Chapter 2

Using Taxes to Manage a Multigear Fishery: An Application to a Spanish Fishery

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http://dx.doi.org/10.5772/62285

Abstract

When fishing gears alter the composition of fish populations or modify the recruitment rate, it is advisable to include the degree of their fishing selectivity in the analysis. Fishing selectivity can cause two different management problems: interspecies selectivity or by-catch of fish stocks for which no quota has been set by the regulator. The case study is the Spanish fishery of hake (*Merlucius merlucius*), where the fleet operates using two main gears; most of the vessels are trawlers but a few boats use longlines and other fixed gears. Fishery management by means of effort taxes and how the degree of intraspecies selectivity may affect the resource and tax levels are analyzed. The results show that the tax level will depend on the social value of the marine stock, the marginal productivity of each fleet's effort, and the effect that the fishing activity of each one has on the growth of the hake biomass.

Keywords: European hake, fisheries management, multigear fishery, tax, Spanish fishery, fishing selectivity

1. Introduction

From an economic point of view, fishery resources are assets that provide flows of income over time but show certain characteristics. These are linked with the renewable character of fish stocks, the institutional structure under which the activity takes place, and the existence of externalities in the use of a resource. Bioecological rules are essential to determine the functions of production and meet the necessary biological restrictions in an objective function optimization. However, the institutional conditions in the fish stock exploitation establish who is entitled to capture that resource and under what circumstances, and this is essential to understand and predict the behavior of the economic agents involved in the economic activity (the fishermen) and properly drive any regulatory intervention.

Concern for the implications associated with the extraction of marine resources is relatively recent; scarcity problems were largely associated with nonrenewable natural resources until the mid-twentieth century. From then on, the fishing economy has developed quickly. This can be explained by the increasing concerns for the conservation of resources to the perception of degradation of nature and the environment. The effects of the decisions taken at the Third Conference of UN on Law of the Sea in the mid-1970s also have influenced this development, as it recognized the extension of fishery jurisdiction to 200 miles from coastal line and transforming the status of fishery resources from free access to the exclusive property of coastal states.

Marine resource exploitation is one of the typical examples of the tragedy of the commons in which the logic of individual maximization of benefits leads to a continual increase in pressure on the resources and their consequent overexploitation. As the population has expanded, the problem of a lack of resources has become more evident. Society has increasingly valued natural and environmental resources. Key institutional figures have become more necessary for establishing more efficient and sustainable management of natural resources to prevent a tragedy of the commons. Thus, the study of the commons is relevant when analyzing common ownership or open access systems, but its conceptual significance goes far beyond these concrete systems because it represents the starting point in the search to understand the rise and formation of institutions.

These characteristics pose specific management problems for those who need to build theoretical formalization different from those used for the rest of economic assets and those who must be focused on the determination of optimal trajectories for the exploitation of the renewable natural resources sustainably over time. The marine resources must be managed in a rational way, especially if the welfare of future generations is taken into account in the decision-making process.

In a fishery where two or more fleets are using several fishing technologies or gears, it is useful to assume that fishing activity influences the net natural dynamics of the marine resources through the catches, whereas the natural growth function depends on the fish biomass and environmental conditions, and these are taken as stable and constants over time in the specialized literature [1–4]. However, in some fisheries (as the Spanish hake fishery), several fishing technologies could alter the composition of fish populations or modify the recruitment rate [5]. In this case, it is advisable to include the degree of their fishing selectivity in the study. The selectivity could cause two different management problems: interspecies selectivity or by-catch of fish stocks for which no quota has been set by the regulator [6–9].

The case study is the Spanish fishery of European hake *(Merlucius merlucius*) in Ibero-Atlantic grounds. The Spanish fleet involved in this fishery operates uses two main gears; most of vessels are trawlers, but a few boats use longlines and other fixed gears (majority gillnets). Trawlers harvest mainly young individuals of hake of a lower size than that corresponding to sexual maturity (although it too catches mature fish). The other fishing technology (artisanal fleet) catches only mature fish. Based on this, we focus on the intraselectivity problem. We introduce in the analysis of the management of the fishery by means of effort taxes [10–16].

