WP 2005-15
June 2005

Working Paper

Department of Applied Economics and Management
Cornell University, Ithaca, New York 14853-7801 USA

Evolution of the Stock of Red Seabream in the Strait of Gibraltar: DEA-Malmquist Index and Stochastic Frontier Analysis

David Castilla Espino, Harold O. Fried, Juan José Garcia del Hoyo, and Loren W. Tauer

Evolution of the Stock of Red Seabream in the Strait of Gibraltar: DEA-Malmquist Index and Stochastic Frontier Analysis

David Castilla Espino
MEMPES – AEA

Harold O. Fried
Union College

Juan José Garcia del Hoyo
MEMPES – AEA

Loren W. Tauer
Cornell University

Paper presented at the IX European Workshop on Efficiency and Productivity, Brussels, Belgium, June 29–July 1, 2005.

This study was partly funded by EU project ‘‘Scientific Observatory for Traditional Fishing (OCIPESCA)’’ in the framework of EU program INTERREG III B “Atlantic Area”, 2000-2006.

Abstract

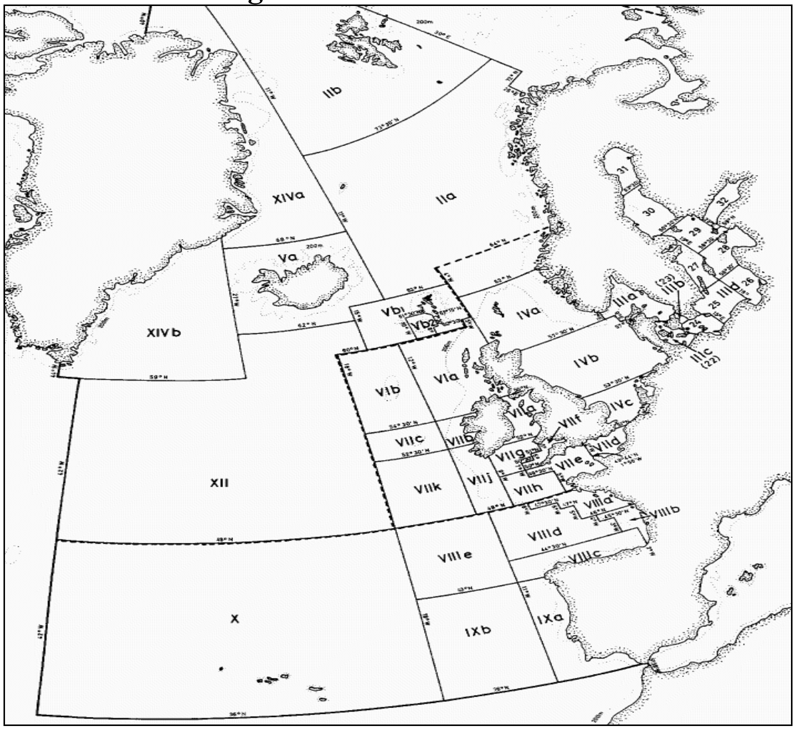
Red Seabream is a valuable fish resource for ports in Southern Spain. It is critical that this fishery be well managed to ensure a sustainable and viable commercial fishery into the future, which recent fishing regulations should accomplish. Fish stocks appear to be increasing. We use Data Envelopment Analysis and Stochastic Frontier Analysis techniques to estimate the impact of recovering fish stocks on fishing output. Since imposed fishing regulations to protect the fishery essentially have halted technological progress in the fleet, we alter the standard Malmquist decomposition of efficiency and technological change instead into efficiency and the impact of fishing stock change. We find that over the 3 year period of 1999 through 2001, increase in fishing stocks lead to a 2.05 annual percent increase in fishing output by DEA computations, and 2.70 annual percent increase by SFA computations

I. Introduction

The wedge between the returns to an individual fisherman and the impact on the future of a fishery is a classic externality problem. The lure of high profits attracts vessels to the fishery, leading to a decrease in the fish stock, eventual overexploitation and then depletion as a result of the stock falling below a minimum sustainable level. The oceans of the world are littered with barren fisheries which once thrived, provided a livelihood for fisherman and an important food source for the rest of us. In the absence of private ownership of the fishing resources, public management is the only alternative available for sustainability of a fishery.

Red seabream is an interesting example. The coast of Northern Spain was an important source of red seabream until 1990 when uncontrolled fishing led to its demise. Fish stocks of red seabream are almost depleted in most grounds of the International Council for the Exploration of the Seas (ICES), except for regions IX (mainly located in the Strait of Gibraltar area) and X (Azores). See Figure 1 below. Regions IX and X are at risk. This paper is about Region IX.

Figure 1: ICES Subdivisions



Source: ICES

It was apparent by the end of 1998 that Region IX was being overexploited to the point at which the fish stock was in danger of falling below the critical level that would compromise the future of the fishery. This was the motivation to implement a recovery plan in 1999 consisting of licensing access to the fishery, fishing gear restrictions, a cap on the number of fishing trips, a minimum size on fish caught and incentives for fisherman to seek other employment. The program was successful in curtailing the drop in red seabream stock. According to a preliminary report by the Instituto Español de Ocenografía (IEO), the fish stock was in equilibrium by 2004.

The objective of this paper is to investigate the evolution of the fish stock over the recovery period, 1999 – 2002. The conventional approach is to estimate a surplus production model (Schaeffer 1954). We estimate this model as a benchmark. However, because the recovery plan included detailed restrictions on fishing gear, it essentially froze the technology for catching fish (Castilla Espino, 2005). This enables us to employ frontier production methodologies in a relatively novel way (Pascoe and Herrero, 2004). We estimate shifts in the production frontier over the period using data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Production frontier shifts are usually attributed to technical change, but in this case, we know that technology is constant; frontier shifts map the impact of fish stock changes over the recovery period.

A shift in the frontier means that more fish are caught with the same inputs which, accepting technical change, implies that the fishing grounds are more productive. However, the existence of Atlantic pomfret is a confounding factor. This fish eats the bait before it reaches the bottom of the ocean where the red seabream lives, reducing the productive catch of seabream. Atlantic pomfret are more plentiful in some seasons than others. We treat the density of Atlantic pomfret as an environmental variable which reduces the transformation of fishing effort into the catch of red seabream.

