BIOECONOMIC DYNAMIC MODELLING OF THE CHILEAN SOUTHERN DEMERSAL FISHERY

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ABSTRACT

The demersal fishery of southern Chile is a complex system including multiple species, fishing fleets and markets. Fishing activity is conducted under a rights-based system for southern hake (Merluccius australis) and hoki (Macroronus magellanicus), where a TAC is allocated in an even manner among fleets and operators. New management approaches not only call for the need of the simultaneous consideration of biological, technologic, economic, social, legal and institutional factors but also, stakeholders perceptions and interests are becoming increasingly relevant for decision making. In spite of the undeniable importance for stakeholder inclusion in fisheries management, their perception of the system status and expectations are frequently partial and biased by short term needs and interests. Thus, information on expected impacts of alternative management measures are a valuable guiding input to improve stakeholder perception. This paper, therefore explores the value of dynamic simulation model in providing illustrative information on bioeconomic impacts to the fishery system from alternative management measures. The dynamic simulation model is based on two main modules. A biologic module depicting the fish population dynamics, considering recruitment based on Beverton and Holt function. A bioeconomic module depicting fleet dynamics based investment functions by Clark et al. (1979) Munro and Munro (1998) and catch per unit of effort proportional to biomass. The model outputs are the species biomass, fleet size, effort level, fleet and vessel net benefits presented on a year basis. Fishery and fleet cumulative NPVs are also presented.

Keywords: dynamic simulation, groundfish fishery, economic benefits, social equity, sustainability

BACKGROUND

This paper has been developed as part of the project "Technical Basis for the Management Plan for the Chilean Southern Demersal Fishery", which aimed to lay down the foundations for a participatory management plan including large-scale and small-scale users and integrating their various visions and interests under a sustainable development approach.

The southern demersal fishery is one of the most complexes of the Chilean fisheries, ranging from parallel 41 º 28.6 'L.S. to the parallel 57 º 00 'L.S. It is defined as a complex system based on the exploitation of southern hake (Merluccius australis), hoki (Macruronus magellanicus), southern blue whiting (Micromesistius australis), pink cusk-eel (Genypterus blacodes), patagonian toothfish (Dissosticus eleginoides) and yellownose skate (Dipturus chilensis). The southern demersal fishery (SDF) is conducted by multiple fishing fleets including different scales of production and technologies, grouped in an industrial or large-scale segment operating in the open sea and a, artisanal or small-scale segment operating in fjords and channels. The geographic spread of these fleets, the fragmentation and isolation of the landings, the organizational structure of the small-scale fleet and its extensive monopsonistic supply chain characterizes this as a complex fishery and intricate administration system, under which the traditional command and control management mechanisms are not effective enough.

This work focuses on the fishing activity based upon southern hake and hoki fish stocks, which represents two thirds of the total landing and gross value generated by the SDF. Southern hake is targeted by a large number of small-scale longline fleet and the large-scale trawling fishing fleet. Hoki is targeted only b y the large-scale fishing fleet. This fishery presents strong technological interactions since both species are caught simultaneously and in addition, there are biological interactions southern hake predates over hoki.

Prior to 2001 the fishery was regulated by a total allowable catch (TAC) for the large-scale sector, in addition to area restrictions, later went into effect a system of non transferable individual quotas, which nonetheless, allowed for annual effort partnership between different quota owners at the vessel level for harvest purposes. Simultaneously, the small-scale fishing sector is governed by a quota system allocated to fishermen's organizations and regionally distributed. The distribution of the organization' quota among individual members is autonomously decided and managed by these organizations. The TAC of southern hake is distributed in equal proportions between the small-scale and large-scale sectors, while the hoki TAC is entirely allocated to the later sector.

The biomasses of both resources have long-term declining trends, even when the hoki shows signs of recovery in recent years. Fishing yields are stabilizing in tandem with the decline in industrial fishing capacity, resulting from the individual quota system. However, the costs of fishing have a tendency to increase. The general appraisement of the fishery indicates it is not viable in the long run, this may be due to flaws in the application and control of the management system in place and to weak governance of the fishery as reflected by existing problems in the decision making structure and to stakeholder low levels of participation and compliance (Cerda et al. 2009).