On the contrary, and given that the International Council for the Exploration of the Sea (ICES; this institution analyzes the stock situation and proposes management measures to the European regulator) and the European Commission (EC) recommend that one of the two technologies involved in the hake fishery (in particular, trawling fleet) improves the level of fishing selectivity and aim to individuals of a larger size, we pose several scenarios and study how the levels of hake stock and the tax applied to each group of vessels would be affected. The results obtained show that the optimum tax level depends not only on the social value of the marine resource and the marginal productivity of each fleet's effort but also on the effect that the fishing activity of each one has on the growth of the hake biomass. Furthermore, and as the fleet that is less conservationist with the stock (trawlers) improves the degree of selectivity of its technology, the equilibrium fishing effort level for this fleet increases and the optimum tax falls, to the detriment of the stationary values corresponding to the other fleet.

The particular issue with which this chapter is concerned is how the degree of intraspecies selectivity may affect the hake stock and tax levels. The chapter is structured as follows: the Spanish fishery is described in Section 2. A simple management model applied to the fishery is analyzed in Section 3. The primary results are summarized in Section 4. Lastly, the chapter concludes with the discussion presented in Section 5.

2. Description of the fishery

The *M. merlucius* species is listed within the group of demersal beings and therefore a fish stock of long life. Although it is distributed in the area located between the coast north of Morocco and the North Sea, the ICES valued it separately since 1979, distinguishing two biological units: Northern stock (corresponding to zones IV, VI, and VII and divisions VIIIa and VIIIb; see **Figure 1**) and Southern stock (divisions VIIIc and IXa). Thus, these two stocks are considered by European regulators as two different management units. This is due to the existence of two well-differentiated recruitment areas: one on the west coast of France (Northern stock) and the other on the coast northwest of the Iberian Peninsula (Southern stock).

The fishery we are studying is European hake in ICES divisions VIIIc and IXa, better known as the Southern stock of European hake. The juvenile individuals of European hake mainly feed on zooplankton and decapod prawns (*Nephrops norvegicus*). Larger hake feed predominantly on fish, with blue whiting (*Micromesistius poutassou*) being the most important prey in waters deeper than 100 m. Horse mackerel (*Trauchurus trauchurus*) and mackerel (*Scomber scombrus*) are the most important prey species in shallower waters. Hake are known to be cannibalistic species located at the top of the food chain. European hake recruitment processes lead to patches of juveniles found in the localized areas of the Iberian continental shelf. European hake concentrations could vary in density according to the strength of the year class; however, they remain generally stable in size and spatial location. The ICES estimates that the spatial patterns could be related to environmental conditions. On the eastern shelf of the Cantabrian Sea, years of large inflow of the shelf-edge current have produced low recruitment rates due to larvae and pre-recruits being transported away from spawning areas. The recent high recruitment has not yet been linked to an environmental process.

