EFFICIENCY AND CAPACITY OF FULLY EXPLOITED FISHERIES MANAGED USING VESSEL CATCH LIMITS COMBINED WITH EFFORT RESTRICTIONS

David Castilla Espino, MEMPES-AEA, Universidad de Huelva, david.castilla@dehie.uhu.es
Félix García Ordaz, MEMPES-AEA, Universidad de Huelva, felix@uhu.es
Basil M. H. Sharp, Department of economics, The University of Auckland,
b.sharp@auckland.ac.nz

ABSTRACT

A wide range of fisheries are managed using vessel catch limits combined with different kinds of effort restrictions. This management framework is expected to have desirable consequences for the bio-economic sustainability of fisheries. When appropriately implemented this approach produces outcomes that are similar to those associated with individual fishing quotas. However, there is little empirical evidence of this fact. Provided vessel catch limits are defined according sustainable criteria this management framework applied in a fully exploited or overexploited fishery results in most of the vessels actually landing the maximum amount of fish allowed. This observation makes it necessary for the analysis to adopt an input orientation because vessels can only be more technically efficient if they use the optimal quantity of productive inputs for the given maximum output. However, few studies illustrate this point despite the fact that the measurement of technical efficiency has been theoretically well described in efficiency and productivity analysis literature. An input-oriented DEA model is solved in this paper to determine technical efficiency of Striped venus (*Chamelea gallina*, Linnaeus, 1758) fishery of the Gulf of Cádiz (South Atlantic Spanish Region / Spanish IX-a ICES subdivision). Technical efficiency is interpreted as an observed measure of input capacity utilization and enables a comparison of differences in technical efficiency across the different technologies that co-exist in this fishery.

Keywords: DEA, input orientation, technical efficiency, Stripped venus, fisheries management

INTRODUCTION

A wide range of clam fisheries are managed using vessel catch limits (VCL) combined with different kinds of input controls including fishing effort restrictions. This is the case of the striped venus (*Chamelea gallina*, Linnaeus, 1758) fishery of the Gulf of Cádiz (Spain) or the Mediterranean sea of Italy. This management approach produces outcomes regarding the bio-economic sustainability of a fishery that are similar to those associated with individual fishing quotas in an appropriate institutional framework [1, 2].

The efficiency and fishing capacity levels of a fishery provide the policy-maker with a useful instrument to design the management and to control the responses of the fishing industry to this management. This reason makes necessary to implement the mathematical and econometric techniques available to measure efficiency and fishing capacity appropriately to get a reliable measure. The way the efficiency and fishing capacity is measured will strongly depend on the management and specific characteristics of a certain fishery.

Provided VCL are defined according sustainable criteria in a fishery managed using this management measure together with fishing effort restriction in an appropriate institutional framework, when it is applied in a fully exploited or overexploited fishery results in most of the vessels actually landing the maximum amount of fish allowed. This observation makes it necessary for the analysis to adopt an input orientation because vessels can only be more technically efficient if they use the optimal quantity of productive inputs for the given maximum output.

Additionally, different VCL are commonly defined by the policy-maker considering differences of fishing power depending on the fleet segment or the use of different fishing gears (technologies). The decision of

the policy-maker on this issue is crucially important for the overall efficiency of the fleet and would be desirable that take into account a benchmark analysis to set the appropriated VCL in the design of this management framework that consider not only sustainability criteria but also efficiency criteria.

The adoption of an input orientation is crucially important for the measurement of the efficiency and fishing capacity considering that returns to scale are generally assumed to be non-increasing (NIRS) or variable (VRS) in fisheries. This is due to the fact that the results attained using the non-parametric DEA, which is the best option when cost data are not available under input orientation; vary depending the orientation when CRS are not imposed. However, few studies illustrate this point in this specific fisheries management framework despite the fact that the measurement of input-oriented technical efficiency has been theoretically well described in efficiency and productivity analysis literature.

