VIABILITY OF TRANSBOUNDARY FISHERIES AND INTERNATIONAL QUOTA SHARING

Richard Curtin, AZTI - Tecnalia, rcurtin@azti.es
Vincent martinet, INRA, vincent.martinet@grignon.inra.fr

ABSTRACT

This paper examines the viability of the management of a transboundary resource, the Bay of Biscay anchovy (Engraulis encrasicolus L.). A deterministic model is used to simulate the anchovy dynamics, with the fish stock consisting of two age groups, "young" and "old", while recruitment follows a Beverton Holt pattern. Two countries, France and Spain, harvest the resource, with two different types of gear, the purse seiner for Spain and the pelagic trawler for France. These technologies impact the different age-groups of anchovy at differing rates. A regulatory agency defines an annual fishing quota and its allocation between the two countries, with the aim of sustainability in the overall allocation design. A set of constraints is defined to describe the sustainability of the system which encompasses the economic, ecological and social aspects of the fishery. The optimal harvest share between the two countries is found and a number of scenarios are then tested in relation to their ability to remain within the set of constraints, or viability kernel. Other scenarios, including the historical trajectory, the optimal harvest share trajectory and the minimum time of crisis trajectory, are examined.

Introduction

European Anchovy (Engraulis encrasicolus L.) is known to occur on Eastern Atlantic coasts as far north as Bergen, Norway to as far south as Southern Africa while being present throughout the Mediteranean, Black and Azov Seas (Whitehead et al., 1998). On the European Atlantic coast, the Bay of Biscay anchovy fishery is the most important with smaller fisheries present in the English Channel, in the south of the North sea and in the Bay of Cadiz to the south of Spain and Portugal (Uriarte et al., 1996). In this article the effects of different fishing gears on the sustainability of the fishery will be investigated. We also consider the distribution of harvest shares which is optimal from an economic point of view. This work aims to build on publications such as Munro (1979) and Escapa and Prellezo (2003), which deal with the optimal management of transboundary resources. The paper will describe the management of the Bay of Biscay anchovy stock between Spain and France. In reality the Spanish fleet uses one type of gear to fish the anchovy stock and that is the purse seiner while the French fleet utilizes two types of gear, the purse seiner and the pelagic trawler. In relation to the anchovy fishery the French pelagic trawler fleet catches around 90% of the French quota with the remainder caught by the purse seiners. Therefore it shall be assumed that the French fleet is entirely composed of pelagic trawlers with the Spanish fleet all purse seiners. The distribution of harvest shares between Spain and France must be defined taking into account the effect of their respective gear types on the reproductive capacity of the anchovy stock.

In this paper, it is assumed that a regulatory agency must allocate a fishing quota between two countries with different fishing patterns. The agency is interested in the sustainability of its allocation design. To describe the sustainability of the system, it is assumed that the allocation should satisfy a set of constraints. First, from an ecological point of view, the spawning stock biomass should be over a biological threshold, ensuring preservation. Second, from an economic point of view, the profit of each country should be above a given threshold, ensuring profitability. Last, from a socially equitable point of view, the quota sharing should satisfy some acceptability constraints, ensuring compliance. To address this issue, we adopt the viability approach. We define the configurations of the

fishery, and the associated quota's level and sharing, which make it possible to respect all these constraint over time. To study the viability of the system, we follow the methodology proposed by Martinet et al. (2007, 2010).

The two-country fishery model
In this section, the bio-economic model developed to address our issue is presented.

The fish stock dynamics
The fish stock is composed of two age groups: "young" and "old." The "young" age group represents the recruits. Its biomass is denoted B0. The "old" age group represents the spawning stock biomass, which is denoted Bsp. We first provide an overview of the timing of our discrete time model. The time step is annual. At the beginning of year t, stock is (B0(t);Bsp(t)). First, the spawning stock Bsp(t) spawns (before harvesting), producing the eggs that will become recruits at the end of the year (B0(t + 1)). Harvest then takes place. At the end of the year, the non-harvested biomass of each age group grows (or declines if natural mortality offset natural growth in weight). This gives the spawning stock biomass for next year (Bsp(t+1)). The sequence is thus 1) reproduction, 2) harvesting and 3) growth.