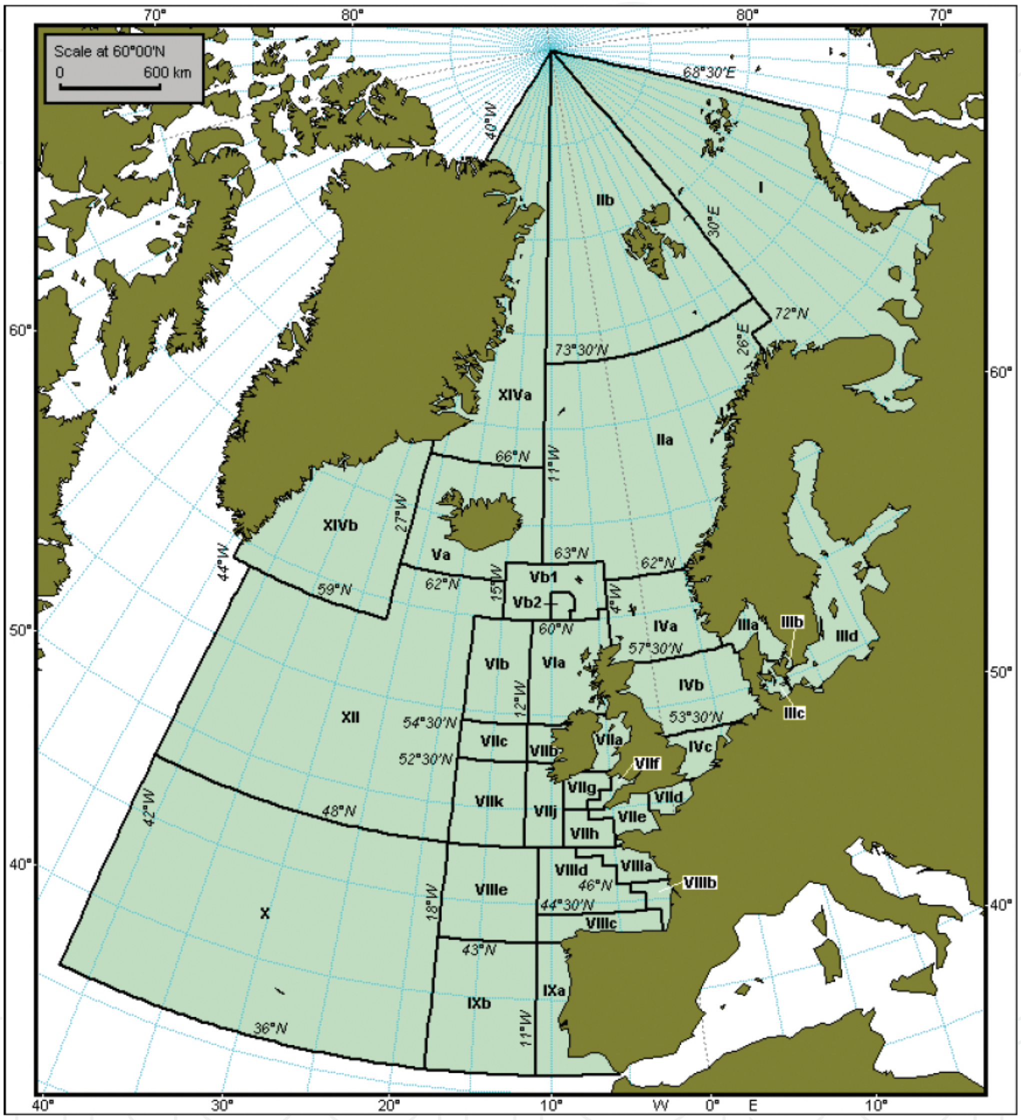

Figure 1. ICES zones. Source: Spanish Oceanographic Institute.

European hake in ICES divisions VIIIc and IXa is caught in a mixed fishery by trawlers and artisanal vessels. The trawling fleet is homogeneous and uses mainly two gears: pair trawl and bottom trawl. The artisanal fleet is quite heterogeneous and uses a wide variety of fixed gears, mainly large and small fixed gillnets and longlines. The amount of hake in the landings of Spanish trawlers is low in relative terms. However, trawling vessels provide by 55% of the total Spanish hake landings for last years. These fishing gears affect the hake biomass in different ways. Trawling, although it catches individuals of all ages, has a negative impact on young individuals preventing them from reaching adulthood. The more traditional method, however, affects mainly mature fish and is less damaging to the hake stock.

Trawl fleet is one of the most important fleets among those operating on the Spanish Atlantic continental shelf in terms of landings value. The standard vessel has approximately 145 GRT of fishing capacity and 330 kW of engine power, is close to 28 m long, has 9 crew members, and has an average age of 20 years. The main target species are hake, megrim, anglerfish, lobster, and horse mackerel. The longline and gillnet fleet is less important than the trawler fleet and the standard vessel has approximately 35 GRT and 150 kW, is close to 20 m long, has 5 crew members, and has an average age of 18 years.