The fleet that composed the striped venus fishery of the Gulf of Cádiz (South Atlantic Spanish Region / Spanish IX-a ICES subdivision) is located at the Spanish ports of Isla Cristina, Punta Umbría and Bonanza and represents the 43% and 37% of the weight and value respectively of molluscs landed in this area. The fishery has experienced a significative reduction of the capture per unit of effort (CPUE) since 2001 as a consequence of overexploitation. The striped venus is captured in this area using two different fishing gears: the hydraulic dredge and the towed rake. This fishery is managed by a set of effort restrictions and two VCL that depend on the fishing gear.

The aim of this paper is to calculate technical efficiency of a fishery managed with a binding VCL combined with fishing effort restrictions using an input-oriented DEA determining the impact that the VCL set and the fishing gear used has on technical efficiency.

THE STRIPED VENUS FISHERY

Striped venus (*Chamelea gallina*, Linnaeus, 1758) is a bivalve mollusc that lives near the shore in sandy grounds of the Eastern Atlantic and the Mediterranean Sea. Striped venus is highly valued in Spain and has been exploited by artisanal vessels located in the Gulf of Cádiz (Spain) since the 1950s.

Operating out of the ports of Punta Umbría, Isla Cristina and Sanlúcar de Barrameda, high profitability resulted in the fleet targeting striped venus expanding during the 1960s. Landings reached 30,000 T. in 1968. The fleet consisted of multi-gear artisanal vessels equipped with a towed rake. Increased fishing effort resulted in overexploitation, a drastic reduction of landings, and a fall profitability that persisted throughout the 1970s [3].

The depressed state of the fishery encouraged some vessels of the fleet to exit the fishery or target other bivalve molluscs. The decline in profitability coincided with the increased competition in the Spanish fish markets of striped venus harvested in Italy where this mollusc bivalve was captured using a hydraulic dredge. Relative to the towed rake, the hydraulic dredge is more productive, the catch is cleaner, and the percentage of broken clams is smaller [4]. Thus Italian sourced striped venus is more competitive.

Competition from the Italian striped venus fishery encouraged the adoption of dredge technology in the striped venus fishery of the Gulf of Cádiz during the 1990s. This resulted in a considerable transformation of fishing technology away from vessels equipped with tow rakes to single-gear vessels equipped with a hydraulic dredge. The introduction of the hydraulic dredge increased the fishing power of vessels which resulted in serious depletion of the striped venus stock by the end of the 1990s [5]. Fig. 1 shows fishing effort in the striped venus fishery of the Gulf of Cádiz increased by 232% between 1992 and 2001 coinciding with a decreasing of the capture per unit of effort (CPUE) of 15% in the same period.
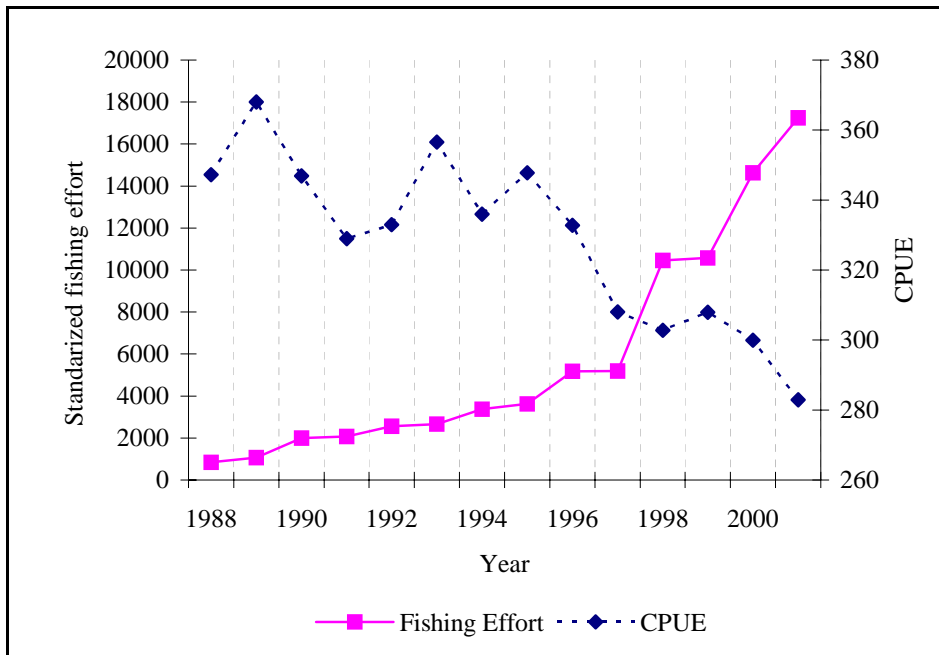
Figure 1: CPUE and fishing effort evolution of the striped venus fishery of the Gulf of Cádiz

