing mortality and the fishing-mortality trajectories that maximize the net present value of yield in weight (scenario 1), yield in value (scenario 2), value added (scenario 3), and profits (scenario 4). Note that the optimal trajectories have also been calculated under the restriction that the mortality rate does not change by >15% per year. The Supplementary material shows in detail how the calibration is prepared using the dataset reported for working groups STECF/SGBRE-07-03 and SGBRE-07-05, and daily sales by the Spanish fleet.

Following the working group reports, we consider that there is uncertainty about the initial age distribution and the recruitment process. In particular, lognormal distributions are used to describe the population distribution for the initial conditions (Supplementary Table S1). For each scenario, 20 000 simulations were run.

Table 3 lists the net present values in each scenario using a discount factor of $\beta = 0.95$, the age-structured model and economic calibration described in the Supplementary material. Notice that the F steady-state solution associated with maximization of the net present value of each economic indicator is different. In particular, the steady-state F is much lower when profits (scenario 4) rather than yield in weight (scenario 1) are used as the benchmark economic indicator.

It is worth highlighting that the economic indicators calculated represent the present value of the fishery for the whole future. Although the stationary fishery rate is reached within 8–10 years for each scenario, the value of the objective function (1) is calculated for the optimal trajectory taking into account an infinite number of years.

Table 3. Economic indicators (net present value with $\beta = 0.95$; best scenario for each indicator emboldened) for the northern hake fishery for different objectives and F reference points (source: own calculations).

Indicator	*Status quo* (0.25)	Maximizing yield (weight) (0.21)	Maximizing yield (value) (0.17)	Maximizing value added (0.14)	Maximizing profit (0.10)
Yield (t) (*CV*)	1 136 (3.29)	**1 144** (3.32)	1 133 (3.36)	1 095 (3.38)	1 024 (3.36)
Yield (million €) (*CV*)	6 041 (3.26)	6 236 (3.31)	**6 310** (3.36)	6 208 (3.40)	5 892 (3.40)
Value added (million €) (*CV*)	4 570 (4.31)	5 020 (4.11)	5 307 (4.00)	**5 387** (3.92)	5 221 (3.84)
Profit (million €) (*CV*)	2 157 (9.13)	3 027 (6.81)	3 664 (5.79)	4 042 (5.22)	**4 120** (4.86)

Table 4. Implicit net present value and costs calculated with the EIAA model for the years 2008–2016 for the northern hake fishery (best scenario emboldened) for different objectives and levels of annual reduction in F (source: own calculations).

		1.2 F_{max}			F_{max}			0.8 F_{max}		
Fleet segment	***Status quo***	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**
Net present value (million €) with $\beta = 1/(1 + 0.05)$										
French	**1 870**	1 851	1 852	1 852	1 836	1 830	1 830	1 832	1 696	1 677
Spanish	**1 642**	1 609	1 605	1 603	1 591	1 571	1 566	1 590	1 542	1 526
Net present costs as a percentage of costs under the *status quo* scenario										
French	100.00	98.98	99.04	99.04	98.18	97.86	97.86	97.97	90.70	89.68
Spanish	100.00	97.99	97.75	97.62	96.89	95.68	95.37	96.83	93.91	92.94

Why does our analysis rank scenarios that Grafton *et al.* (2007), Dichmont *et al.* (2010), Kompas *et al.* (2010), and the EIAA analysis did not? Our intuition is that the EIAA model calculated all economic indicators as if they were monotonic transformations of yield in weight, because pr^a was constant across ages and, more importantly, it underestimated differences in effort cost between scenarios.

From the information that appears in the report of STECF/SGBRE-07-05 (STECF, 2008b), it is not possible to reproduce the cost indicators computed by the EIAA model. Therefore, we calculate the implicit costs used by the EIAA model by computing

$$\sum_{t=2008}^{2016} \beta^t C(F_t) = \sum_{t=2008}^{2016} \beta^t \text{value of landings}_t - \sum_{t=2008}^{2016} \beta^t \text{net profits}_t. \quad (11)$$

Table 4 lists these implicit costs used by the EIAA model. The differences in effort cost between scenarios are much smaller than the differences in F between scenarios. According to the EIAA model calculations, reductions of >15% in fishing mortality (from F_{sq} to 1.2 F_{max}) imply reductions of <1% in the effort cost for the French fleet segments, and <2.5% for the Spanish ones. Therefore, the effort cost is close to constant, which is equivalent to assuming a marginal cost close to zero. Therefore, EIAA economic indicators are monotonic transformations of net present value of yield. In other words, the EIAA model selects scenarios that maximize the net present value of the yield.