The paper is organized as follows. The next section discusses the biology of red seabream, the fishing technology and the culture.[1] Section III summarizes the traditional model of the dynamics of a fishery and establishes the factors that lead to changes in the equilibrium fish stock. This lays the groundwork to analyze the red seabream fishery in Section IV. We trace out the evolution of the fishery over the recovery period, 1999 – 2002, using three approaches. We begin with the surplus production model which is a familiar method in the fishery literature, and then we consider two frontier methods, data envelopment analysis and stochastic frontier analysis to compute Malmquist indices. These results are compared in the concluding section.

II. Red Seabream in the Strait of Gibraltar

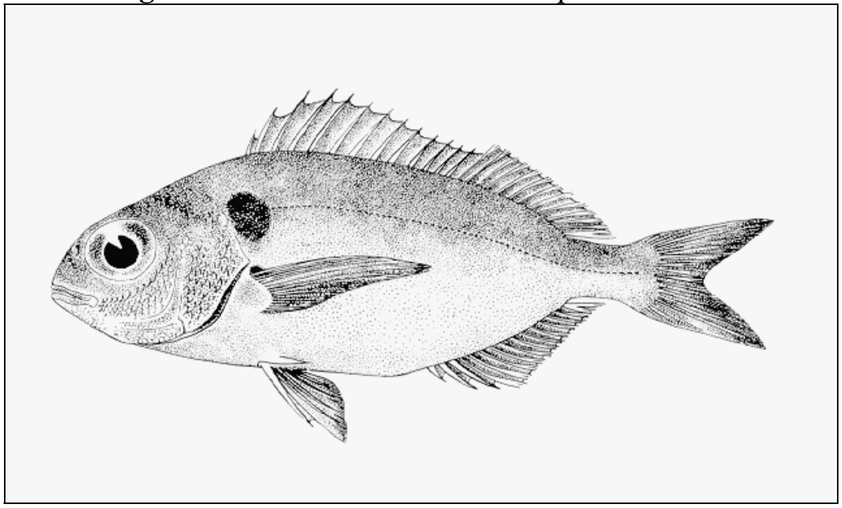
The red seabream (see Figure 2), also referred to as blackspot seabream (*Pagellus bogaraveo*, Brünnich, 1768), is a benthopelagic fish species that belongs to the family sparidae, and the order perciformes, and inhabits inshore waters over rocky, sandy, muddy bottoms between 400 and 700 m. in the Mediterranean Sea, especially the Alborean sea and the Gulf of Lion (Spedicato, *et al.* 2002) and the Eastern Atlantic Ocean from Norway to Mauritania (www.FishBase.org).

Red seabream eats small pelagics, mollusks, worms, crustaceans and other fish larvae. Young seabream live near the coast and migrate to deeper water as they become adult. It is hermaphrodite, beginning as an adult male at 30 cm., becoming female at 32-33 cm. and a mature female at 35 cm. The spawning season is in the first four months of the year (Gil and Sobrino, 2001: 2-3).

---

[1] Delicious recipes for preparing red seabream are available from David Castilla Espino upon request.

Figure 2: Red Seabream or Blackspot Seabream

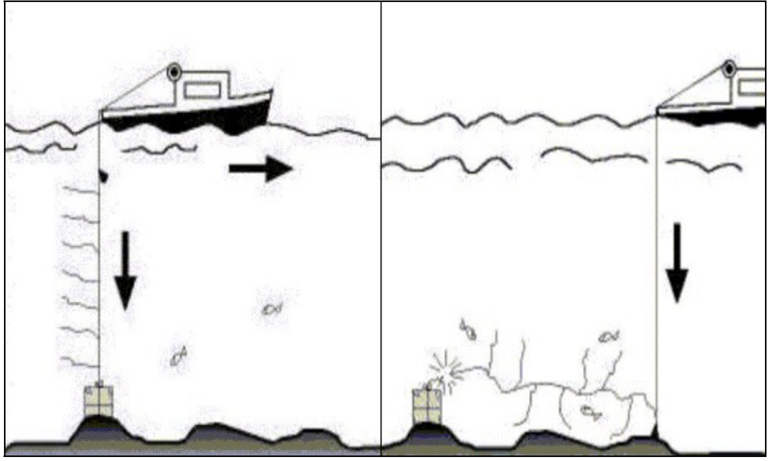


Source: FAO

Most red seabream are caught from the International Council for the Exploration of the Sea subdivisions IX and X. Subdivisions VI and XII once were important fishing regions, but have suffered the fate of over-fishing (ICES CM 2004/ACFM: 15). See Figure 1.

In subdivision IX, the fish is caught using a very selective deep-sea longline fishing gear (Bravo, *et al*. 2000). This fishing gear consists of a 2000 m. line ("madre"), which is attached to a weight and a subsidiary 120 m. line with a maximum of one hundred 1 m. spliced lines with baited hooks locally called "voracera". The voracera is thrown from the boat, and the madre is tightened, releasing the subsidiary line and the splicing hooks which settle on the bottom of the ocean (Diputación Provincial de Cádiz, 1991: 36; 1994: 91). See Figure 3. Vessels carry around 30 "voraceras" which are thrown during the movement from low to high tide in the morning. The fleet returns to port with its catch in the evening before sunset; fishing trips are day trips. More than half of the days in the season are lost due to poor weather conditions.

Figure 3: Operations for Drawing the "Voracera"



Source: Castilla Espino elaboration

The fleet is composed of Spanish vessels that operate out of Tarifa and Algeciras. Boats are family owned and operated and are full time occupations. The primary catch of the fleet is red seabream, supplemented by tuna during selected months. Fishing operations in Section IX expanded as the productivity of other subdivisions declined. The fleet based in Tarifa increased, for example, from 43 vessels in 1983 to 106 in 1999, coinciding with a general decreasing trend in capture per unit of effort during the period, especially sharp in years where there was a high relative density of Atlantic Pomfret. Weather could also have influenced this evolution (García del Hoyo, *et al*. 2001:145-201).