MANAGEMENT

Exploitation of the striped venus fishery of the Gulf of Cádiz (South Atlantic Spanish Region / Spanish IX-a ICES subdivision) takes place in coastal waters near the shore up to 20 meters deep and its regulation and management is responsibility of Andalusia regional government according to the European Union and Spanish regulations. Management of the fishery currently consists of a daily trip vessel catch limits (VCL) combined with different input controls. Other technical measures like time and area closure or specimen size complete the management framework of the striped venus fishery of the Gulf of Cádiz (Table I).

Table I: Management measures of the striped venus fishery of the Gulf of Cádiz

Type	Description
Input controls	Limited licences program for vessels equipped with towed rake (tr) and hydraulic dredge (hd)
	No more than 5 fishing trips per week (from Monday to Friday)
	No more than 11 hours per trip (from 7.00 to 18.00)
	The fishing gear and the way it operate is defined by the regulation
Output controls	Vessel catch limits (kg.): 300 (3/00 – 07/00), 250 (hd)-100 (tr) (23/07/00 - 12/03/02), 150 (hd)-100 (tr) (13/03/02-9/08/04), 200 (hd)-100 (tr) (9/08/04-30/06/2005)
Technical measures	Time closures (from 1 to 2 months depending on the year and place)
	Protected areas: grounds not deeper than 5 m. and fishing reserve of Guadalquivir river
	Selectivity restrictions: 25 mm.
Institutional arrangements	striped venus consortium (1999-2003) and advisory committee (2003-)
Commercialization and control	Ports and authorized markets: Punta Umbría, Isla Cristina & Bonanza
	Commercialization procedure and the definition of different striped venus commercial categories

VCL have been used in this fishery since the 1960s when the VCL was first set at 600 kg/trip. Currently, two different VCL coexist depending on the fishing gear used by the vessel; the VCL for vessels with a hydraulic dredge is set at 200 kg/trip and 100kg/trip for vessels equipped with a tow rake.

The main input controls of the striped venus fishery of the Gulf of Cádiz consist of a limited licenses program, a limited number of fishing daily trips per week and different fishing gear restrictions. Limited licenses, set at 80 and 47 for hydraulic dredge and towed rake vessels respectively, have been in operation since 2001. Despite the evidence of overexploitation of the fishery, the census of vessels that operate in this fishery shows an increasing number of vessels during the 1990s. This increase has been mostly due to the increase of licensee vessels equipped with hydraulic dredge in the fishery since the introduction of this fishing gear. The number of fishing trips per week is limited to 5 and the number of hours per trip to 11. Finally, the characteristics of the fishing gear and the way they are operated are completely defined by the management framework.

Some additional institutional arrangements have been implemented in order to increase the participation of the fishermen in the management and control of the fishery and the trade of the striped venus. From 1999, the striped venus consortium was established and from 2003 an advisory committee was established that devolved the management and control of the fishery to fishermen, employees and fisheries experts.

This management framework combines VCL with fishing effort restrictions and is expected to lead to similar results regarding the adjustment of the incentives of the fishermen that the individual transferable quotes in other New Zealand or Iceland fisheries providing high levels of efficiency together with economic and biological sustainability [2]. However, empirical evidence from this fishery shows that policy has failed.