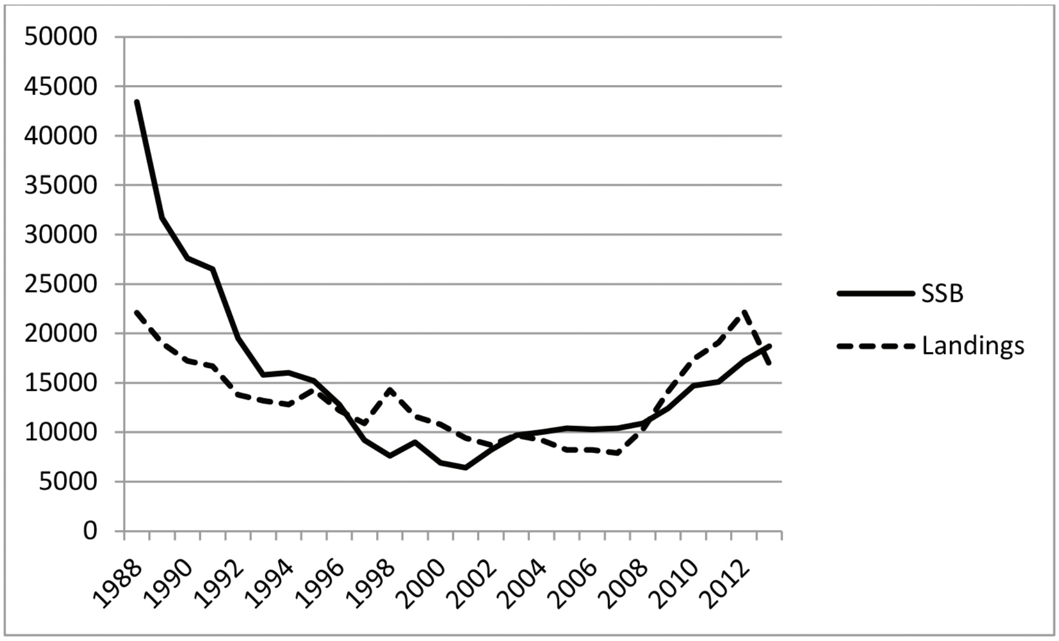

Figure 2. Spawning stock biomass (SSB) and landings. Data in tons. 1988–2013. Source: Own compilation from ICES.

The European Union (EU), within the framework of the Common Fisheries Policy (CFP), manages European hake fishery with total allowable catch (TAC), mainly set based on biological criteria. In addition to TACs, EU implements minimum sizes of catches for hake since 1987 and closed areas. The Spanish Government sets a closed list of vessels of each fishing fleet for the last decades. Furthermore, and in the face of the poor biological situation of the stock (see **Figure 2**), since 2006, a recovery plan has been implemented, aimed at recovering the spawning biomass above precautionary biomass and reducing fishing mortality to 0.27 [17]. To do so, the EC, while continuing with the establishment of downward TAC, proposes to reduce the effort exercised in the fishery and includes the improvement in the selectivity of some of the fishing methods.

Regarding the Southern stock of European hake, we have obtained information from the ICES on the spawning biomass for the period 1985 to 2014. **Figure 2** shows how the hake biomass has decreased to such an extent in the late 1990s, as it reached only 25% of that which existed in the early 1980s, falling well outside the biological safety limits in spite of the recovery experienced in the last 3 years [18]. This hake biomass evolution indicates that the resource is being exploited to excess. With respect to the total catches, we can see that it has shown a decreasing trend in the said period and in keeping with the deterioration of the fish biomass (see **Figure 2**).

The trends in both variables show that the measures adopted by the EU were not sufficient to avoid the overexploitation of hake stock and the resource is still being overfished in the last years. Therefore, it is necessary to introduce a regulatory mechanism to manage the hake fishery in a sustainable way to avoid the overexploitation of resource and depletion of the fish stock.