The dynamics of this fish stock is represented by the following mathematical model. We follow Tahvonen (2009) for the description of the age structured fish population. We consider a discrete time dynamic model with two state variables representing "young" and "old" age groups biomass. The recruitment at year t + 1 depends on the spawning stock biomass at year t, i.e., B0(t + 1) = R(Bsp(t)), where the recruitment R follows a Beverton-Holt pattern, which leads to the following dynamic equation for the "young" age group:

$$B_0(t+1) = \frac{r B_{sp}(t)}{1 + b B_{sp}(t)}$$

where r is the natural growth rate. We assume that harvesting is instantaneous and takes place in the middle of the year.

The dynamics of the spawning stock biomass depends both on the previous year's biomasses (B0 and Bsp) and harvest level. Growth occurs after harvesting. The harvesting functions will be described in details in the next section on harvesting design. However, we can already introduce notations, and the rational behind them. The harvest of "young" and "old" fish depends on the fishing effort of two

countries, i.e., e^S and e^F. These fishing efforts determine harvesting level, according to the harvesting

functions H0(B0; e^S; e^F) and Hsp(Bsp; e^S; e^F), defining respectively the harvest
on the "young" and "old" stocks. Altogether, the dynamics of the spawning stock biomass is described by the equation

$$B_{sp}(t+1) = \delta_0 \left(B_0(t) - H_0(B_0(t), e^S(t), e^F(t)) \right)$$
$$+ \delta_{sp} \left(B_{sp}(t) - H_{sp}(B_{sp}(t), e^S(t), e^F(t)) \right)$$

where δ_0 and δ_{sp} < 1 are the growth rates of both age groups (survival or natural growth rates in biomass units).

Eqs. (1) and (2) represent the dynamics of our system. Note that the total biomass at year t is defined as B(t) = B0(t)+Bsp(t). In this model, the long-run equilibrium of a unexploited stock is given by

$B_0^{eq} = \frac{1}{b} \left(r - \frac{1 - \delta_{sp}}{\delta_0} \right)$ and $B_{sp}^{eq} = \frac{1}{b} \left(\frac{r \delta_0}{1 - \delta_{sp}} - 1 \right)$. These biomasses can be interpreted as the natural

carrying capacity of the ecosystem for the species.

3.2 Harvest design
This stock is harvested by the fisheries of two countries, denoted S and F (for Spain and France). Each country decides its own fishing effort, i.e., e^S and e^F. The technology in the two countries is different, so that a unit of effort will not yield the same catches of "young" and "old" fish in the two countries. We define a selectivity pattern for both fisheries (a vector $\left[q_0^i, q_{sp}^i\right]$, where i is either country S or F).

The catches are supposed to be linear in both the effort and the biomass level. We thus have, from a general point of view, a catch equation $Y_{age}^i(t) = q_{age}^i B_{age}(t) e^i(t)$. The yield of a country i is thus defined as $Y^i(t) = (q_0^i B_0(t) + q_{sp}^i B_{sp}(t)) e^i(t)$.

The harvest level, at year t, for each age group can be defined as follows:

$$H_0(t) = B_0(t)(q_0^S e^S(t) + q_0^F e^F(t))$$
$$H_{sp}(t) = B_{sp}(t)(q_{sp}^S e^S(t) + q_{sp}^F e^F(t))$$

The total production (supply on the market) is thus defined as the sum of each country's yield, or as the sum of the two age-group's harvest:

$$Y(t) = Y^E(t) + Y^F(t) = H_0(t) + H_{sp}(t)$$

Market design
We assume an inverse demand function regulates the price of anchovy, with high harvests of the fish ensuring a low price and vice versa. We also consider a maximal price p, when catches are low, corresponding to the maximal observed price, related to substitutes.

$$P(Y^S + Y^F) = \min\{\bar{p} \quad ; a + b(log(Y^S + Y^F))\}$$

Historically the price of anchovy has oscillated between 1 and 3 Euro per kilogram. However with the crash of the stock in 2005 prices have increased substantially, to a peak of 20 Euro at the beginning of the 2010 fishing season. We take a limit price of 25 Euro per kilo, corresponding to highest observed price.

Quota allocation mechanism
We assume that the regulatory agency defines a Total Allowable Catch level, which represents the total quota Q(t) to share between the countries. The regulator then shares the quota among the countries, according to a ratio α(t) for country S and 1-α(t) for country F. From that point of view, the quota at year t for country S will simply be QS(t) = α(t)Q(t), while the quota for country F will be QF (t) = (1 - α(t))Q(t). Note that the total quota will influence the product price via the market effect, and the share of quota will influence both the profit of each country and the stock dynamics.