It can be proven analytically that the long-term F that maximizes the net present value of yield in weight when the future is discounted, $\beta < 1$, is always $> F_{max}$. We illustrate this claim graphically. First, notice that the optimal long-term F that maximizes the net present value of yield in weight is given by

$$\sum_{a=1}^{A} \frac{dy^a(F)}{dF} \phi^a(F) = \sum_{a=1}^{A-1} p^a \left[\sum_{j=1}^{A-a} \beta^j y^{a+j}(F) \phi^{a+j}(F) \right], \quad (12)$$

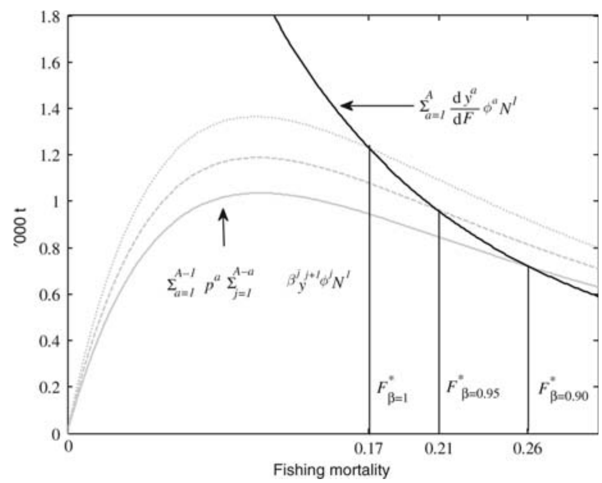

Figure 1. Optimal F for different values of β using the age-structured parameters listed in Supplementary Table S1. The black line represents the left side of Equation (12), and the grey lines the right side of Equation (12) for $\beta = 1$, $\beta = 0.95$, and $\beta = 0.90$, respectively. The steady-state F is determined for each β from the intersection between the black line and the corresponding grey line. It shows that if the discount rate, β, is <1, then the optimal F that maximizes the net present value of yield in weight $> F_{max}$.

taking into account that when yield in weight is the economic indicator, the function to be maximized requires $pr^a = 1$ and $dC(F)/dF = 0$. Second, we plot in Figure 1 the right and left sides of Equation (12) for different values of β. The optimal long-term F is determined graphically by the cross between the right- and left-side representations. The left side of Equation (12) represents how the present yield would change as F increases. Notice first that β does not appear on the left side of Equation (12). The right side of Equation (12) represents how the net present value of future yield varies as F increases. Second, notice that the right side depends on the discount factor β. When β decreases, future yield is lower and the net present value of the future yield decreases (graphically, the right side shifts down). Graphically, it is clear that the lower the discount factor, the higher is the long-term F. Third, if $\beta = 1$, the optimal long-term F is equal to $F_{max} = 0.17$, so with $\beta = 0.95$ and $\beta = 0.90$, the long-term F is higher (0.21 and 0.26, respectively). Therefore, it can be concluded that when the EIAA model uses a discount factor <1, scenarios in which F is higher than F_{max} will always be preferred.

Discussion

Most fishery agencies consider biological and economic analyses when giving their advice on long-term plans. However, the analysis is performed generally in two steps: the biological criterion determines the desired scenarios and subsequently an economic criterion is applied to assess the impact of the proposed scenarios. This two-step procedure may lead to contradictory results. For instance, the long-term management plan for northern hake initially designed nine scenarios based on F_{max} as a good approximation of F_{msy}. However, the economic model used subsequently always preferred the *status quo* ($F_{sq} = 0.25 > F_{max}$) to any of the alternative scenarios proposed.

Obviously, one of the causes of this result is that the economic assessment did not consider the criterion used when designing the scenarios. When the long-term management plan was designed, the fishery was in a high-risk situation. All biological models unanimously concluded that if fishing effort was not reduced, the SSB would very likely fall below B_{pa} within a very short period. Therefore, the economic analysis should have considered the restrictions necessary for recovering the stock (Da Rocha *et al.*, 2010). In other words, the *status quo* scenario should not have been included among the set of scenarios to be evaluated by the economic assessment because it did not satisfy the precautionary criteria.

Nevertheless, a more important question is why the *status quo* scenario was selected by the economic assessment. Recently, Grafton *et al.* (2007), Dichmont *et al.* (2010), and Kompas *et al.* (2010) proved that when the stock affects the operating costs, optimal rates of F (or biomasses) are much lower (higher) if profits rather than yields are used as the benchmark economic indicator. Similarly, when a cost function is introduced that depends linearly on F, the long-term value of F associated with maximization of the discounted profits, F_{mey}, is $<F_{max}$. However, if the numerical model underestimates the effort cost, the economic assessment would be based on economic indicators that are monotonic transformations of yield in weight, so the scenarios with $F > F_{max}$ would always be preferred to those with $F < F_{max}$. This implies that long-term management plans designed to reach F_{max} will always be rejected.

Supplementary material

Supplementary material is available at the *ICESJMS* online version of the manuscript, showing in detail how the calibration of the model was prepared using the dataset reported for working groups STECF/SGBRE-07-03 and SGBRE-07-05, and daily sales by the Spanish fleet.

Acknowledgements

We thank editor Sarah Kraak, three anonymous referees, and the participants in the Lisbon and Brussels 2007 northern hake working group meetings for valued comments. Financial aid from the Spanish Ministry of Science and Innovation (ECO2009-14697-C02-01 and 02) and the Basque Government (IT-241-07 and HM-2009-1-21) is gratefully acknowledged.

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