In this context, ex-ante knowledge of potential impacts of policies for the conservation of fishery resources is considered to be important if efficient and effective fishery management, based on good interaction between users and decision makers, is to be achieved. Accordingly, the development of operational models to measure such impacts are considered to be important to guide the decision-making process.

The purpose of this paper is to illustrate the relevance of such models in generating ex-ante knowledge of potential impacts of management policies, through a dynamic simulation model under certainty conditions. This analysis is focused in the determination of potential socioeconomic impacts of changes in TAC levels and overall quota allocation between large-scale and small-scale sectors considering a threshold of sustainability of the fishery.

THE MODEL

Even though the fishery model developed in this work includes two fish stocks (southern hake and hoki) and five fleets (factory trawlers and trawlers for the large-scale sector and two types of small-scale fishing fleets distributed in three regions), for the sake of presentation simplicity the model is presented as including only one fish stock and one fishing fleet.

The following general diagram depicts the dynamics of the fishery including fish stock dynamics and stock-fishing fleet interactions, through fishery biological, production and economic modules (Figure 1).

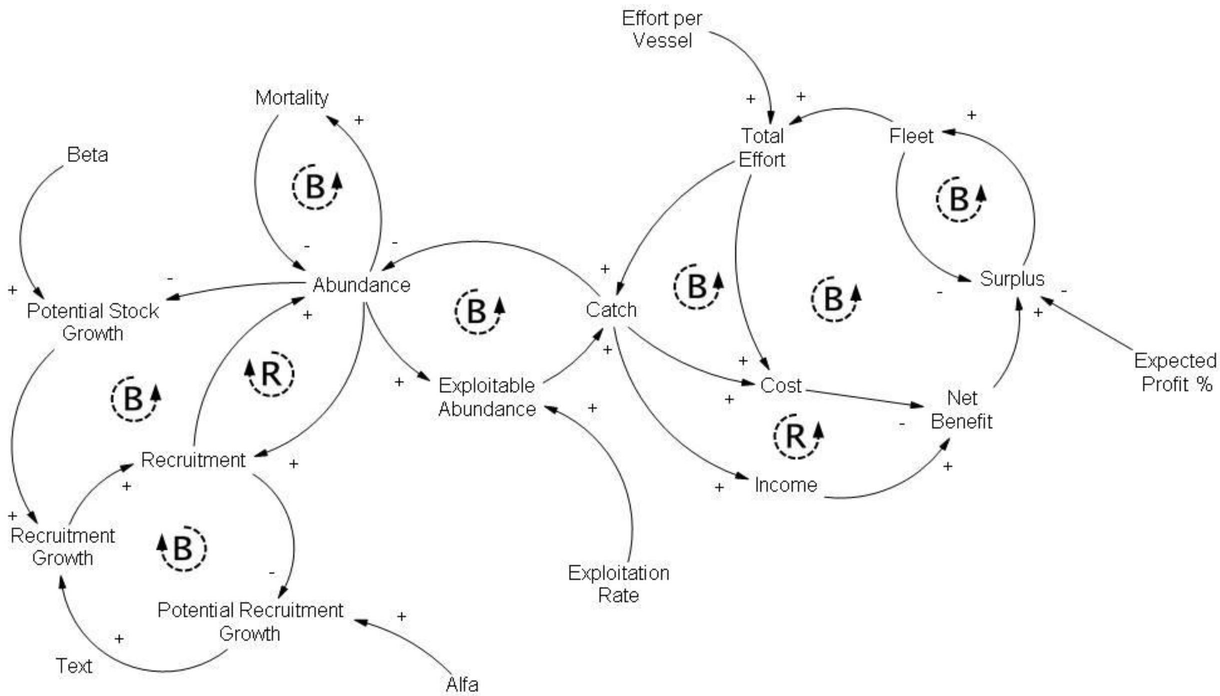

Figure 1 Dynamic diagram of the Southern Demersal Fishery (SDF)

As shown in Figure 1, the biological module of the fishery includes the fish stock size, measured in number of individuals (i.e., abundance) what is the net result of the interaction between natural mortality and recruitment. Recruitment is considered to be dependent upon the size of a parental stock and it will be modeled as a Beverton-Holt relationship which includes parameters α and β (Sparre and Venema). The production module is represented by the interaction between exploitable stock size and harvest represented as catch in Figure 1. Catch is the result of the interaction between fishing effort per vessel, the number of vessel in the fishing fleet the size of the exploitable fish stock. The economic module represents the relationship between income, fishing costs, capital investment as fleet size and net benefits. Fleet size is dependent upon the interaction between expected net benefits per vessels and the level of net benefits generated by the fishery in previous periods. Fleet size determines in turn the level of fishing effort, catch and fish stock abundance. Mathematical formulation of the relationships of this model is presented as follows.