The countries' problem under quota regulation We consider a profit function for each country.
$$\pi^i(t) = p(Y)Y^i(t) - c^i e^i(t) , \quad (9)$$
where p is price of anchovy, set at Basque prices due to the Basque market being principal market for anchovy (given by eq. 8).
Given a catch level (quota level Qi), the effort of both fleets is given by the following equation;

$$e^i(t) = \frac{Q^i(t)}{q_0^i B_0(t) + q_{sp}^i B_{sp}(t)} .$$

This effort depends on the structure of the fish stock (B0(t);Bsp(t)), and on the fishing pattern of the fleet $\left[q_0^i, q_{sp}^i\right]$.

Necessary condition for positive profit and fishing effort:
Using the expression of resource price (eq. 7) and catches (eq. 3), the profit (eq. 9)
Becomes

$$\pi^i = (a + b(log(Q)))\left(q_0^i B_0(t) + q_{sp}^i B_{sp}(t)\right) e^i(t) - c^i e^i(t) .$$

A necessary condition for the profit to be positive is that

$$log(Q) \leq \frac{1}{b}\left(\frac{c^i}{q_0^i B_0(t) + q_{sp}^i B_{sp}(t)} - a\right) .$$
1

This condition ensures that the quota level is suffciently low, and thus the resource price high enough, so that it is profitable to harvest the given stock (B0(t);Bsp(t)). This condition also ensures that the marginal profit of effort is positive, and that effort will be maximized.(Note that there are two conditions, one for each country.3 As long as these conditions are satisfied, the two countries have a positive fishing effort and maximize their profit by fully fishing their share of the quota.)

Viability of the quota sharing in a transboundary fishery
In this section, we consider that a regulatory agency is defining the annual quota for the species, and the share between countries. Given this allocation mechanism, each country defines its optimal effort, with the given share of quota as a constraint.
As the profit is linear in the effort, we have a "bang-bang" strategy. When condition (11) holds, it is optimal to have the highest possible effort. On the contrary, it is optimal to have a nil fishing effort when the condition doesn't hold. It is interesting to note that, depending on the structure of the Anchovy population(the relative abundance of young and old age groups), and given the different fishing patterns of the countries, one of the constraint will be stricter than the other.

The viability constraints
From a viability perspective, we assume that
the quota sharing is accepted if the following constraints are satisfied.

$$\pi^i(t) \geq \pi_{min}^i , \qquad i = F, S .$$
$$Q^i(t) \geq Q_{min}^i , \qquad i = F, S .$$

These constraints represent a guaranteed profit and a minimum level of activity for each countries' fishery.

The viability kernel
Formally, for our problem, the viability kernel is defined by

$$Viab = \left\{ (B_0, B_{sp}) \left| \begin{array}{l} \exists (Q(.), \alpha(.)) \text{ and } (B_0(.), B_{sp}(.)), \text{ starting from } (B_0, B_{sp}) \\ \text{satisfying dynamics (1) and (2)} \\ \text{and constraints (12) for any } t \in \mathbb{N}^+ \end{array} \right. \right\}$$
(14)

(14)

The minimum time of crisis criterion Following Martinet et al. (2007, 2010), we use the Minimum Time of Crisis approach (Doyen and Saint-Pierre, 1997) to define the viability kernel of our problem. The Minimum Time of Crisis criterion is defined as follows.

$$\mathcal{C}(B_0, B_{sp}) = \inf_{Q(.), \alpha(.)} \sum_{t=0}^{\infty} \mathbf{1}(B_0(t), B_{sp}(t), Q(t), \alpha(t))$$
$$s.t. \quad dynamics$$

where 1, the characteristic function that counts the number of period when viability constraints do not hold true, is defined by

$$\mathbf{1}(B, K, e, \xi) = \begin{cases} 0 & \text{if } (B_0, B_{sp}, Q, \alpha) \text{ satisfy constraints (12) and (13)} \\ 1 & \text{otherwise} \end{cases}$$