III. The Dynamics of a Fishery

The case for management of a fishery hinges upon the interplay between resources applied to fishing and its impact on the supply of fish in the future. Where fish are plentiful, they can be caught with little effort (at low cost), but excessive fishing that depletes the stock faster than the natural rate of growth reduces the stock, sending the fishery into a downward spiral and the costs of catching fish into an upward spiral. This suggests that there is an optimal sustainable yield for the fishery. Achieving this optimum requires luck and appropriately defined property rights or public management of the fishery.

It is relatively easy to obtain information on the number of fish caught; it is not so easy to estimate the natural increase in the stock. There are two methods to determine the fish stock. Analytical or age-structured models separately examine each of the factors that influence the dynamics of a certain fish stock (Russell (1931, 1939)[2]. Surplus production models treat the stock as a homogeneous biomass and parameterize the growth process. This approach requires less data and fewer parameters to estimate (García del Hoyo, *et al*. 2001: 39). We adopt this approach.

Schaefer (1954) applied the surplus production model to fisheries. The evolution over time (t) of the fish stock [$X(t)$] is a function of a natural growth function which depends on the size of the fish stock minus mortality caused by fishing [$h(t)$] in period t:

$$\frac{dX(t)}{dt} = F[X(t)] - h(t). \tag{1}$$

Schaefer chose the logistic curve of Verhulst (1838) for the natural growth function and assumed that fishing mortality was a linear function of fishing effort in period t, [$E(t)$]. If r is the natural intrinsic growth rate of the fish stock, k the environmental carrying capacity that represents the maximum size of the fish stock, and q the catchability coefficient given the state of the technology, the growth function and the capture function are given by equations (2) and (3):

---

[2] According this author this factors are the natural growth, the recruitment of new fishes that become visible to fishers and the mortality cause either by natural causes and fishing. Sustainability is reached when the factors that increase the stock equal the factors that decrease it.

$$F[x(t)] = rx(t)\left[1 - \frac{x(t)}{k}\right] \tag{2}$$

$$h(t) = qE(t)x(t). \tag{3}$$

Sustainability requires that the natural growth function equal the capture function:

$$F(x) = h \tag{4}$$

Solving for *x in (4) and substituting into (3)* yields the sustainable catch:

$$h = qE\left(1 - \frac{qE}{r}\right)k\ . \tag{5}$$

Without belabouring the comparative statics which can be found elsewhere, Figure 4 illustrates the underlying mechanism. In the absence of fishing, the fish stock is at the environmental carrying capacity. As fishing effort increases, new equilibrium levels are reached where more fish are caught up to a point, but the fish stock declines. However, the marginal return to fishing effort falls since it is more difficult to catch fish as the stock declines. At some point, the fish stock falls sufficiently that the marginal return to fishing effort becomes negative. The amount of fishing effort that maximizes the catch is the maximum sustainable yield (MSY). This is a biological optimum point of exploitation of the fishery. An economic optimum point for the fishery cannot be identified without enriching the model with cost and revenue specifications.

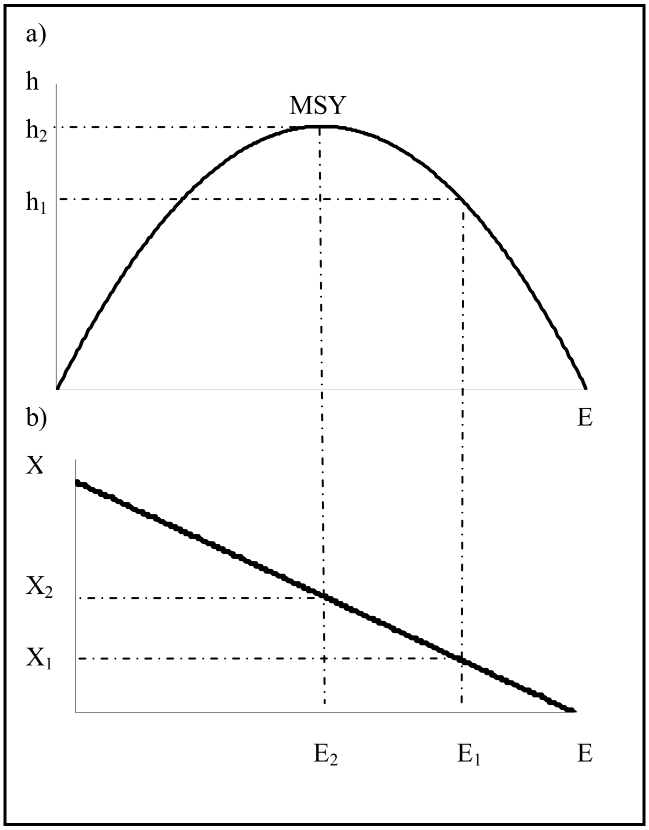
The problem is that fishermen individually continue to have an incentive to fish beyond the point at which the fish stock is at the MSY level since their catch is still positive. They are able to capture the rent of other fishermen due to the fact that the exploitation of the fish stock is not exclusive. Additionally, fishermen have no incentives to invest in conservation of the fish stock. In the extreme, with zero marginal fishing costs, the increased fishing effort will drive the stock to zero. Even short of that, fishing effort can easily drive the stock sufficiently low that it could take many years for the fishery to recover to the point that the MSY level or any other optimum level of exploitation of the fishery could be attained without the implementation of drastic management.

Biological over exploitation of the fishery is illustrated in Figure 4 where effort is first at E_1, the catch is h_1, and the fish stock is X_1. Reducing fishing effort to E_2 increases the catch (h_2) and the fish stock (X_2). A recovery plan that held fishing technology constant and reduced fishing effort from E_1 to E_2 would require less effort resulting in a greater catch. In a dynamic production function framework, this would manifest itself as an outward shift in the frontier.[3] This is where we are going.

---

[3] The converse also holds. Moving from E_2 to E_1 would manifest itself as an inward shift in the frontier.