The population dynamics of the fishery resources is modeled as

(1) $$\frac{dN}{dt} = -m(N - y) + R$$

Where N_t fish population abundance at time t, y_t fishing fleet yield or harvest rate at time t, R_t recruitment to the fishery at time t and m is the instantaneous natural mortality rate.

The recruitment function considered is of the familiar Beverton and Holt form (Sparre and Venema 1997).

(2) $$R_t = \frac{\alpha\left(N_{t-r} - y_{t-r}\right)}{\beta + \left(N_{t-r} - y_{t-r}\right)}$$

Where α and β are parameters representing the maximum recruitment level and the abundance level generating a recruitment equal to $\alpha/2$, respectively. The sub-index r is age of recruitment to the fishery in years.

The harvest rate is modeled as the familiar Cobb-Douglas production function, traditional in fishery models.

(3) $$y_t = qE_t N_t = qeK_t N_t$$

Where E_t is the fishing effort of the fishery and the parameter q is the catchability coefficient of the fishing vessel. Notice that $N_t \geq 0$ and $0 \leq E_t \leq E_{max} = e^*K_t$. Where E_{max} is the maximum effort capacity in days at time t, K_t is the amount of capital invested in the fishery at time t and e is the annual effort per vessel in days per year. Kt represents the number of "standardized" fishing vessels of a given fishing fleet and sector existing in the fishery. Thus, the maximum effort capacity is considered to be equal to the number of vessels available and the actual level of effort employed at any time cannot exceed E_{max}.

Adjustments to the number of vessels in the fishery are modeled as follows Clark et al. (1979) and Munro (1998).

(4) $$\frac{dK}{dt} = I - \gamma K,\ \ K_0 = K^0$$

Where I_t is the gross investment rate at time t (expressed in physical terms) and γ is constant rate of depreciation and $\gamma > 0$ and $-\infty \leq I_t \leq +\infty$.

The discounted net cash flow generated by the fishery is presented in equation (5) and the net present value of net cash flow is presented in equation (6).

(5) $$NB_t = e^{-\delta t}\left[py_t - cE_t - \pi I_t\right]$$

(6) $$PVNB = \int_0^\infty e^{-\delta t}\left[py_t - cE_t - \pi I_t\right]dt$$

Where δ is the instantaneous rate of discount, p is the price of landed fish, c is the operating cost per unit of effort and π is the purchase or replacement price of capital. All these parameters are considered as constant and positive.

It is assumed that entry and exit to the fishery will be given by the relationship between the expected annual net benefits per vessel and the level of net benefits being generated by the fishery as whole. It is also assumed that entry and exit will be modulated by the availability of vessels (from other fisheries or by shipyard capacities) or by the possibility of reallocating vessels to other activities. Scrap value and market are not considered.

(7) $$I_t = \frac{NB_t - \varphi K_t}{\varphi \mu}$$

Where φ is the expected net benefit per vessel and μ is a modulation factor for entry and exit of vessels to or from the fishery.

The existing pray-predator relationship interaction between hoki and southern hake is modeled through relational functions between the instantaneous mortality rate of one fish stock and the correspondent stock size of the other fish stock. This relation is negative for hoki with respect to southern hake and positive for southern hake with respect to hoki (Figure 2).

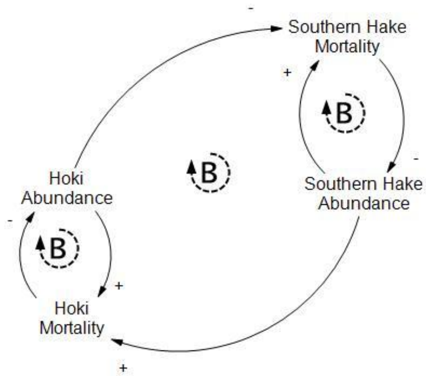

Figure 2 Dynamic diagram depicting the inter-specific interactions between of southern hake and hoki.