The viability kernel is the set of states (potentially empty) with a nil minimum time of crisis. Fig. 1 illustrate the results. One can see that the viability constraints on minimal quota and minimal profit can be satisfied dynamically only if the resource stock is large enough. We can see that there is a substitutability effect when the adult stock is large enough (almost linear substitution between adults and juveniles along the boundary of the viability kernel), but that this substitution is less important if the adult stock is too small. The interpretation is as follows: If adult stock is small, it is not viable to fish on the juvenile stock as it will worsen the
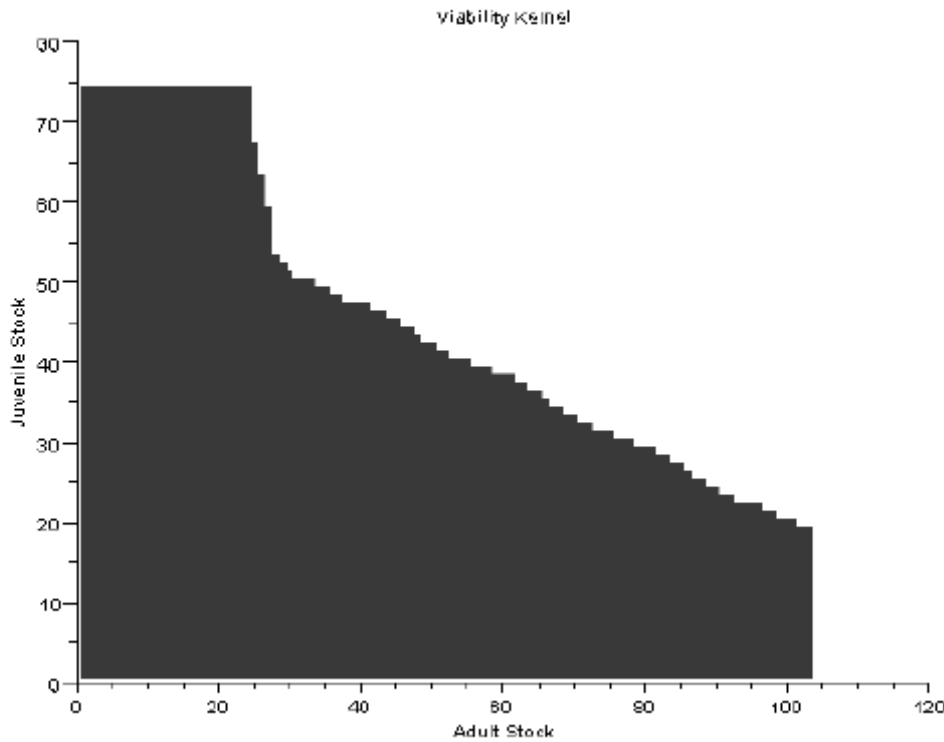

Figure 1: Viability Kernel (in white)

situation of the adult stock next years. This is confirmed by the results in Fig. 2, which presents the time of crisis around the viability kernel. One can see that, close to the upper-right side of the kernel, the fishery's viability can be recovered by closing the fishery for one year (Martinet et al., 2007, 2010).

Interpretation of the results for the Anchovy fishery
The optimal harvest (Quota and share) trajectory
To optimize the harvest shares the aim is to find the shares of harvest that lead to the most optimal exploitation of the resource. This means that we must find the maximum value of rent obtainable from the fishery. The aim is the joint determination of the optimal stock and the fishing quotas, with strictly positive quotas for both countries. Differences in harvest cost assumed to be due to unit cost of fishing effort.

$$c^i(B_{total}) = a^i/qB_{total}, i = 1, 2, \quad (16)$$

where ai is country i's unit cost of fishing effort and q is the catchability coefficient.
Figure 2: Time of Crisis
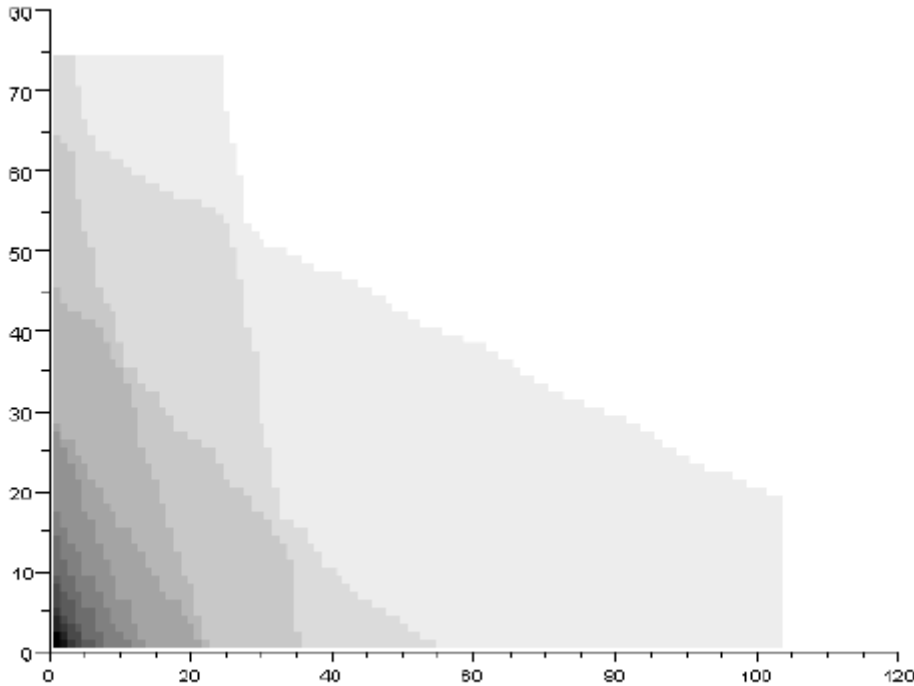
The social planner wants to maximise the discounted net cash flow from the fishery. The objective function is expressed as:

$$NPV = \sum_{t=0}^{\infty} \frac{1}{(1+\rho)^t}[\alpha\left[p - c^S(x)\right] + (1-\alpha)[p - c^F(x)]]h(t)$$

where ρ is the discount rate.

The following figures present the trajectories defined by the discounted utility approach, from different initial states of the fishery. Fig. 3 represents the profit. Fig. 4 presents the associated path of quota, while Fig. 5. presents the quota sharing.
One can see that, whatever the initial state of the fishery, the system reaches an equilibrium. Except is some configurations, the whole quota is allocated to France. This is due to lower per catch costs.

5.2 The scenarios
We here present a comparison of the results, for 3 trajectories, starting from the same initial state (1995). We have B0 = 59735 tons and Bsp = 52977 tons. The three trajectories under consideration are:

_ The historical trajectory
_ The optimal harvest share trajectory
_ The minimum time of crisis trajectory

Fig. 8 presents the trajectory of juvenile biomass B0. Fig. 9 presents the trajectory of adult biomass Bsp. Fig. 10 presents the trajectory of total quota, while Fig. 11 presents the share between the two countries in each scenario.

Conclusion
In this paper, we examine the sustainability of a transboundary fishery, when two countries harvest the same stock with different technologies, and the Total Admissible Catches is defined by a regulatory agency. We consider both the economic optimal sharing and the viable solution when constraints are imposed. We illustrate our results with the Bay of Biscay Anchovy fishery case. We show that the economic solution (maximizing the net present value of the fishery) may result in a strongly inequitable quota sharing, all the quota being given to the more cost-efficient country. In our illustrative case-study, it is economically optimal to give all the quota to France, even if its technology is less selective, and thus less environmentally friendly. On the contrary, defining viable quota sharing insuring a minimal profit to both countries results in more equitable sharing of the quota, and smaller quotas. The viable solutions are characterized by larger stocks, which may improve the sustainability and resilience of the stock.
Figure 5:
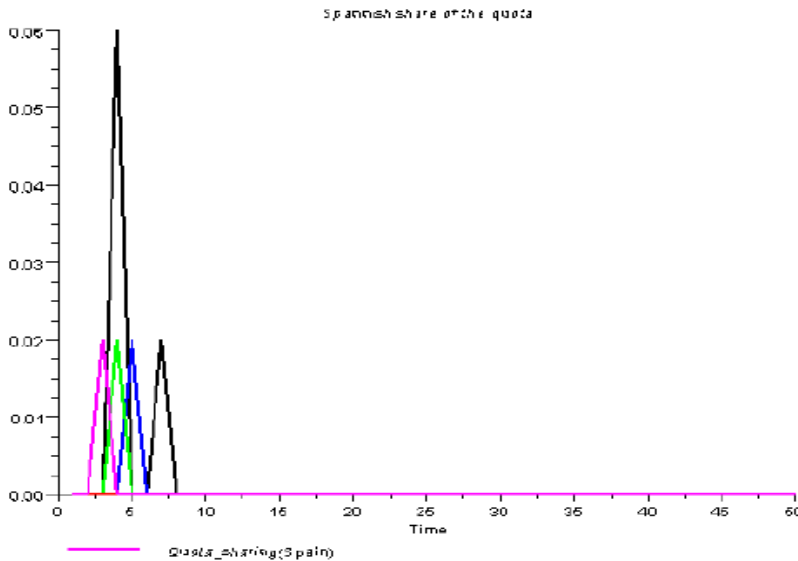
Appendix A