Figure 4: Sustainable Fishing Effort, Catch and Fish Stock



IV. Empirical Results

A. The data

The data consists of a daily panel over three years, 1999 – 2002, on the size of the catch, labor, density of Atlantic Pomfret and technical characteristics of the boats that operate out of the port of Tarifa.[4] The coverage of the sample increases over time, accounting for almost 73% of the landings of red seabream in 2002. Table 1 contains the details. The data was aggregated into monthly and annual unbalanced and balanced panels. The balanced monthly panel includes 12 boats, and the balanced annual panel includes 57 boats.

---

[4] Data on harvest comes from ID@PES data base on daily red seabream sold in the public exchange market of Tarifa, elaborated by the Empresa Pública de Puertos de Andalucía for the regional government of Andalusia. Technical characteristics of vessels are from the Spanish artisanal census of operative fleet and labour from the Ministerio de Asuntos Sociales.

Table 1: Red Seabream Landings (1999-2002) [5]

Year	Sample (Kg.)	Total (Kg.)	Sample/Total
1999	88616	407121	21.77%
2000	162961	283677	57.45%
2001	133084	223126	59.65%
2002	123338	169258	72.87%

Source: Consejería de Agricultura y Pesca of the regional government of Andalusia.

Table 2 contains the descriptive statistics of the technical characteristics: gross tonage (GT), length (metres), horse power (HP) and crew size[6].

Table 2: Descriptive Statistics of Technical Characteristics (1999-2002)

Year	GT		Length (m.)		HP		Crew	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1999	5.59	2.62	8.33	1.73	65.39	31.38	4.83	2.07
2000	5.57	2.60	8.36	1.76	65.95	31.46	4.81	2.09
2001	5.68	2.56	8.49	1.67	67.24	31.23	4.85	2.10
2002	5.70	2.68	8.37	1.78	64.93	31.68	4.81	2.20

Source: Ministerio de Agricultura y Pesca and Ministerio de Asuntos Sociales

The relative density of Atlantic pomfret impacts the transformation of fishing effort into productive catch. Table 3 contains the annual values of Atlantic pomfret catch and catch per trip over the sample period.

Table 3: Atlantic Pomfret Catch (1999-2002)

Year	Catch(kg.)	Trips	*Catch/Trip*
1999	14926	2690	5.55
2000	332166	3858	86.10
2001	4426	2444	1.81
2002	1426	2139	0.67

Source: Consejería de Agricultura y Pesca of regional government of Andalusia

Table 2 clearly confirms the binding regulatory constraint on the fishing technology. Table 3 clearly confirms the variation in the impact of Atlantic pomfret; 2000 was a particularly bad year.

B. The Surplus Production Model

The Schaefer (1954) surplus production model can be used to estimate the evolution of the fish stock. This was estimated using the observation error / time series

---

[5] The small sample size in 1999 is due to missing data for March, August, November and December.

[6] We experimented with the material of the hold and gross registered tonnage. These variables do not appear to affect the production process.

fitting procedure (Hilborn and Walters, 1992: 310) using the non-linear discrete time approximation of the Schaefer (1954) model shown in (6) and (7).

$$x(t+1)-x(t)=rx(t)-\frac{r}{k}x^{2}(t)-\mathrm{h}(\mathrm{t}) \tag{6}$$

$$\mathrm{h}(\mathrm{t})=\mathrm{x}(\mathrm{t})\left(1-\mathrm{e}^{\mathrm{qE}(\mathrm{t})}\right). \tag{7}$$

Equation (6) was estimated by non-linear ordinary least squares using standardized fishing effort and capture from 1986 through 2003 assuming that all vessels use the same technology after 1998 (García del Hoyo, *et al.* 2001: 145-173). This provided preliminary estimates of the intrinsic growth rate (*r*), the environmental carrying capacity (*k*) and catchability of the fish stock (*q*) as shown in Table 4[7].

Table 4: Parameters Estimates (P.E.), Standard Error (S.E.) and t Values (T) of Discrete Time Surplus Production Model

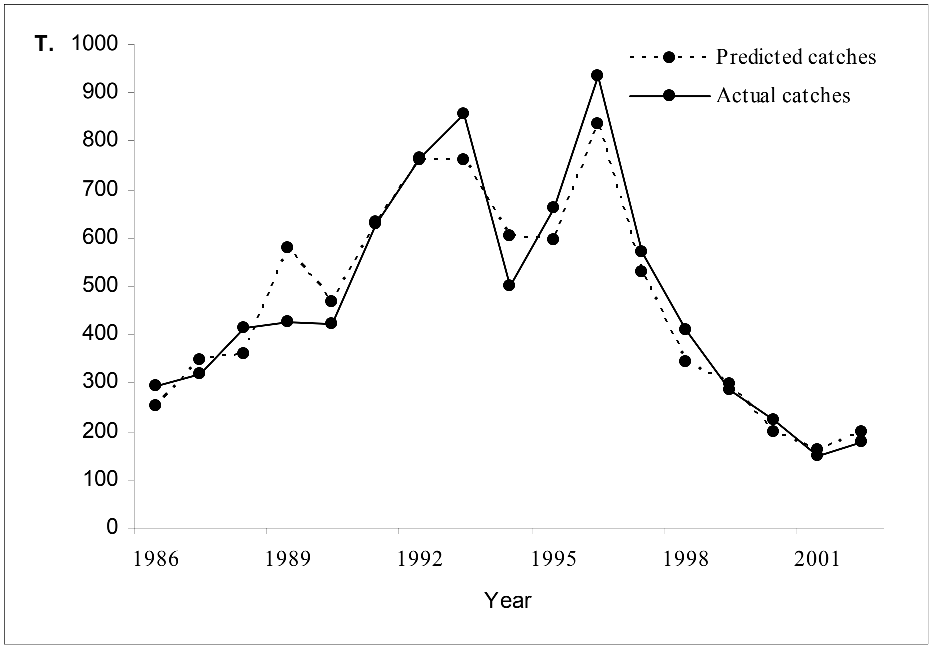
Variables	P.E.	S.E.	T
q	1.77×10^{-5}	2.58×10^{-5}	0.686
r	0.626	0.283	2.212
k	4973409	5275433	0.943
R^2	0.530		
Log-likelihood	2.986		
Durbin Watson Statistic	2.225		
F Statistic	7.340		

The final parameters estimates of the growth function: r = 0.3040, q = 3.07 × 10-5 and k = 9206 T. Graph 1 shows the fit of the actual capture and the predicted capture.