3. Method

If the regulator of fishery establishes a tax on effort (τ_i), both fleets will assume an increase in the unit cost of the effort and will be faced with the following problem:

$$\underset{e_i}{Max}\int_{o}^{\infty}\{p_i h_i(e_i(t),X(t)) - (w_i + \tau_i)\, e_i(t)\}\, e^{-\delta t}\partial t \qquad i=1,2 \tag{1}$$

where p, w, h, e, and X denote the unit price of hake, unit cost of effort, total landings, fishing effort, and fish stock, respectively. The parameter δ represents the discount rate.

The usual natural growth function of the marine resource (F) is modified by a new parameter θ, which catches the selectivity of both fleets. The fish stock dynamic is shown as follows:

$$G(X_t,\theta_t) = \theta_t \; \mathrm{F}(X_t) \tag{2}$$

where $F(\cdot)$ is the natural growth function of the resource. The effects that the different technologies have on it are defined as follows [19]:

$$\theta_t = 1 - \sum_i \gamma_i \frac{h_i(X_t,e_{it})}{h(X_t,e_t)} \qquad \text{con } \; 0<\theta\le 1; \quad \mathrm{i}=1,2 \tag{3}$$

where the parameter γ_i($0\le\gamma_i<1$, i=1,2) shows the level of fishing selectivity of each technology or fleet. If the i-fleet technology has no effects on the fish stock dynamics, the fleet shows a high selectivity level and this fleet can be considered as conservationist with the marine resource. In this case, the parameter γ_i takes on a zero value. In contrast, if technology has effects on the marine stock dynamics in a negative way, the fleet shows a nonselective level and it can be considered as a less conservationist fleet with the fish stock. Therefore, the fishing selectivity parameter will approach the unit value.

From one of the first-order conditions to resolve the problem (1) [20], the following equation is obtained:

$$p_i \frac{\partial \mathrm{h_i}(.)}{\partial \mathrm{e_i}} = \mathrm{w_i} + \tau_\mathrm{i} \qquad i{=}1{,}2 \tag{4}$$

In the absence of regulation (i.e., no tax would be implemented), we would obtain the following expression [19]:

$$(p_i - \mu)\frac{\partial \mathrm{h_i}(.)}{\partial \mathrm{e_i}} + \mu \frac{\partial \mathrm{G}(.)}{\partial \mathrm{e_i}} = \mathrm{w_i} \tag{5}$$

and if both expressions (4) and (5) are compared, the optimum tax value can be obtained (i=1,2):

$$\tau_\mathrm{i} = \mu\left[\frac{\partial \mathrm{h_i}(.)}{\partial \mathrm{e_i}} - \frac{\partial \mathrm{G}(.)}{\partial \mathrm{e_i}}\right] = \mu \frac{\partial \mathrm{h_i}(.)}{\partial \mathrm{e_i}}\left[1 - \frac{(\gamma_\mathrm{j} - \gamma_i) h_j(.) F(X)}{(h_i + h_j)^2}\right] \tag{6}$$

This expression indicates that the tax level depends not only on the social value of the marine resource (μ) and the marginal productivity of the effort ($\partial h_i/\partial e_i$) but also on the effect on the natural growth of the resource ($\partial G(\cdot)/\partial e_i$). On the contrary, the lower (higher) the marginal productivity of the fleet i, the lower (higher) the tax level that will have to be paid to fish in the fishery.

On the contrary, and for $\gamma_i \neq \gamma_j$, if fleet i shows a high (low) selectivity level and with $\gamma_i < \gamma_j$ ($\gamma_i > \gamma_j$), then $\gamma_i \to 0$ ($\gamma_i \to 1$) and the effect of the activity of i on the natural growth function will be lower (higher), allowing a greater (smaller) growth of the fish population, that is, $(\gamma_j - \gamma_i) > 0$ ($(\gamma_j - \gamma_i) < 0$) and $\partial G(\cdot)/\partial e_i > 0$ ($\partial G(\cdot)/\partial e_i < 0$). Consequently, given that $\partial h_i(\cdot) > 0$, the tax level for this fleet will be higher (lower) than that which corresponds to the other fleet.