A.2 Data and parameter estimation

The biological data on the anchovy stock comes from the ICES Report of The Working Group on Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy, table 10.8.1.2 of said document, ICES (2006). Median spawning stock biomass and median recruitment calculated from acoustic and DEPM surveys have been used from this data to calculate a rate of recruitment of 0.9 and a carrying capacity of 72,716 tonnes for the juveniles and a carrying capacity of 101,206 tonnes for the adults. Catch data has been also been taken from table 10.2.1.1 of the same report, ICES (2006).
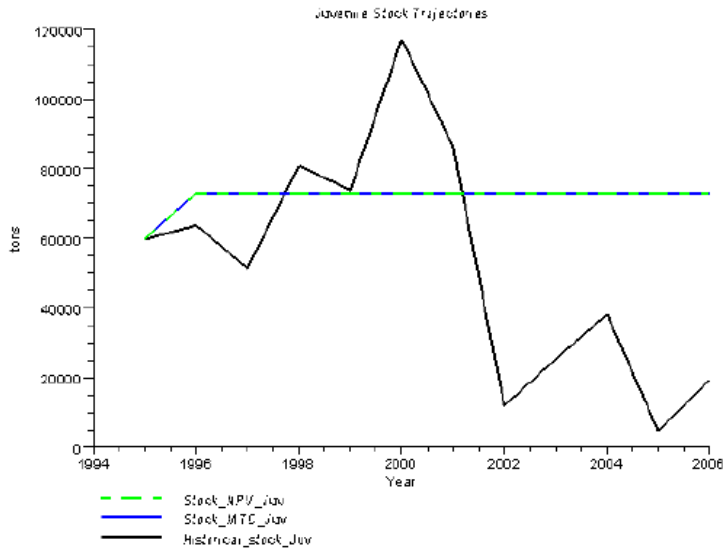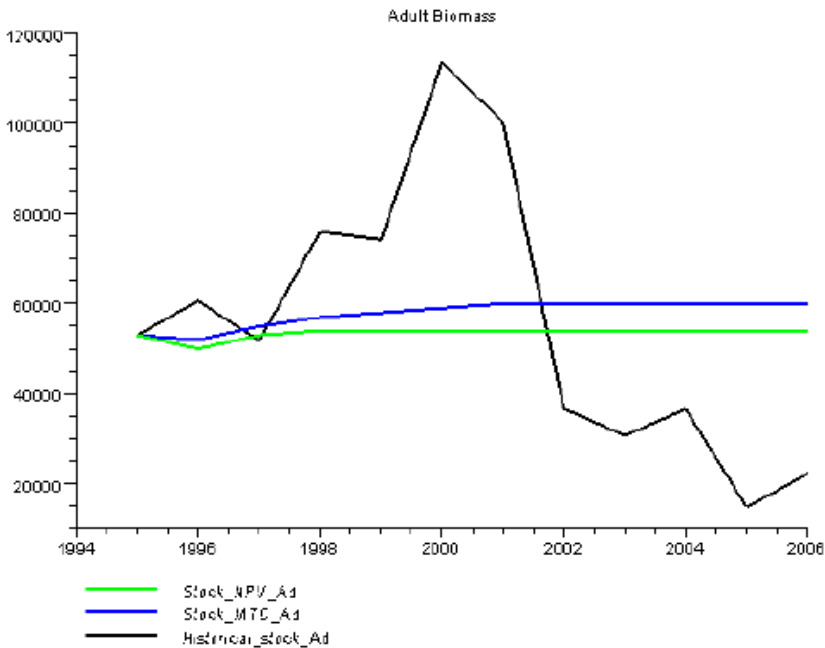
Figure 8: Juvenile Biomass