---

[7] The capture during periods where Atlantic pomfret density was exceptionally high has been estimated by means of linear interpolation of the capture of the closest periods where the incidence of this environmental factor was not significant in order to determine the annual capture per unit of effort [*U(t)*].

Graph 1: Actual and Predicted Catches of the Observation Error / Time-SeriesFitting Procedure (1986-2003)



Graph 2 depicts the fish stock estimated for the period 1986-2003.

Graph 2: Fish Stock (1986-2003)

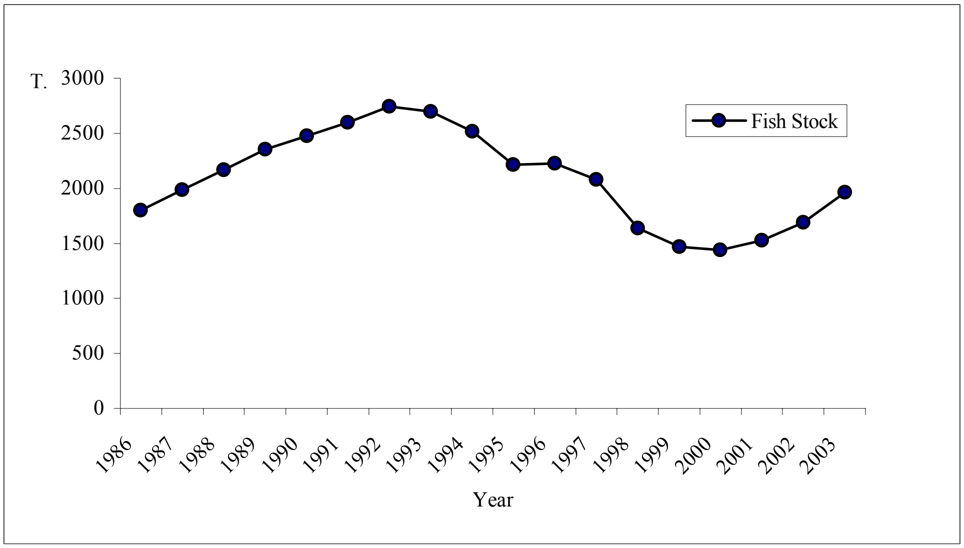


Table 5 shows the estimated values of the fish stock and its evolution over the period 1999-2002. The fish stock increased by 14.88 percent over the period.

Table 5: Fish Stock (1999-2002)

Year	Fish Stock (T)	Fish Stock change
1999	1471	-
2000	1439	-2.13%
2001	1525	5.94%
2002	1689	10.74%

C. The Malmquist Index

The Malmquist index can also be used to measure the evolution of the fish stock (Pascoe and Herrero, 2004). We choose the DEA based output oriented specification (Fare et al.1994). In contrast to the surplus production approach, it utilizes benchmark frontiers rather than conventional regressions that pass through the middle of the data. The DEA method is nonparametric, it is nonstochastic, but it controls for inefficiency. Standard applications of the Malmquist index identify productivity change that is the result of technology improving (typically) over time and efficiency improving, deteriorating or remaining the same. In this application, the technical change component of the Malmquist index identifies increases or decreases in the fish stock since technology remains constant.

The Malmquist index is derived as follows: For each input vector $x^t \in \Re_+^M$ at time t, let $P^t(x^t)$ be the set of feasible outputs where vector $y^t \in \Re_+^M$. The output correspondence is $P^t(x^t) = \{y^t : (x^t, y^t) \in S^t\}$ where S^t is the technology set at time *t*. An output distance function gives the reciprocal maximum proportional expansion (ϕ) of the output vector y^t, given inputs x^t , and characterizes the technology completely for all inputs vectors (Brümmer, Glauben and Thijssen, 2002: 629):

$$D_0^t\left(x^t, y^t\right) = \inf\left\{\phi > 0 : \frac{y^t}{\phi} \in P^t(x^t)\right\}. \tag{8}$$

Assuming an output orientation, a DEA-based Malmquist productivity index for each of J vessels that catch S species (y_{js}) using M productive inputs (x_{jm}) takes the form:

$$M_k^{k+1} = \sqrt{\frac{D_0^k\left(x^{k+1}, y^{k+1}\right)}{D_0^{k+1}\left(x^k, y^k\right)} \cdot \frac{D_0^{k+1}\left(x^{k+1}, y^{k+1}\right)}{D_0^k\left(x^k, y^k\right)}}. \tag{9}$$

The first product inside the root represents the change in efficiency, and the second product represents the shift of the production frontier or technological change (evolution of the fish stock) experienced by a vessel between period k and k+1.

$D_0^k\left(x^k, y^k\right)$ and $D_0^{k+1}\left(x^{k+1}, y^{k+1}\right)$ are the radial output oriented distances between the actual performance of a vessel and the benchmark production frontiers in periods k and k+1 respectively. These distances can be calculated by solving a standard DEA problem for each vessel in periods k and k+1:

$$\begin{aligned} & \max_{\lambda,\phi} \phi \\ \text{s.t.} \quad & \phi_2 y_{js} - \sum_{j=1}^{J} \lambda_j y_{js} \leq 0, s = 1,2,\ldots,S \\ & \sum_{j=1}^{J} \lambda_j x_{jm} - x_{jm} \leq 0, m = 1,2,\ldots,M \\ & \lambda_j \geq 0, j = 1,2,\ldots,J. \end{aligned} \tag{10}$$

$D_0^k\left(x^{k+1}, y^{k+1}\right)$ is the radial output oriented distance between the actual performance of a vessel in period k+1 and the production frontier performance in period k. These distances can also be calculated by solving a standard DEA problem for each vessel:

$$\begin{aligned} & \max_{\lambda,\phi} \phi \\ s.t. \quad & \phi_2 y_{js}^{k+1} - \sum_{j=1}^{J} \lambda_j y_{js}^{k} \leq 0, s = 1,2,\ldots,S \\ & \sum_{j=1}^{J} \lambda_j x_{jm}^{k} - x_{jm}^{k+1} \leq 0, m = 1,2,\ldots,M \\ & \lambda_j \geq 0, j = 1,2,\ldots,J. \end{aligned} \tag{11}$$