4. Estimations

Because fishing effort (fishing days) data are not available separately for the trawling and artisanal fleets for the last 10 years, we will use the parameter values estimated by Garza-Gil and Varela-Lafuente [19] for this fishery, who made an econometric estimation through the Ordinary Least Squares (OLS) method with annual observations for 20 years and for different options of the natural resource dynamic and the production functions. These values are summarized in **Table 1**. Substituting those values of the parameters in the above expression (6), the stationary solutions for the tax levels can be estimated.

However, previously, and because the selectivity parameters are unknown, we must assume some value for them. Regarding trawling, this fleet catches mainly smaller-sized individuals, as mentioned in the previous sections, and therefore has a negative impact on the Southern stock hake population by preventing a greater number of young fish from reaching maturity and being able to spawn for next years. On that basis, we will assume a selectivity parameter value for this fleet initially closer to unit value than to zero, in particular γ_1=0.7.

Regarding the artisanal fleet, although it captures mostly mature individuals, it also captures a small amount of young individuals. This figure does not reach 10% of the landings [19]. Therefore, we will assume a selectivity value for artisanal fleet closer to zero (0.1).

	Expression/value	**Unit**
Hake dynamic	$G(X,\theta) = \theta\ F(X) = \tilde{a}X^{0.82310} = 8.9263\ \theta\ X^{0.82310}$ with $\tilde{a} < a$	
Trawl technology	$h_{1t} = 20.82804 e_{1t}^{0.37744} X_t^{0.17164}$	
Artisanal technology	$h_{2t} = e_{2t}^{0.12609} X_t^{0.74163}$	
Price of trawl landings	4,565	Euros per tonne
Price of artisanal landings	7,482	Euros per tonne
Cost of trawl effort	373	Euros per fishing day
Cost of artisanal effort	419	Euros per fishing day
Discount rate	5	Percentage

"1" indicates trawling and "2" artisanal.
Source: Own compilation from Refs. [19, 21].

Table 1. Parameter values for estimations.

On the contrary, the trawling may improve the selectivity of this gear, as the EC [17] and the ICES [18] proposed in its management recommendations with a view to improving the pattern of hake production for this fishery. Accordingly, some options may increase, for example, the size of the mesh and expand the cod-end of the fishing nets (the "cod-end" is the rearmost part of a trawl net, of net of the same mesh size, having either a cylindrical or a tapering shape). If this technology improves its fishing selectivity level, the negative effects of its activity on hake dynamic will decrease. In this case, other possible and lowest values for γ_1 can be posed. The results obtained for different values of parameter γ_1 are shown in **Table 2**.

It can be seen that the tax level on trawling (in euros per fishing day) is higher than that applied to the artisanal fleet in the scenarios contemplated for selectivity parameter due fundamentally to the fact that it shows a greater marginal productivity in the effort and a negative effect on hake biomass. Consequently, it should pay more to fish in the fishery. Furthermore, as the trawling selectivity improves ($\gamma_1 \rightarrow 0$) and therefore the negative effect of the activity of this fleet on the hake population diminishes, the tax per unit of effort applied to this fleet also decreases, whereas, for the artisanal fleet, it increases and its effort level decreases.

γ_1	X	τ_1	τ_2
0.7	31,416	2,389	38
0.6	34,143	2,183	53
0.5	37,116	1,627	83
0.4	37,262	1,075	109
0.3	42,499	1,062	242
0.2	43,014	994	262

“1” indicates trawling and “2” artisanal.

Table 2. Hake biomass (metric tons) and tax levels (euros/day) for different γ_1 and $\gamma_2 = 0.1$.

5. Discussion and conclusions

The intensive exploitation of the fishery resources around the world for the last decades has shown the natural limitations of the productivity of fish stocks. In this environment with a depletion of marine resources, economists have been worried about searching for management tools oriented to change the behavior of fishermen to save the resource and also to maintain a positive economic return. From an economic point of view, fish populations are treated as capital assets that can provide flows of income over time. The aim is therefore to determine the path of exploitation of marine resources in a sustainable way and to incorporate the biological conditions of the marine resource and institutional conditions of fishing into the analysis. In this way, the fishing economy has advanced since the first works by Gordon [22] and Scott [23], which includes biological and institutional conditions of basic form, to the development raised by Clark [11] and Clark and Munro [24], who introduced the theory of capital to manage a fishing resource in a dynamic context.

