Assessing Technical and Economic Efficiency of the Artisanal Dredge Fleet in the Portuguese West Coast

M.M. Oliveira, A.S. Camanho, and M.B. Gaspar

Abstract   The bivalve dredge fleet is by far the most extensively studied fleet among the Portuguese artisanal segment. It is considered one of the most important artisanal fisheries, essentially due to the number of fishermen and vessels involved and to the high volume and value of the catches. The present study aimed to explore the efficiency of the dredge fleets that operated in the west coast of Portugal between 2006 and 2012. The methodology was based on the use of data envelopment analysis to assess vessels' efficiency. The inputs considered included the number of days at sea, a biomass stock indicator, and the characteristics of the vessels (power, length and tonnage). The annual fishing quota per vessel was also included in the model as a contextual factor. In the technical efficiency analysis, the outputs were defined by the weight of captures for three different bivalve species. Using data on the prices of each species in the wholesale market, revenue efficiency was also estimated to complement the technical efficiency analysis. The results allowed to gain insights concerning the performance of both Northwest and Southwest fleets, considering both technical and economic aspects of the fishery. It was also possible to identify the benchmark vessels, whose practices should be followed by the other vessels of the fleet.

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1   Introduction

The estimation of a Decision Making Unit (DMU) efficiency, according to Farrel [9] can be based on a comparison between observed and optimal values of production (outputs), given the resources consumed (inputs). This author distinguished two components of efficiency: technical and allocative. In fisheries, the first component can be interpreted as the ability of a vessel to obtain maximal catch from a given set of inputs (e.g. vessel's characteristics, fishing days, crew, and fuel consumption), whereas the second component reflects the ability of a vessel to use the outputs in optimal proportions, given their respective prices and the production technology. These measures can be combined to provide a measure of economic efficiency (also called revenue efficiency when an output orientation is adopted for the assessment). From this perspective, revenue efficiency can be defined as the ability of a vessel to maximise the revenue obtained, given the inputs consumed, the value of the catches and the features of the production technology. Hence, efficiency analysis in fisheries is an asset that contributes to the sector sustainability by guiding managerial decision making. The efficiency studies require data on input and output factors that are frequently not available for artisanal fisheries (the lack of data is an unsolved issue, with important consequences in this context (Guyader et al. [10])). The factors most frequently used as inputs are vessel characteristics, fishing effort, operational costs and stock abundance indices (e.g. Sharma and Leung [27]; Kirkley et al. [14, 15]; Pascoe and Coglan [23]). Concerning the output factors, most studies in both single and multispecies fisheries use the landed weight of the catches (e.g. Sharma et al. [28]; Pascoe and Herrero [24]; Hoff [12]; Lindebo et al. [18]) or the value of the catches (e.g. Tingley et al. [32]; Maravelias and Tsitsika [19]; Idda et al. [13]). As argued by Herrero and Pascoe [11], in single-species fisheries, the weight and value of the catches are quite often proportional, resulting in similar efficiency measures whilst in multispecies the use of weight and/or value of catches leads to different results, and thus should be selected in accordance with the purpose of the analysis. An efficiency assessment can be performed with different methodologies. Data Envelopment Analysis (DEA), a nonparametric, linear programming method, is the most frequently used in fisheries due to its characteristics. This method constructs an envelopment production frontier which maps out the greatest output for a given level of input, such that all observed points lie on or below this frontier. The production frontier (also known as "best practice frontier") is formed by the efficient DMUs. The efficiency of the remaining DMUs is measured by the distance to this frontier. Measuring efficiency with DEA allows the analyst to incorporate multiple inputs and outputs directly in the analysis, and does not require the specification of a structural relationship between the inputs and the outputs, leading to greater flexibility in the frontier estimation. Therefore, the DEA approach has been successfully applied in fisheries in order to assess technical efficiency (e.g. Dupont et al. [7]; Kirkley et al. [16]; Tingley et al. [31]; Vestergaard et al. [33]; Pascoe and Herrero [24]; Tingley and Pascoe [29, 30]), revenue efficiency (e.g. Lindebo et al. [18]; Oliveira et al. [20, 22]), profit efficiency (e.g. Pascoe and