A.3 Catchabilities

Catchabilities for the two fleets have been taken from a model constructed in AZTI - Tecnalia by Marga Andres. The catchabilities for the Spanish and French fleets are 0.002093 and 0.008321 respectively. These catchabilities have been used in this model for the calculation of the effort used by the two fleets. To calculate the catchabilities of the fleets in respect to their catch of juveniles or adults the results of catch surveys by age groups carried out by AZTI - Tecnalia have been used. These surveys were carried out in semester 2 for the French surveys and during quarter 2 for the Spanish survey and catches were noted for age groups 0, 1, 2 and 3+. Age groups 0 and 1 were combined to from the juvenile group while age groups 2 and 3+ formed the adult group and then percentages calculated for how much each fleet captured of both groups. It was calculated that the French fleet captured a ratio of 86:14 juveniles to adults and that the Spanish fleet captured in the ratio of 65:35. From these estimates the historical catches of juveniles and adults for both fleets were calculated as with their respective catchabilities by age. The catchabilities for France were 0.0162373 and 0.0022222 for juveniles and adults respectively, and for Spain, 0.0030869 and 0.0013974.
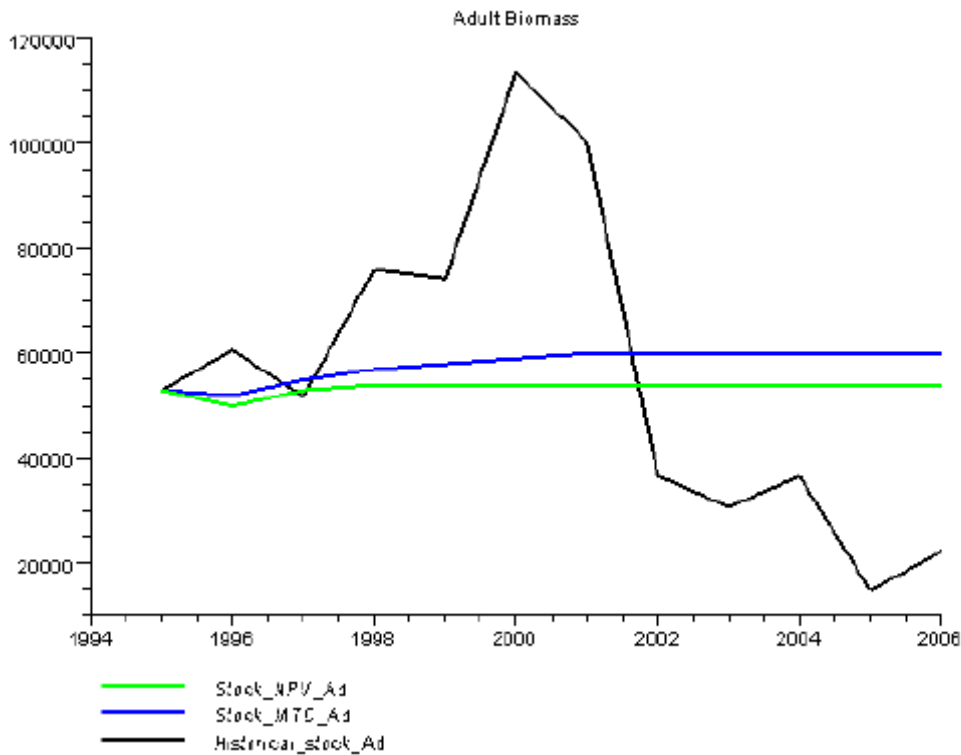

Figure 9: Adult Biomass

A.4 Price

Price data have been compiled from AZTI - Tecnalia and have been adjusted to constant prices using the year 2006 as the base year.

A.5 Costs

Cost data for the French fleet has been taken from the STECF report "Long- Term Management Of Bay Of Biscay Anchovy (SGBRE-08-01)", STECF (2008). A sample of French trawlers of between 14 and 25

metres was included in the report, from which total cost data for the years 2002-2006 were used. Spanish purse seiner cost data was taken from the model of Marga Andres, where the data has been taken from AZTI's internal database.

The method of calculating the total costs involved finding similar estimates of all the costs involved for both fleets. These costs include fixed costs and variable costs, with variable costs including bait costs, ice costs, fuel costs and other variable costs. Due to the diffculty of finding matching data sources for the two fleets, the total costs calculated in this model do not include wages.