TECHNICAL EFFICIENCY OF THE STRIPED VENUS FISHERY OF THE GULF OF CÁDIZ

Methods

A decision making unit (DMU - v.g. vessel) is technically efficient when it produces the maximum potential output given the productive inputs assuming an output orientation. A DMU is also technically efficient when it produces the actual output with the minimum quantity of productive inputs assuming an input orientation. The measurement of the ability of a DMU to be technically efficient requires that the production function of the completely efficient DMU to be known. The foremost approaches that attempt to solve this difficulty to measure this ability are data envelopment analysis (DEA) and stochastic frontier analysis (SFA) [6, 7, 8].

SFA is a parametric procedure based on econometric models while DEA is non-parametric and uses mathematical programming techniques. Most of the efficiency and productivity analysis of fisheries literature uses the non-parametric DEA instead of SFA because it does not require the specification of the production technology which is quite difficult in the case of fisheries [9]. Applying SFA to fisheries managed using VCL and fishing effort restrictions requires the use of cost data which generally are not available in fisheries. DEA offers additional advantages because it can handle technologies in multi-species fisheries, it is relatively simple and imposes few theoretical restrictions [10].

DEA measures technical efficiency of a DMU by comparing its performance with that obtained by the rest of the DMU. Fig. 2 illustrates this under the assumption of an input orientation in the case of a technology that produces one output (y) using one input (x). First of all, DEA defines an envelopment surface or frontier which is supposed to contain the DMUs that operate efficiently. The calculation of the technical efficiency of a DMU is calculated by the radial distance between the actual performance of a technically inefficient DMU (x, y_1) and the hypothetical performance on the frontier of that DMU (x^*, y_1).
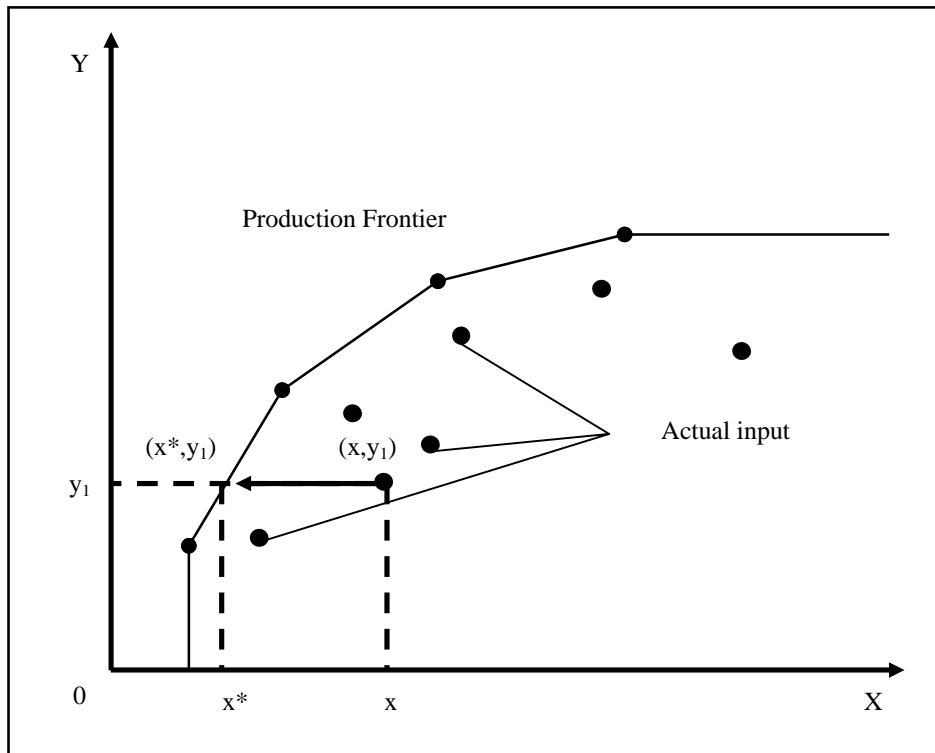
Figure 2: The production frontier and input-oriented technical efficiency