$D_0^{k+1}\left(x^{k}, y^{k}\right)$ is the radial output oriented distance between the actual performance of a vessel in period k and the production frontier performance in period k+1. This distance can be calculated by solving a standard DEA problem for each vessel analogous to the one above:

$$\begin{aligned} & \max_{\lambda,\phi} \phi \\ s.t. \quad & \phi_2 y_{js}^{k} - \sum_{j=1}^{J} \lambda_j y_{js}^{k+1} \leq 0, s = 1,2,\ldots,S \\ & \sum_{j=1}^{J} \lambda_j x_{jm}^{k+1} - x_{jm}^{k} \leq 0, m = 1,2,\ldots,M \\ & \lambda_j \geq 0, j = 1,2,\ldots,J. \end{aligned} \tag{12}$$

We computed Malmquist indexes for annual and monthly data. The output is the catch of red seabream. Inputs are engine power, vessel length, number of trips and size of the crew. The catch of Atlantic pomfret is included as an exogenous variable to control for its impact on the desirable catch. Tables 6 and 7 contain the results. The index is decomposed into efficiency change (EC) and the change in the fish stock (FS). Results are included for the geometric and arithmetic versions of the Malmquist index.

Note that instead of decomposing the Malmquist index into efficiency change and technical change components, we show the decomposition of the Malmquist index into efficiency change and fish stock change components since fishing regulations prevented technological change in the fishery over this period of time. Also note that the fishing stock column is not the change in the fishing stock itself, but rather the impact of the change in fishing stock on the output of the fishery. Thus for instance, the fishing stock change in 1999 lead to an output increase of 0.59 percent in annual output, and in the year 2000 lead to an output increase of 4.93 percent, and in 2001 to 0.97 percent. Over this three year period that translates into an annual impact of 2.05 percent (Table 6).

Fishing efficiency of the fleet also increased on average at 1.02 percent each year, distributed fairly uniformly across years at 0.92 for year 1999, 1.08 for year 2000 and 1.10 for year 2001.

The use of monthly data yielded different estimates for both annual efficiency and fishing stock changes for the two years that the data overlap – years (2000 and 2001). For instance, the results attained for monthly data were more similar to the annual results in efficiency change but not for fish stock change. Monthly data analysis shows a significantly bigger increase in fish the stock in 2000 and 2001..

Although DEA estimates the impact of increases in fish stock on output increases rather than direct estimates of change in fish stock, there should be a relationship between the annual fish stock change estimates from the surplus production model (Table 5), and the annual DEA impact estimates. Unfortunately, this appears not to be entirely the case. Fish stock percentages are estimated to increase each of the three years, from 4.50% in 2000, to 13.06% in 2001, and to 16.32% in 2002. The DEA fish stock impacts do increase significantly from the first to the second year, as the fish stock percentage does, but the DEA fish stock impact percentage declines from 4.75 percent in year 2000 to 0.95 percent in year 2001. There may be a number of reasons for this incongruity, including the non stochastic nature of the DEA approach.

D. Stochastic Frontier Analysis (SFA)

The third and last approach that we used to estimate the evolution of the fish stock is by estimating the stochastic frontier. This approach can be viewed as a hybrid between the surplus production approach and the DEA based Malmquist index. Like the Malmquist index, it is frontier based, it controls for inefficiency, and the technical change estimate can be interpreted as an estimate of the evolution of the fish stock. Like the surplus production approach, it is parametric and stochastic.

The stochastic frontier is derived as follows: A capture frontier is the maximum potential output (y_{jt}) that can be attained given productive inputs (x_{jm}), the technology and the size of the fish stock (S_t). A stochastic capture frontier is specified as:

$$y_{jt} = q \cdot S_t^{\alpha} \cdot G\left[\tau_j, f\left(x_{j1}, x_{j2} \ldots x_{jm}\right)\right]^{\beta} \cdot e^{v_{jt} - u_{jt}}, \tag{13}$$

where *G(.)* is the fishing effort defined as a combination of its activity (τ_{jt}) and its fishing power or effectiveness [*f(.)*] in time *t,* v_{jt} is a symmetric error term that represents the stochastic factors that influence capture, and u_{jt} is an asymmetric non-negative error term ($u_{jt} \geq 0$) that represents inefficiency. It is usually assumed that v_{jt} is normally distributed with zero mean and constant variance, and u_{jt} is assumed to have a truncated normal at 0, half-normal, exponential, or gamma

Table 6: Annual Malmquist index and its decomposition (1999-2002)

Year		Malmquist Index			Efficiency Change			Fish Stock		
Period 1	**Period 2**	**Geometric mean**	**Arithmetic mean**	**S.D.**	**Geometric mean**	**Arithmetic mean**	**S.D.**	**Geometric mean**	**Arithmetic mean**	**S.D.**
1999	2000	0.52	0.56	0.26	0.92	0.94	0.22	0.56	0.59	0.21
2000	2001	4.96	5.36	2.14	1.04	1.08	0.30	4.75	4.93	1.32
2001	2002	1.01	1.06	0.30	1.07	1.10	0.25	0.95	0.97	0.22
1999	2002	2.09	2.29	0.99	1.02	1.06	0.29	2.05	2.16	0.68

Table 7: Monthly Malmquist index and its decomposition (2000-2002)

Year		Malmquist Index			Efficiency Change			Fish Stock		
Period 1	**Period 2**	**Geometric mean**	**Arithmetic mean**	**S.D.**	**Geometric mean**	**Arithmetic mean**	**S.D.**	**Geometric mean**	**Arithmetic mean**	**S.D.**
2000	2001	6.98	15.23	22.33	1.19	1.40	1.06	5.85	9.03	8.54
2001	2002	1.95	3.08	3.27	1.03	1.09	0.37	1.89	2.72	2.39
2000	2002	9.68	24.58	22.44	1.06	1.17	0.65	9.10	20.15	13.38

We chose a Cobb Douglas specification with time-variant technical efficiency (Kumbhakar and Lovell, 2000: 285-287):

$$y_{jt} = \beta_0 + \beta_\tau \ln \tau_j + \sum_m \beta_m \ln x_{jm} + \beta_z \ln z_j + \beta_t t + v_{jt} - u_{jt}, \tag{14}$$

where t is a time trend to account for technical change (evolution of the fish stock), and *z* is a vector of exogenous influences, in this case, the catch of Atlantic pomfret. The specification of the asymmetric error term follows Battese and Coelli (1992) and permits technical efficiency to vary over time but not over vessels:

$$u_{jt} = e^{-\eta(t-T)} \cdot u_j, \tag{15}$$

where T is the total number of time periods.