Tingley [25]) and cost efficiency (e.g. Alam and Murshed-e-Jahan [1]). The present study explores the technical, allocative and revenue efficiency of the artisanal bivalve dredge fleets that operated in the west coast of Portugal (Northwest and Southwest) between 2006 and 2012. The main purpose of this analysis was to identify the best practices to be followed in both fleets, including the specification of most appropriate features of the vessels in terms of inputs. The efficiency of each vessel was estimated with DEA, considering fixed inputs (vessel power, length, tonnage, and an indicator of stock biomass) and a variable input (number of days at sea). An annual quota per vessel was also included in the model as a contextual factor. Revenue efficiency was estimated as a complement to the technical efficiency, using price data for each species in the wholesale market. A two-dimensional graphical representation of vessel's performance enabled us to identify the benchmark vessels, both in terms of those that maximized the weight of the catch for the species landed, given their inputs, as well as the vessels that selected the most appropriate target species to maximize the revenue of the fishing activity, given output prices. The definition of targets for inefficient vessels was also addressed, corresponding to the values of the catch for each species that would maximize the revenue.

2   Methodology

The DEA models were first proposed by Charnes et al. [5]. In the last three decades, several models were developed, covering a broad range of issues. In the present study, it was used a formulation with upper bound constraints on the outputs (see Cooper et al. [6], p. 224), which is particularly useful for evaluations involving maximum levels of outputs, as is the case of quota managed fisheries. In a quota managed fishery, a vessel may not be able to expand output fully because the catches are capped by regulation. Thus, the quota should be considered as an upper bound for the output variables representing the weight of catches.

Consider n DMUs, denoted by DMU_j for $j = 1, \ldots, n$, which use the inputs x_{ij}, where $(x_{1j}, \ldots, x_{mj}) \in \mathbb{R}_+^m$, to obtain the outputs y_{rj} $(y_{1j}, \ldots, y_{sj}) \in \mathbb{R}_+^s$. Assume that the maximum value of the sum of all outputs is bounded by the quota limit Q_{j_0} for each DMU_{j_0}. The efficiency of each DMU_{j_0} is given by the reciprocal of the factor (δ) by which the outputs of the DMU_{j_0} can be expanded, obtained from the following model based on Cooper et al. [6]:

$$
max\{\delta \mid
$$

$$
x_{ij_0} \geq \sum_{j=1}^{n} \lambda_j x_{ij}, \quad i = 1, \ldots, m
$$

$$
\delta y_{rj_0} \leq \sum_{j=1}^{n} \lambda_j y_{rj}, \quad r = 1, \ldots, s \tag{1}
$$

$$\sum_{r=1}^{s}\sum_{j=1}^{n} \lambda_j y_{rj} \le Q_{j_0},$$

$$\lambda_j \ge 0, \forall j\}$$

Model (2) is an output oriented model and assumes the existence of constant returns to scale (CRS). The value of $1/\delta^*$ is the measure of technical efficiency (TE) of DMU_{j_0}. Comparing the formulation of model (2) and the one proposed by Cooper et al. [6], the main difference resides is that the bounds are not specified for each output considered individually, but are instead specified in terms of the total weight of captures allowed for each vessel. An important by-product of the efficiency assessments concerns the specification of peers (i.e. benchmarks) and targets for inefficient units. The benchmarks for the DMU_{j_0} under assessment are the units with values of λ_j^* greater than zero in the optimal solution to model (2). Since the vessels were analysed with an output oriented perspective, the estimation of output targets for each DMU_{j_0} is particularly important. The targets corresponding to both radial and non-radial expansion of the outputs leading to efficient operation in the Pareto-Koopmans sense are obtained as shown in (2). According to Koopmans ([17], p.60), a producer is technical efficient if an increase in any output requires a reduction in at least one other output or an increase in at least one input. For further details on the Pareto-Koopmans definition of efficiency (see Cooper et al. [6], p.45).

$$y_{rj_0}^{target} = \sum_{j=1}^{n} \lambda_j^* y_{rj}, \quad r = 1, \dots, s. \tag{2}$$