Finally, to assess the potential impacts of the current management policies, the simulation model is run under four scenarios, namely: BASELINE, TAC40%, TAC20% and SMALL70%. Scenario BASELINE represents the current management policy and considers a TAC of 30% of the stock size for each of the fish resources, southern hake and hoki. It also considers that the TAC for southern hake is allocated in equal shares to the large-scale and small-scale sectors. The TAC for hoki is entirely allocated to the large-scale sector. Scenario TAC40% considers an increase of 10% in the TAC level for both southern hake and hoki, but no changes in TAC allocation between both fishing sectors. Scenario TAC20% considers a 10% decrease in the TAC level for both fish resources and no changes in TAC allocation between sectors. Scenario SMALL70% considers the current 30% level for the TAC of both fish resources and a 20% increase in the allocation of southern hake TAC to the Small-Scale sector. It does not consider changes in the allocation of the TAC for hoki between sectors.

Table 1 summarizes the data used to calibrate the model to the fishery current conditions, which is based upon several official technical reports from IFOP 2010a,b,c and official statistics.

Table 1 Operational and economic data for the SDF

		Large-Scale Fleet		Small-Scale Fleet		
ITEM	**Units**	Trawller Refrigetrated	Trawller Factory	Xth Region	XIth Region	XIIth Region
Operational days	days/year	200	250	50	50	90
Catchability coeff. (q)						
Hoki		1,13E-04	1,14E-04			
Southern Hake		5,66E-05	7,03E-05	3,81E-06	8,93E-06	3,37E-06
Cost per unit of effort	USD/day	5.072	9.570	127	127	725
Mantainance	USD/year	382.799	956.997	746	746	4.785
Vessel price (π)	USD	4.784.987	9.569.973	21.054	21.054	34.452
Landing costs	USD/ton	159		96		
Ex - vessel price						
Hoki	USD/ton	900				
Southern Hake	USD/ton	1.780		1.780		
Entry/Exit factor (μ)		5%				
Expected benefit per vessel (φ)		10%				
Depresiation factor (g)		5%				

Source: elaborated from IFOP 2010 a,b,c and SERNAPesca statistics.

RESULTS

Potential impacts of the existing management policies for the SDF and possible changes are presented in Figures 3 to 6 and they are depicted by the levels attained by stock size of both fish resources[1], fleet size for large and small scale fishing sectors involved in the fishery, the annual net benefit generated by these fishing fleets and the cumulative net present value of net benefits generated at the fishery and fleet levels. Notice that initial levels for all considered variables have been calibrated to the situation observed in year 2007 in the SDF.

Current management policy, represented by scenario BASELINE indicates that fish stock size (Figure 3) for both resources would reach equilibrium levels. Hoki stock size (depicted by the black line) would increase from approximately 160 thousand tons to 590 thousand tons in 25 periods, approximately. Southern hake stock size (depicted by the brown line) would decrease from approximately 93 thousand tons to 78 thousand tons in 35 periods, approximately. Simultaneously, fleet size for the large-scale sector would increase reaching 29 vessels in 18 periods as depicted by the solid brown line in Figure 4. Fleet size for the small-scale sector, would show an early increase in the number of boats probably reaching of 1.129 boats in period 19, to later start an ever declining trend (solid blue line in Figure 4).