DEA calculates this radial distance [or technical efficiency (TE_i) - ϕ_i] assuming an input orientation solving for each DMU the linear programming problem (1). Eq. 1 assumes constant return to scale (CRS), input orientation, and that each of i DMU (vessels) produce (catch) K outputs (species - y_{ik}) using J productive inputs (x_{ij}). Each DMU (vessel) must use at least one input ($x_{ij}>0$) and produce (catch) at least one output (species - $y_{ik}>0$).

$$\min_{\lambda}{}_{,}\ \phi_i$$

$$s.t. \quad y_{ik} - \sum_{i=1}^{N} y_{ik}\lambda_i \leq 0, k = 1,2,...,K$$

$$\phi_i x_{ij} - \sum_{i=1}^{N} x_{ij}\lambda_i \geq 0 \text{ for } j = 1,2,...,J$$

$$\lambda_i \geq 0, i = 1,2,...,N$$

(Eq. 1)

Utilization of DEA to measure technical requires - as in linear programming problem of Eq. 1 - assumptions about the returns to scale of the production technology. The assumptions of variable returns to scale [VRS – 11, 12, 13 – (Eq. 2)] or non-increasing return to scale [NIRS - 14 –(Eq. 3)] are the most common in fisheries literature.

$$\sum_{i=1}^{N}\lambda_i = 1$$

(Eq. 2)

$$\sum_{i=1}^{N}\lambda_i \leq 1$$

(Eq. 3)

The optimal solution of linear programming of Eq. 1 for ϕ_i can be interpreted as observed capacity utilization of productive inputs (CU_{obs}) given the management framework of a fishery managed and the state of the fish stock (Eq. 4).

$$TE_i = CU_{i,obs} = \phi_i$$

(Eq. 4)

Data

The data used in this paper consisted of labor, technical characteristics of vessels, and aggregated annual harvest of striped venus in the Gulf of Cádiz from 2002 to 2004 landed by vessels located in authorized ports to land and commercialize striped venus in this area. Data on harvest were provided by the Andalusia regional government which has a daily data base (ID@PES) on harvest sold at fish markets in Andalusia ports. Inputs were obtained from Spanish artisanal census and labor from the Ministerio de Asuntos Sociales. Table II shows sample vessel landings between the 67 and 84 %.

Table II: Sample representativity

Year	Sample		Gulf of Cádiz		Sample/Gulf of Cádiz	
	Weight (kg)	Value (€)	Weight (kg)	Value (€)	Weight (kg)	Value (€)
2002	2530733	7525701	3019871	8988744	83.80%	83.72%
2003	2587466	6044883	3373809	7903756	76.69%	76.48%
2004	2306610	5988563	3449396	8827500	66.87%	67.84%

Table III provides descriptive statistics of the technical characteristics (tonnage measure in GT, length measured in m. and engine power measured in HP) and the crew of vessels for each year.

Table III: Descriptive statistics of the characteristics and crew of sampled vessels

Year			Fishing gear						
			Towed rake			Hydraulic dredge			
	Variable	Vessels	Mean	S.D.	Variance	Vessels	Mean	S.D.	Variance
2002	Trips		97.24	48.00	2303.86		167.90	54.46	2965.66
	GT		3.05	2.14	4.59		14.21	5.64	31.83
	Lenght (m)	37	7.88	1.58	2.48	79	12.96	1.74	3.04
	HP		38.97	19.15	366.58		120.95	42.77	1829.02
	Crew		2	0.84	0.70		6	2.22	4.92
2003	Trips		93.94	52.32	2737.48		178.96	49.66	2465.90
	GT		3.30	2.33	5.43		14.59	5.78	33.46
	Lenght (m)	36	8.07	1.66	2.76	70	13.10	1.77	3.13
	HP		41.33	20.35	413.94		121.84	44.29	1961.70
	Crew		2	0.87	0.75		6	2.15	4.63
2004	Trips		96.70	52.53	2759.22		178.28	50.39	2538.87
	GT		3.43	2.50	6.24		14.61	5.85	34.22
	Lenght (m)	27	8.18	1.68	2.82	64	13.17	1.61	2.60
	HP		43.15	21.24	450.98		121.66	45.32	2053.66
	Crew		2	0.92	0.85		6	2.21	4.87