Once total costs were calculated they were multiplied by the number of boats active in the fishery, which included around 200 boats for the Spanish fleet between the years of 2002 and 2004, STECF (2008) and between 45 and 54 French pelagic trawlers for the same years, Vermard et al. (2008). Finally, to attribute total costs to the anchovy fishery the percentages owed to the anchovy catch were found, ranging from 20-17% for the Spanish purse seiners between 2002 and 2004,(AZTI database), and 76.5% for the French
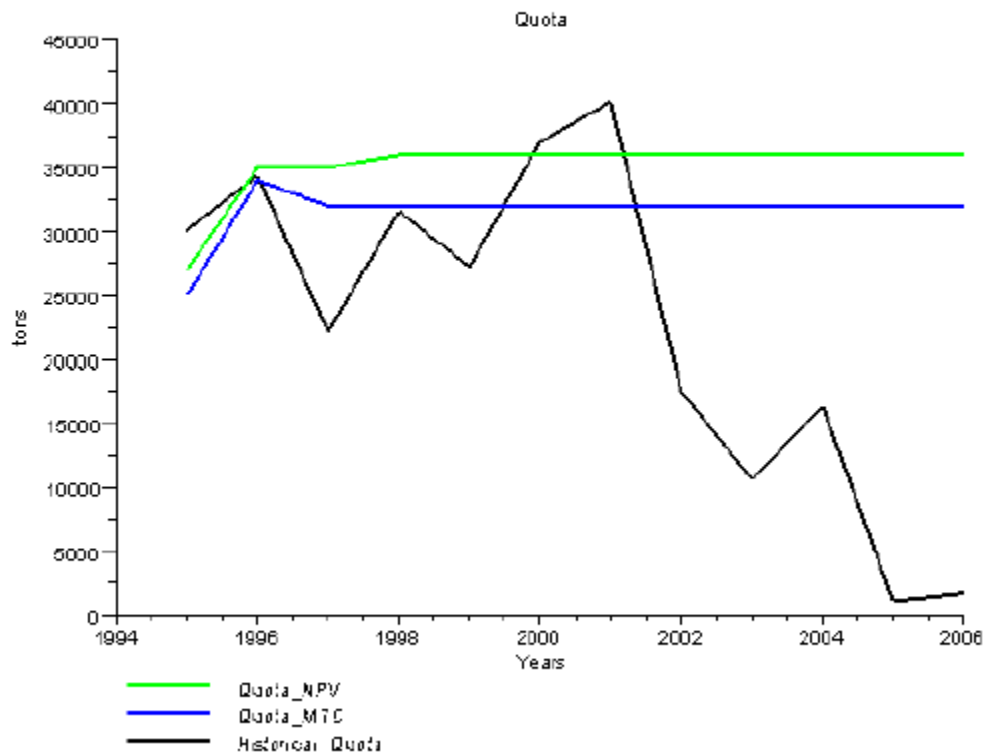

Figure 10: Quota

pelagic trawlers, Vermard et al. (2008). The average total costs for both fleets between the years 2002 and 2004 were then used to calculate their respective unit costs of effort and unit costs of harvesting.

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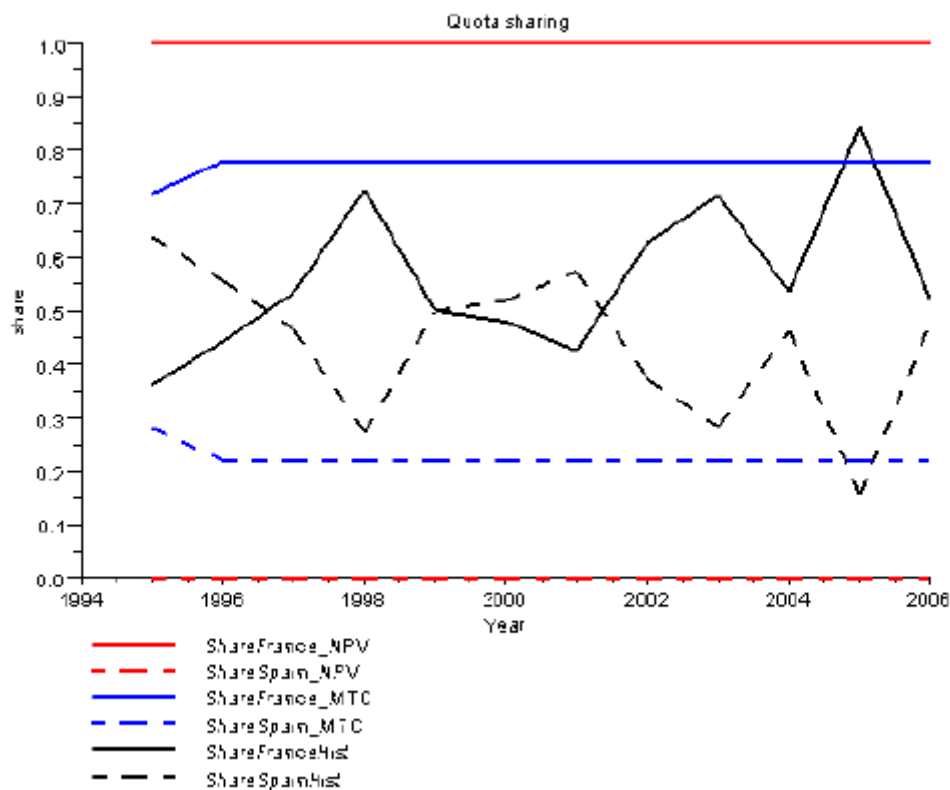

Figure 11: Quota sharing

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