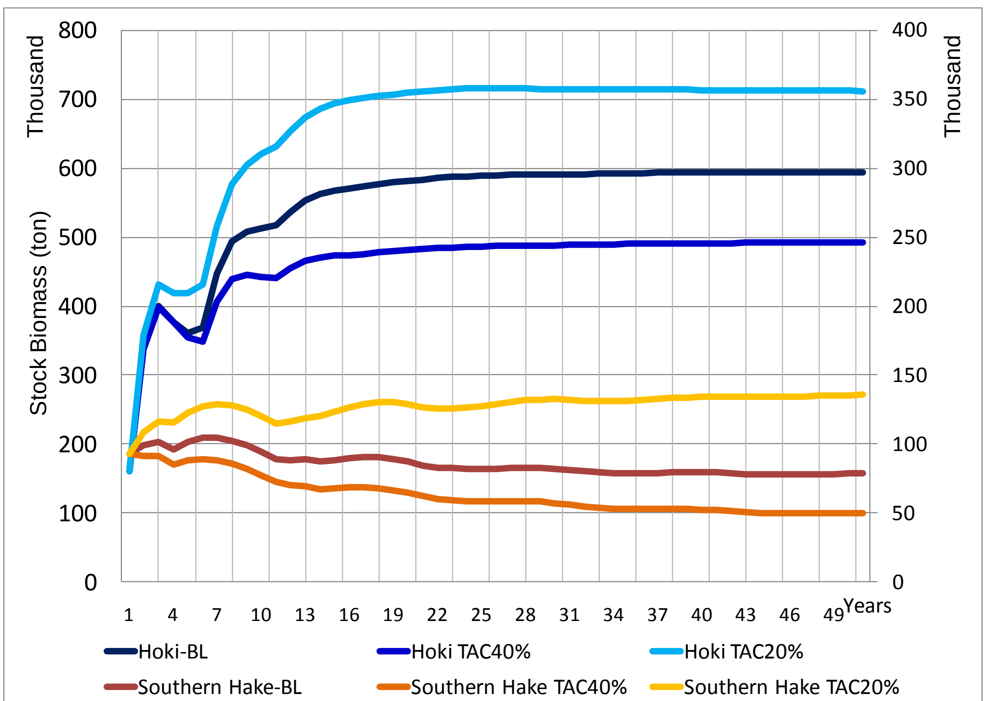

Figure 3 Stock size in biomass under scenarios BASELINE(BL), TAC40% and TAC20%

Accordingly to this fleet dynamic, the level of annual net benefits for the large-scale fleet would stabilize at a level of 71 million USD per year, solid brown line in Figure 5. Annual net benefits for the small-scale fleet would experience a decreasing trend, possibly reaching a level of approximately 4 million USD per year at the end of 50 year horizon used for modeling purposes, solid blue line in Figure 5.
Figure 6 shows that the cumulative net present value of the SDF would reach 650 million USD in approximately 43 periods, the large-scale sector would account for 91% of the total value (light brown area) and the small-scale sector for only the remaining 9% (brown area).