Technical change (TC) or the impact of fish stock change in this case (FS) and technical efficiency change (TEC) are given by the following expressions:

$$TC = \frac{\partial \ln f(\tau, x, z, t; \beta)}{\partial t} = \beta_t \tag{16}$$

$$TEC = -\frac{\partial u_{jt}}{\partial t} = \eta e^{-\eta(t-T)} \cdot u_j \tag{17}$$

Stochastic frontiers models were estimated for the unbalanced annual panel (1999-2002) for half normal and truncated normal specifications of the asymmetric error term using maximum likelihood (Battese and Coelli, 1992). Table 8 contains the results.

Table 8: Stochastic Frontier Estimates

Model	**Half Normal**			**Truncated Normal**		
Variable	**Coefficient**	**Std. Error.**	**t-statistic**	**Coefficient**	**Std. Error**	**t-statistic**
Intercept	***3.274	0.192	17.089	***3.328	0.174	19.077
Ln (trips)	***1.041	0.020	53.153	***1.038	0.018	56.198
Ln (length)	0.054	0.109	0.492	0.075	0.112	0.671
ln (hp)	***0.112	0.045	2.496	**0.094	0.046	2.024
Ln (crew)	0.038	0.040	0.954	0.030	0.041	0.726
Atlantic pomfret	***-0.049	0.010	-4.938	***-0.045	0.010	-4.617
t	*0.027	0.021	1.335	0.002	0.018	0.128
γ	***0.949	0.011	89.717	***0.982	0.004	2349.317
σ^2	***0.854	0.156	5.485	***2.380	0.451	5.279
μ	-	-	-	***-3.057	0.503	6.075
η	***-0.745	0.056	-11.052	***-0.719	0.052	-13.295

*** Significant at 1% significance level, ** Significant at 5% significance level,
* Significant at 10% significance level

The null hypothesis that the truncated normal specification is preferable to the half normal is not rejected using a log-likelihood ratio test. Most coefficients are significant and have the expected signs. The negative and significant coefficient on Atlantic pomfret confirms that it is a detrimental environmental variable. It is noteworthy that the coefficient on t is insignificant in the truncated normal specification, suggesting that there was no change in the fish stock over the recovery period, but the coefficient on t is 0.027 which is statistically different from zero. This implies that the change in the fish stock over the 1999-2000 period increased fish output by 2.70 percent each year as estimated by the SFA with a half-normal distribution of the one-side error term. This translates into an increase in fish capture of 11.25% for the whole period caused by the increase in the fish stock, corresponding closely to the 14.88 percent in the fish stock (not fish caught) previously estimated over this three year period using the surplus production model. Results attained using a truncated normal distribution of the one-side error term shows a smaller change in the capture caused by the evolution of the fish stock (a 0.8 percent for the whole period), however, the estimated coefficient on the time variable in the model is not statistically significant.

The parameter σ^2 is the total variance of the composite error term and γ is the proportion of the total variance of the composite error term explained by inefficiency. Inefficiency clearly matters; t and log-likelihood ratio tests on γ confirm its significance at the 1% level (Kodde and Palm, 1986). The variable μ is the expected value of the truncated normal distribution term, and η is the rate of change of technical efficiency for vessels during the period.

V. Conclusion

The Red Seabream fishery in Southern Spain is a valuable industry. Most of the fishing fleet consists of family owned and operated boats out of small village ports. It is critical that this fishery be well managed to ensure a sustainable commercial fishery. Recently imposed fishing regulations on the fleet appear to be restoring the fishing stock towards an economic sustainable level.

The objective of this paper was to investigate the evolution of the fish stock over the recovery period, 1999 – 2002. The conventional approach is to estimate a surplus production model and we estimate this model as a benchmark. However, because the recovery plan included detailed restrictions on fishing gear, it essentially froze the technology for catching fish. This enables us to employ frontier production methodologies in a relatively novel way. We estimate shifts in the production frontier over the period using data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Production frontier shifts are usually attributed to technical change, but in this case, since implemented fishing regulations essentially have halted technological progress in the fleet, we alter the standard Malmquist decomposition into efficiency and technological change instead into efficiency and the impact of fishing stock change.

We find that over the 3 year period of 1999 through 2001, increase in fishing stocks lead to a 6.27 percent increase in fishing output by DEA computations, and 11.25 and 0.8 percent increase by SFA computations according a half normal and truncated normal distribution of the one-side error term respectively. Additionally, the time trend parameter in the former model is much more statistically significant than in the latter. Estimates of actual fish stock change over this three year period using the surplus production model is 14.88 percent. Therefore, the results attained using SFA with a half normal specification of the one-side error term are the closest to those attained with the traditional approache used in the fishery economics literature. One of the reasons that could explain this result is the consideration of other stochastic factors different than the impact of the relative density of red seabream that have a significant economic impact in the fishery.

References

Bargelloni, L., Alarcon, J.A., Alvarez, M.C., Penzo, E., Magoulas A., Reis C. and Patarnello T. 2003. Discord in the Family Sparidae (Teleostei): divergent phylogeographical patterns across the Atlantic-Mediterranean divide, Journal of Evolutionary Biology, 16, 1149-58.

Battese G.E. and Coelli T.J. 1992. Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India, Journal of Productivity Analisys, 3, 153-69.

Battese, G. and Corra, G. 1977. Estimation of a Production Frontier Model: With Application to the Pastoral Zone of Eastern Australia, Australian Journal of Agricultural Economics, 21 (3), 169-79.