Application

Two different exercises were used to determine the differences on technical efficiency of vessels equipped with towed rake and hydraulic dredge; and the impact by VCL setting by the policy-maker on vessels equipped with hydraulic dredge. Output is measured as aggregate harvest in kg while the inputs are measured as follows: engine power is measured in hp, vessel length is measured in m, the number of crew members, and the number of fishing trips developed in the period. The last two inputs are considered to be variables.

Data have been aggregated in periods without changes in the VCL of the hydraulic dredge in order to get three homogeneous samples in the first exercise. This exercise has consisted of solving three standard DEA linear programmes (Eq. 1) under the assumption of VRS for each of the vessels. The assumption of VRS allows the existence of the different VCL of vessels equipped with towed rake (100 kg.) and hydraulic dredge (250 – Period 1, 150 – Period 2 and 200 – Period 3 kg.) in the same sample. The differences on technical efficiency between the two technologies subject to the VCL set by the policy-

maker have been identified in a second stage looking at the correlation between the technical efficiency and the different technologies (Eq. 2).

The second exercise has consisted of a DEA linear problem which includes the VCL as a neutral non-discretionary input (z) in the model by means of the third restriction in Eq. 5 for each vessel equipped with hydraulic dredge during the whole period aggregating data depending on the VCL [15]. The assumption of VRS has also been done in this exercise for the same reasons as in the first exercise allowing the comparison of vessels with the same environment.

$$\min_{\lambda} \phi_i$$

$$s.t. \quad y_{ik} - \sum_{i=1}^{N} y_{ik} \lambda_i \leq 0, k = 1,2,...,K$$

$$\phi_i x_{ij} - \sum_{i=1}^{N} x_{ij} \lambda_i \geq 0 \ for \ j = 1,2,...,J$$

$$z_i - \sum_{i=1}^{N} z_i \lambda_i = 0$$

$$\lambda_i \geq 0, i = 1,2,...,N$$

(Eq. 5)

Results

The two exercises described in the former section have been implemented using GAMS Minos 2.5 [16, 17] and Excel 2000 spreadsheet.

Table IV shows that the vessels equipped with towed rake are more technically efficient than the vessels equipped with hydraulic dredge subject to the regulation of the fishery each of the period considered in the exercise. Fig. 3 also shows this specific result and relatively higher dispersion on technical efficiency of vessels equipped with hydraulic dredge.

Table IV: Descriptive statistics of technical efficiency depending on the fishing gear