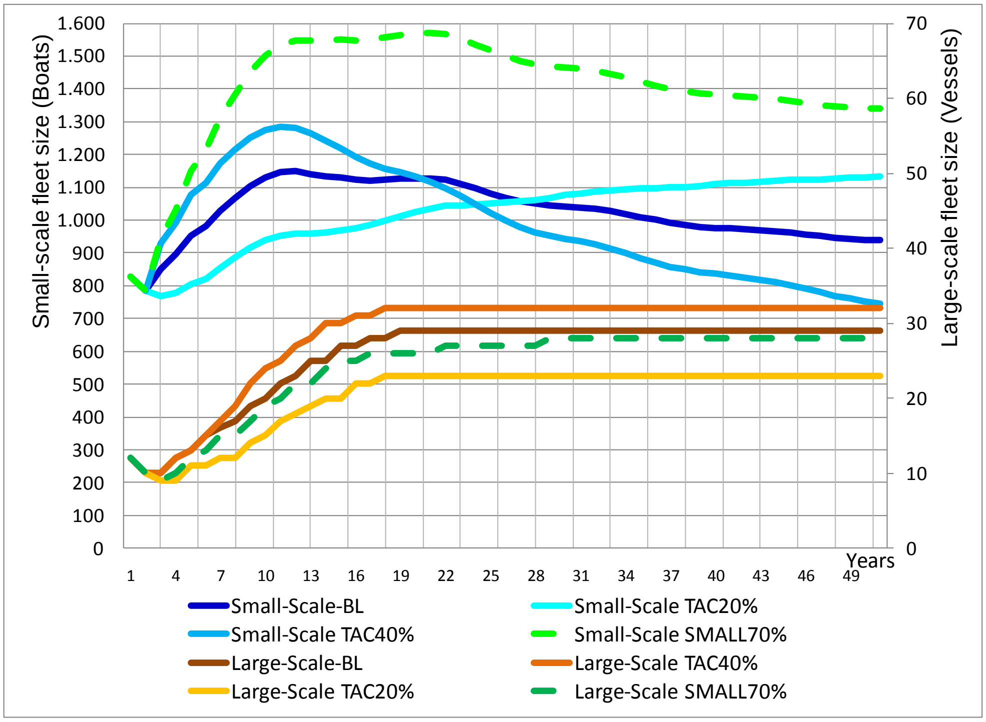

Figure 4 Fleet size under scenarios BASELINE(BL), TAC40%, TAC20% and SMALL70%

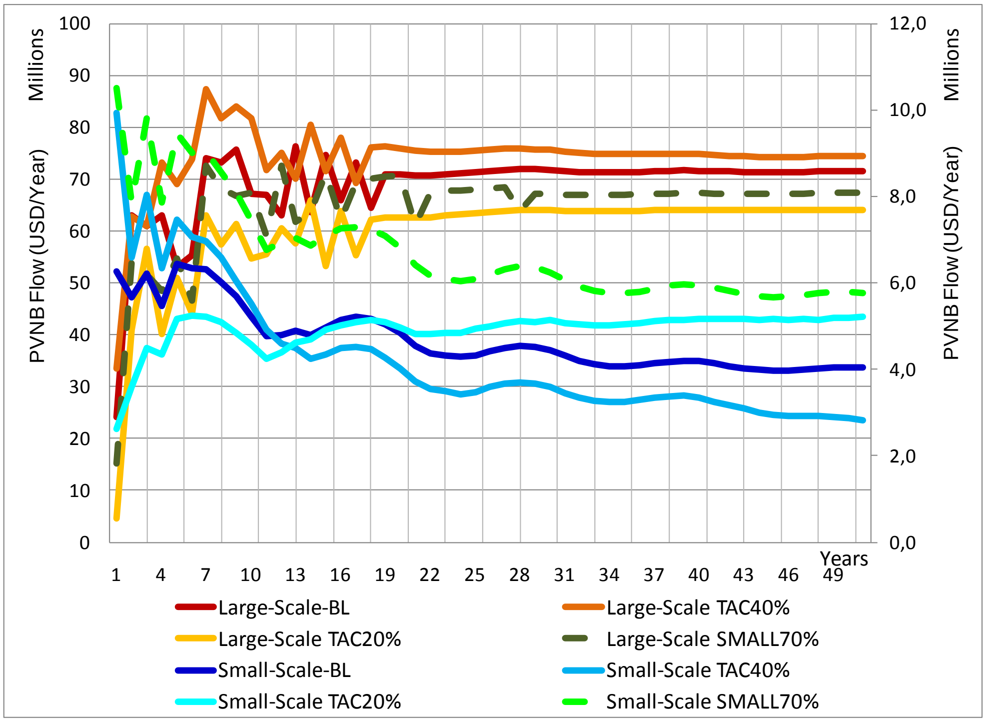

Figure 5 Flow of Net Present Value of Net Benefits of fletes under scenarios BASELINE(BL), TAC40%, TAC20% and SMALL70%