Bravo, R., Casmiro-Soriguer M., Villar N., Gómez-Cama M.C. and Hernando-Casal J.A. 2000. An Approach to Studying the Selectivity of the Voraz (Pagellus bogaraveo, Brünnich, 1768) Fishing Technique Used in Tarifa, Spain, in F. Pinella: International Congress on Maritime Technological Innovations and Research 2º. Cádiz: Universidad de Cádiz.

Castilla Espino, D. 2005. Estimating Fishing Capacity of Red Seabream Fishery in the Strait of Gibraltar: Parametric and Non-parametric Approaches, Ninth European Workshop on Efficiency and Productivity Analysis, Brussels, Belgium, June 28 - July 2.

Caves, D.W. Christensen, L.R. and Diewert, W.E. 1982. The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity, Econometrica, 50, 1393-1414.

Csirke B. 1980. Introducción a la Dinámica de Poblaciones de Peces, FAO Fisheries Technical Paper, 192, Rome: FAO.

Diputación Provincial de Cádiz 1991. El Sector Pesquero de la Provincia de Cádiz. Cádiz: Excma. Diputación de Cádiz.

Diputación Provincial de Cádiz 1994. Las Artes de Pesca en el Litoral Gaditano. Cádiz: Excma. Diputación de Cádiz.

European Commission, 1999. Regional Socio-economic Studies on Employment and the Level of Dependency on Fishing. Final Report. Spain. Lot nº 5. Andalusia (Atlantic Coast), Canary Islands, Estremadura. www.europa.eu.int/comm/fisheries.

Fare, R. Grosskopf, S. and Lovell, C.A.K. 1994. Production Frontiers, Cambridge: Cambridge University Press.

García del Hoyo, J.J., García Ordaz, F., González Galán, M.D. and Vilches Lobato, M.L. 2001. Gestión de Pesquerías Artesanales, Huelva: Servicio de Publicaciones de la Universidad de Huelva.

Gil, J. and Sobrino I. 2001. Studies on Reproductive Biology of the Red (blackspot) Seabream [Pagellus bogaraveo (Brünnich, 1768)] from the Strait of Gibraltar (ICES IXa/SW Spain). NAFO Scientific Symposium on Deep-Sea Fisheries, Varadero, Cuba. Poster 1.

Hilborn, R, and Walters, C. 1992. Quantitative Fish Stock Assessment: Choice, Dynamics and Uncertainty, New York: Chapman y Hall.

Kodde, D.A. and Palm, F.C. 1986. Wald Criteria for Jointly Testing Equality and Inequality Restrictions, Econometrica, 54, 1243-8.

Khumbakar, S.C. and Lovell, C.A.K. 2000. Stochastic Frontier Analysis, New York: Cambridge University Press.

Malmquist S. 1953. Index Numbers and Indifference Surfaces, Trabajos de Estadística, 4, 209-42,

Pascoe S. and Herrero, I. 2004. Estimation of a Composite Fish Stock Index using Data Envelopment Analysis, Fisheries Research, 69, 91-105.

Russell, E.S. 1931. Some theoretical Considerations of the Overfishing Problem, ICES Journal of Marine Science, 6, 3-20.

Russell, E.S. 1939. An Elementary Treatment of the Overfishing Problem, ICES Journal of Marine Science, 110, 5-14.

Schaefer, M.B. 1954. Some aspects of the Dynamics of Populations Important to the Management of the Commercial Marine Fisheries, Bulletin of the Inter-American Tropical Tuna Commission, 1(2), 1-56.

Sherman, K. and Alexander L.M. (eds) 1986. Variability and Management of Large Marine Ecosystems, Boulder: Westview Press.

Spedicato, M.T., Greco S., Sophronidis K., Lembo G., Giordano D. and Argyri A. 2002. Geographical Distribution, abundance and some population characteristics of the Species of the genus Pagellus (Osteichtchyes: Perciformes) in the different areas of the Mediterranean, Scientia Marina, 66(2): 65-82.

Verhulst, P.F. 1838. Notice sur la loi que la population suit dans son accroissement, Correspondence of Mathematics and Physics, 10, 113–21.

OTHER A.E.M. WORKING PAPERS

WP No	Title	Fee (if applicable)	Author(s)
2005-14	Examining the Effects of Deregulation on Retail Electricity Prices		Taber, J., Chapman, D. and T. Mount
2005-13	Turning a Blind Eye: Costly Enforcement, Credible Commitment and Minimum Wage Laws		Basu, A., Chau, N. and R. Kanbur
2005-12	U.S. Dairy Farm Cost Efficiency		Tauer, L. and A. Mishra
2005-11	Household-Level Livestock Marketing Behavior Among Northern Kenyan and Southern Ethiopian Pastoralists		Barrett, C., Bellemare, M. and S. Osterloh
2005-10	An Ordered Tobit Model of Market Participation: Evidence from Kenya and Ethiopia		Bellemare, M. and C. Barrett
2005-09	The Complex Links Between Governance and Biodiversity		Barrett, C., Gibson, C., Hoffman, B., and M. McCubbins
2005-08	Capital Market Governance: How Do Security Laws Affect Market Performance?		Daouk, H., Lee, C. and D. Ng
2005-07	Context and Volutnary Contributions: An Experimental Analysis of Communication, Voting, and Status Quo Bias*		Messer, K., Schulze, W., and H. Kaiser
2005-06	Behavior, Production and Competition		Just, D.R. and D. Zilberman
2005-05	Distributional Implications of the Internet: Can Price Discrimination Improve Farmers' Welfare?		Just, D. and R.E. Just
2005-04	Loss Aversion and Reference Points in Contracts		Just, D. and S. Wu
2005-03	Poverty, Inequality and Development: Micro-Macro Perspectives and Linkages		de Janvry, A. and R. Kanbur

Paper copies are being replaced by electronic Portable Document Files (PDFs). To request PDFs of AEM publications, write to (be sure to include your e-mail address): Publications, Department of Applied Economics and Management, Warren Hall, Cornell University, Ithaca, NY 14853-7801. If a fee is indicated, please include a check or money order made payable to <u>Cornell University</u> for the amount of your purchase. Visit our Web site (*http://aem.cornell.edu/research/wp.htm*) for a more complete list of recent bulletins.