In general, the regulatory mechanisms can be classified into two groups [11]: (1) those that are directed toward the direct control on the fish stocks as well as to maintain high production levels and (2) a group of mechanisms that, in addition to indirectly control the size of the stock, points to sustain activity in economically efficient levels. The methods that have been traditionally implemented, such as production quotas, closed seasons, closed zones, and restrictions on the equipment, correspond to the first group and it has been shown that they have failed to prevent the overexploitation of fish stocks [25–27]. The allocation of property rights and the system of taxes (on production or on the inputs) are in the second group. Among the latter, individual property rights require the creation of markets; the regulator may establish certain rules with respect to fishery exploitation (distribution of the surplus of the marine resource among fishermen involved in the fishery) and allow a rights transaction market to emerge to ensure that fishermen comply with its conduct selling or buying part of that right. Taxes can be defined as mechanisms based on the regulation via prices; the essence of these instruments involves the introduction of a price (cost) linked to the behavior that the regulator wants to promote or discourage.

In this chapter, we have studied the European hake fishery (Southern stock), where two fishing fleets are operating using different technologies. We have shown the way in which effort taxes exercised in this multigear fishery make it possible to reach a socially optimum solution for this marine resource, introducing a variable into the analysis, which includes the effects of fishing activity on the natural growth function of the hake population. The efficient stationary solutions for the hake stock levels, its social value and the effort exercised by the two fleets involved in the fishery (trawling and artisanal), propose different scenarios with regard to the selectivity parameter for the fleet that has a more intensive impact on young individuals and then on marine resource dynamics. If trawling selectivity improves, then the optimum level of the natural resource and its shadow price increases, whereas the global level of effort diminishes, increasing that of the trawling fleet and reducing that of the longline fleet [19].

If the present situation is compared to the optimal estimations obtained in this study, it can be seen that the Southern stock of European hake is being fished in an inefficient way, both from an economic point of view and the conservation of the natural resource point of view. In particular, the amount of hake biomass existing at the end of the period studied is significantly lower than that derived from a socially stationary solution. Even in a few years, landings have exceeded the spawning hake biomass in Iberian-Atlantic waters.

To reach socially stationary solutions, we have incorporated an intervention mechanism based on taxes, particularly a tax based on effort exercised by each fleet. The tax equilibrium level is directly related to the social value of the fishing resource, with the marginal productivity of the effort exercised and with the effect that fishing activity has on the natural growth of the resource. In particular, the tax level on the trawling effort is greater than that applied to the artisanal fleet, as it is more productive and affects the hake population more negatively. Therefore, it will pay more to exercise its effort in the fishery. On the contrary, the equilibrium level obtained for the tax on the effort of the artisanal fleet is lower, as it is less productive and much more selective. However, when the trawling fleet improves its selectivity, its effort equilibrium level increases and the optimum tax decreases, to the detriment of the stationary values that correspond to the artisanal fleet.

In this framework, the proposed regulation involving declines in the level of fishing (reducing the pressure on the stock of fish) is not usually well received by the fishing industry. However, an efficient regulation allows maintaining the marine resources in a sustainable way and it will generate economic income for fishermen. An inefficient situation to an efficient change must be associated with a policy of income distribution suitable based on the criteria of equity. The regulation mechanism based on taxes could offer a solution to the externalities associated with the absence of efficient allocations. Although the analysis shown in this chapter is simple, the results can orient the regulator to achieve a more rational exploitation of the Southern stock of hake.

http://dx.doi.org/10.5772/62285

Acknowledgements

The authors acknowledge the financial support from FEDER and Xunta de Galicia (GRC2014/022) and the Ministry of Economy and Competitiveness (ECO2014-52412-R and ECO2013-44436-R).

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