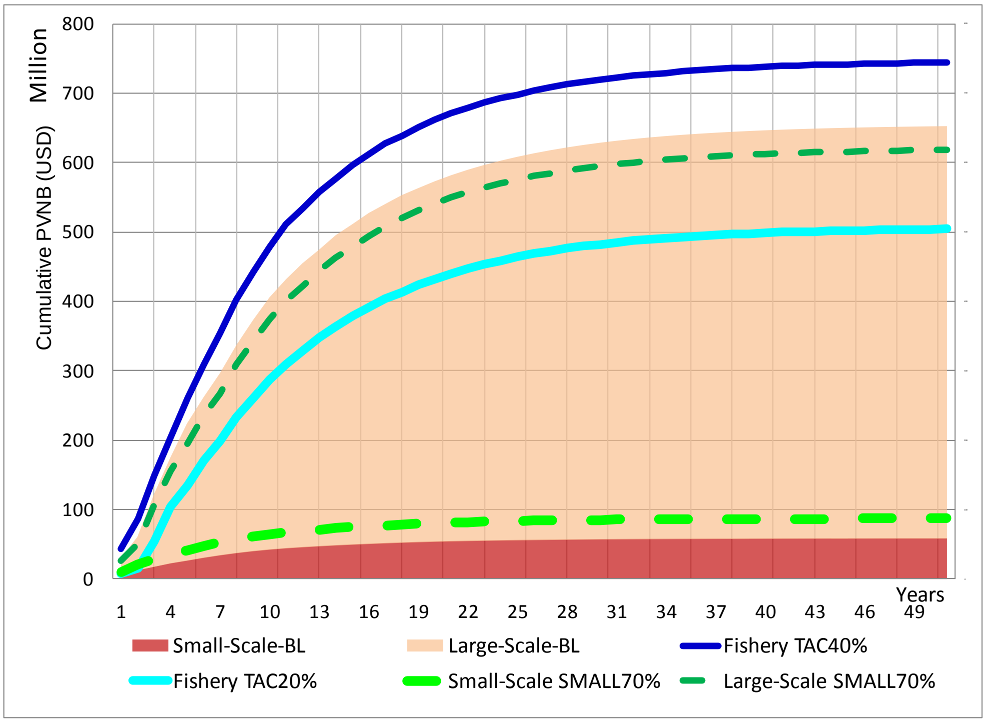

Figure 6 Cumulative Net Present Value of Net Benefits of the fletes and the fishery under scenarios BASELINE(BL), TAC40%, TAC20% and SMALL70%

The TAC40% scenario could be depicted as a policy prone to economic development and its expected effects on stock size, fleet size and net benefits are also shown in Figures 3 to 6. Figure 3 shows that under this policy both fish stock would be reduced, hoki stock would reach of proximately 500 thousand tons in 43 years (blue line), but southern hake would reach only 50 thousand tons in the same time (light brown line). Large-scale fleet would experiment a slight increase reaching 32 vessels (light brown solid line in Figure 4). Small-scale fleet, nonetheless, would experiment a relevant increase during the first 20 periods, experimenting a larger decreasing trend than the one expected under current management policy in the long-run (solid light blue line in Figure 4).

Figure 5 shows a consistent increase in annual net benefits for the large-scale fleet, with relevant increases in early periods but stabilizing at levels only a 4% higher than the ones expected under the current management policy (solid light brown line). Expected annual net benefits for the small-scale fleet (solid light blue line) are larger during the first 10 periods, than the ones expected under the current management policy, but significantly lower in the long-run (23% lower in average).

Figure 6 shows that the overall effect of this policy would be an increase in the net present value of net benefits generated by the SDF, generating a 14% increase in 43 periods with a total of approximately 741 million USD (solid blue line).

The effects of the conservation prone policy represented by TAC20% scenario show relevant positive effects on fish stock biomass, not only with expected increases in equilibrium levels of both fish stock biomasses (light blue and yellow lines in Figure 3), but reverts the decreasing tendency for southern hake, whose stock size shows now an increasing tendency over time.

Effects in fleet size show a relevant decrease of 21% in the expected number of large-scale vessels operating, with 23 units since the 19th period (solid yellow line in Figure 4). Small-scale fishing fleet size experiments a change, expecting a slower but longer increasing trend (cyan solid line in Figure 4), with a final number of small-scale fishing boats slightly larger than 1.100 units in the long-run. Figure 5 shows a reduced level of annual benefits for the large-scale fishing fleet, but increasing levels of annual net benefits for the small-scale fishing fleet with larger long run annual expected net benefits. Figure 6 shows, however a significantly lower level in the present value of net benefits generated by the SDF, which are expected to be 23% lower than under the current management policy, with a total of 500 million USD.

The SMALL70% scenario represents a policy prone to favor the small-scale sector which refers to people with low levels of income. As this scenario only includes changes in the allocation of the currently existing TAC level for the southern hake, effects of this policy are shown with respect to fleet sizes (Figure 4), annual net benefits of each fishing sector (Figure 5) and the share of the cumulative present value net benefits generated by the SDF corresponding to each fishing sector (Figure 6).