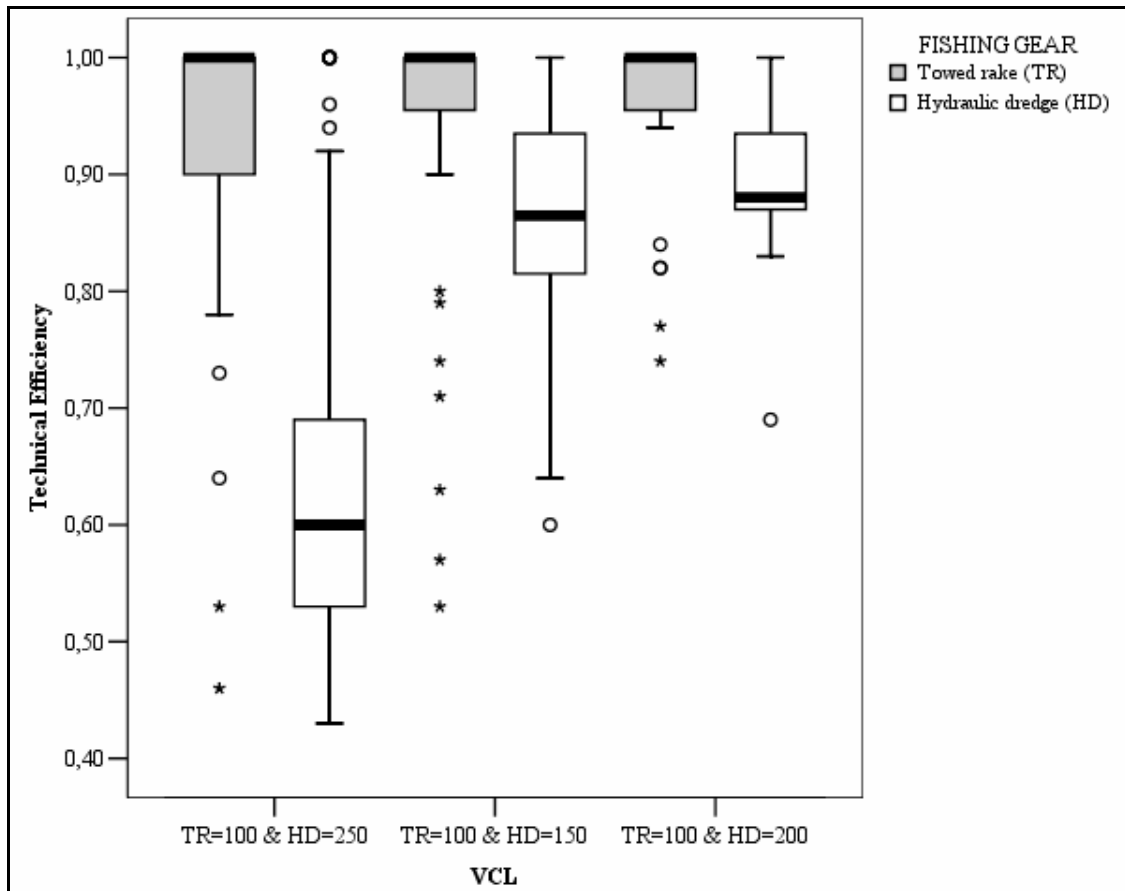| Period	FISHING GEAR							
	Towed rake				Hydraulic dredge			
	Vessels	Mean	SD	Variance	Vessels	Mean	SD	Variance
1	33	0.92	0.15	0.02	76	0.64	0.15	0.02
2	39	0.94	0.13	0.02	76	0.87	0.10	0.01
3	23	0.95	0.09	0.01	59	0.90	0.06	0.00

Figure 3: Box-plots of technical efficiency

Table V presents the results of the second exercise describe in the application section and shows that the higher the VCL is set the smaller the technical efficiency is for vessels equipped with hydraulic dredge of the striped venus fishery of the Gulf of Cádiz.

Table V: Descriptive statistics of technical efficiency depending on the VCL set

VCL	Vessels	Mean	SD	Variance
150	76	0.91	0.07	0.01
200	76	0.85	0.08	0.01
250	59	0.82	0.12	0.01

SUMMARY AND CONCLUSIONS

The technical efficiency of the striped venus fishery located in the Gulf of Cádiz has been calculated using the non-parametric DEA. The specific characteristics of the fishery where the VCL are binding the capture of the vessels requires the use of an input orientation while the co-existence of two different VCL depending on the fishing gear requires the assumption of VRS to allow the comparison of the vessels globally and depending on the VCL set by the policy-maker. Furthermore, the technical efficiency of vessels can be interpreted as a a measure of observed capacity utilization.

Results show that the technical efficiency of the vessels equipped with towed rake is higher than the attained by vessels equipped with hydraulic dredge (Table IV). This fact can be due to the better adjustment of the productive inputs of the vessels equipped with towed rake to the VCL set by the policy-maker and the small variability along time of the VCL set for these vessels that has been hold in 100 T. for long time.