Figure 4 shows that the effect of the 20% increase in the share of the southern hake TAC for the small-scale sector has relevant effects on the number of small-scale boats in the SDF (dashed light green line) but, marginal effects on the large-scale fleet size (dashed green line). Small-scale fleet size is expected to increase in average by 42% in the long-run, moving from approximately 950 fishing units to 1.360 fishing units. Large-scale fleet is reduced in the long-run by only one vessel. Figure 5 shows a significant increase in annual net benefits to be generated by the small-scale fishing fleet (dashed light green line) and a minor decrease in annual net benefits to be accrued by the large-scale fishing fleet (dashed green line).

Figure 6 shows that the overall level of the cumulative present value of net benefits generated by the fishery is reduced by 5%, amount that is transferred to the small-scale sector whose share would represent a 14% of the total value of the SDF in the long-run. This would represent a relevant increase of 49% in cumulative present value of net benefits to be generated by the small-scale sector and only a 10% decrease in that of the large-scale sector.

DISCUSSION AND CONCLUSIONS

Results obtained for the four scenarios considered may be analyzed on the light of the three simultaneous objectives of sustainable development, that is: environmental sustainability, economic growth, and social equity. Thus, current management policy, represented by BASELINE scenario, may be seen as clearly complying with sustainability conditions for hoki fish stock. This is not so clear for southern hake, as the fish stock size for this resource reaches equilibrium level in the long-run at a smaller biomass level than the current ones. It is not clear to the authors whether the long-run equilibrium estimated is above critical values for precautionary purposes.

The TAC40% scenario has a larger effect on both stock sizes further reducing their long-run equilibrium levels. Hoki results still show an increase in stock size level compared to the current or initial levels, thus this resource would not be at risk under this policy. TAC40% may not be advisable for southern hake under environmental sustainability grounds as it further reduces the long-run equilibrium stock size level compared to BASELINE. The TAC20% scenario is clearly positive on environmental sustainability grounds as it favors the growth of the exploitable stock size for both hoki and southern hake resources.

From the point of view of economic growth and social equity, there may not always be clear cut answers. Thus, when only looking at overall net benefits, it is clear that scenarios generating the highest level of net benefits in terms of present value of net benefits are TAC40% and BASELINE. On the contrary, scenario TAC20% generates the lower level for this variable. Thus, from this perspective the adoption of a policy like TAC20% would mean a relevant level of forgone overall net benefits to society.

Social equity aspects may be related to employment and income variables and, fleet size levels and annual net benefits may be used as proxy for these. BASELINE and TAC40% scenarios greatly favor the large-scale fishing through larger fleet sizes and annual net benefits but, mean smaller fleets and annual benefits for small-scale fishing sector in the long-run. TAC20% scenario generates smaller fleet size for the large scale sector but, a larger fleet size for the small-scale sector in the long-run. Annual net benefits for the small-scale fishing fleet are significantly larger for this scenario in the long-run.

The SMALL70% scenario shows positive effects on social equity grounds as the positive impacts on the small-scale fishing sector are significantly larger than the negative impacts that would experiment the large-scale sector. Positive effects on overall economic benefits (cumulative net present value of net benefits) to the small-scale sector would also be significantly larger than negative effects on the large-scale fishing sector and the whole SDF. The minor effects of the policy on the large-scale fishing sector are most probably due to the low dependence of this sector on the southern hake resource. This scenario has the same effects on the resource stock as the current management policy, scenario BASELINE.

In summary, even though expected effects of the more conservative management policy (TAC20% scenario) may show relevant positive impacts on the fish resource and on the small-scale fishing sector, it also would generate the largest level of forgone net benefits at the SDF level. Current management policy (BASELINE) may generate reasonable overall economic benefits and employment levels but, it shows large unbalance on social equity grounds as it clearly favors the large-scale sector. TAC40% would show significant increases in economic benefits and employment in the short-run but, it would generate negative impacts on the small-scale fishing sector in the long-run as well as it would greatly strain the southern hake resource.

Therefore, scenario SMALL70% may be advisable not only on social equity and economic growth grounds but, it also does not impose changes on the current policy on resource sustainability or environmental sustainability grounds.

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ENDNOTES

[1] The dynamics of the stock size in the model is worked in number of individual or abundance as we are working with a global population model and individual growth was not included. Results are present in biomass as abundance is transformed in biomass using the mean average weight for the average individual comprising the exploitable stock