The evolution of technical efficiency of the vessels of the fleet is the same along the different VCL periods and show an increase of technical efficiency (observed capacity utilization) of the fleet over time. Results show that the smaller the VCL is higher the technical efficiency is (Table V) of the vessels equipped with hydraulic dredge. This may be a consequence of the better adjustment of these vessels to the VCL set by the policy-maker given the conditions of the resource in the different VCL periods and suggest the necessity of a smaller VCL for this segment of the fleet.

REFERENCES

[1] Spagnolo, M., 2004, Property Rights as a Management Tool in the Mediterranean: the Case of Adriatic Clam Fishery, *Proceedings of the Conference on Fisheries Economics and Management in Honour of Professor Gordon Munro*, University of British Columbia, August, 5-6, Vancouver (Canada).

[2] OECD, 1997, *Towards Sustainable Fisheries: Economic Aspects of the Management of Living Marine Resource*, París (France): OECD.

[3] García Ordaz, F., 1997, Innovación Tecnológica en la Pesquería de Chirla del Litoral Suratlántico: Conflicto entre Artes y Consecuencias para una Gestión Óptima del Recurso, Huelva (Spain): Servicio de publicaciones de la Universidad de Huelva.

[4] Royo, A., 1995, *Informe sobre la viabilidad de la draga hidráulica*, Informes Técnicos del CICEM Aguas del Pino, 95/1, Huelva (Spain).

[5] García Ordaz, J.J., and F. García del Hoyo 1998, Un Modelo Bioeconómico para la Pesquería de Chirla (Chamelea Gallina) de la Región Suratlántica Española, *Revista de Estudios Agrosociales y Pesqueros*, 184, pp. 183-211.

[6] Fried, H., C.A.K. Lovell and S. Schmidt, 1993, *The Measurement of Productive Efficiency: Techniques and Applications*, New York: Oxford University Press.

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

[8] Ray (2004): Data Envelopment Analysis. Theory and Techniques for Economics and Operation Research, New York: Cambridge University Press.

[9] Pascoe, S., J.E. Kirkley, D. Gréboval and C.J. Morrison-Paul, 2003, *Measuring and Assessing Capacity in Fisheries. 2. Issues and methods,* FAO Fisheries Technical Paper, 433/2, Rome (Italy): FAO.

[10] García del Hoyo, J.J., D. Castilla Espino and R. Jiménez Toribio, 2004, Determination of Technical Efficiency of Fisheries by Stochastic Frontier Models: A Case on the Gulf of Cádiz (Spain), *ICES Journal of Marine Science*, 61(3), pp. 416-421.

[11] Castilla Espino, D., J.J. García del Hoyo and B.M.H. Sharp, 2005, Capacity and Capacity Utilization of "Voracera" Fleet in the Strait of Gibraltar, *Marine Resource Economics*, 20(4), pp. 367-384.

[12] Pascoe, S.,L. Coglan and S. Mardle, 2001, Phisical versus harvest based measures of capacity: the case of the UK vessel capacity unit system, *ICES Journal of Marine Science*, 58, pp. 1243-1252.

[13] Van Hoff, L. and J. Willem de Wilde, 2005, Capacity Assessment of the Dutch Beam-trawler Fleet using Data Envelopment Analysis (DEA), *Marine Resource Economics*, 20(4), pp. 327-345.

[14] Tingley, D., S. Pascoe and S. Mardle, 2003, Estimating capacity utilisation in multi-purpose, multi-métier fisheries, *Fisheries Research*, 63, pp. 121-134.

[15] Coelli, T.J., P. Rao and G. Battese, 1998, An Introduction to Efficiency and Productivity Analysis, Boston (USA): Kluwer Academic Publishers.

[16] Brooke, A., D. Kendrick, A. Meeraus and R. Raman, 1998, *GAMS, a User´s Guide*, Wasington D.C. (EE.UU. de America): GAMS Development Corporation.

[17] Walden, J.B. and J.E. Kirkley, 2000, *Measuring Technical Efficiency and Capacity in Fisheries by Data Envelopment Analysis Using the General Algebraic Modeling System (GAMS): A Workbook*, NOAA Technical Memorandum NMFS-NE-160.