DEA model was also used to estimate economic efficiency, following Farrell [9] concepts. This author described a revenue maximization assessment, corresponding to the assumption that the DMUs intend to maximise the revenue obtained, given the resources consumed and the value of the output prices. In order to obtain a measure of revenue efficiency, the maximum revenue that can be obtained by DMU_{j_0}, given the current level of resources consumption, the quota limit Q_{j_0} and the output prices, is estimated solving the linear programming problem shown in Eq. 4. The model follows the formulation originally proposed by Fare et al. [8], with an additional constraint to reflect the fact that the catches are bounded by the quotas (Q_{j_0}) imposed by fisheries regulatory conditions.

$$\max \left\{ \sum_{r=1}^{s} p_{rj_0} y_r^0 \mid \right.$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_r^0, \quad r = 1, \dots, s$$

$$\sum_{r=1}^{s}\sum_{j=1}^{n}\lambda_j y_{rj} \leq Q_{j_0}, \tag{3}$$

$$\sum_{j=1}^{n}\lambda_j x_{ij} \leq x_{ij_0}, \quad i = 1, \ldots, m$$

$$\lambda_j \geq 0, \quad j = 1, \ldots, n$$

$$y_r^0 \geq 0, \quad i = 1, \ldots, m\}$$

In the formulation above, p_{rj_0} is the price of output r for the DMU_{j_0} under assessment and y_{0r} is a variable that, at the optimal solution, gives the amount of output r to be produced by DMU_{j_0} in order to maximise the revenue, subject to the technological restrictions imposed by the existing production possibility set. Revenue efficiency is then obtained, for each DMU_{j_0}, as the ratio of current revenue observed at DMU_{j_0} to the maximum revenue estimated by the optimal solution to model (4), as follows:

$$Revenue\ efficiency_{j_0} = \frac{\sum_{r=1}^{s} p_{rj_0} y_{rj_0}}{\sum_{r=1}^{s} p_{rj_0} y_r^{0*}}. \tag{4}$$

In the context of fisheries studies, the revenue efficiency of a vessel indicates by how much the current revenue of a vessel could be increased without requiring an increase in the level of resources used or in the quota limits, or changes in the prices paid for the species landed. The increase in revenue must be achieved either by a proportional increase in the quantities captured of each species (measured in kg), corresponding to the estimate of technical efficiency, and/or by a different composition of captures, corresponding to the estimate of output allocative efficiency, which involves an optimization in the selection of the target species taking into account their relative prices. The relation between revenue efficiency and its components, associated to technical efficiency and allocative efficiency is as follows:

$$Revenue\ efficiency_{j_0} = Technical\ efficiency_{j_0} \times Allocative\ efficiency_{j_0}. \tag{5}$$

As a result, in the DEA framework, the measure of output allocative efficiency can be obtained residually as the ratio of revenue efficiency, obtained from expression (4), and the output oriented technical efficiency measure, obtained from model (2). The definition of output allocative efficiency is as follows: output allocative efficiency captures the ability of the DMU to choose the best mix of outputs (i.e., the best combination of species captured) in order to maximise revenue, given their relative prices. DEA model was implemented with AIMMS® and the remaining statistical analysis was undertaken using SPSS®.

3 Dredge Fleets that Operates in the Portuguese West Coast of Mainland Portugal

Currently the artisanal dredge fleet that operates in the west coast of mainland Portugal comprises 36 vessels (11 and 25 vessels operating in the Northwest and Southwest fishing areas respectively) (Fig. 1). Dredge vessels in the Northwest area have an overall length ranging from 10 to 16 m, an engine power between 73 and 128 kW, a gross tonnage (GT) between 9 and 25 tons and a crew composed of five fishermen, whereas in the Southwest area dredge vessels have an overall length ranging from 9 to 14 m, an engine power between 46 and 97 kW, a gross tonnage (GT) between 6 and 15 tons and a crew composed of 4–5 fishermen. The bivalve dredge fishery in the Northwest area is monospecific (single species) targeting the surf clam (*Spisula solida*), whilst in the southwest area the fishery is multispecific, targeting four species, the surf clam, the smooth clam (*Callista chione*), the donax clam (*Donax spp.*) and the pod razor clam (*Ensis siliqua*).

Although the majority of the management measures are similar in both fishing areas (e.g. seasonal closure, the minimum landing sizes and the gear specifications), there are differences in terms of the quota allocated. The quotas are reviewed on an annual basis considering the result of the annual monitoring surveys carried out by
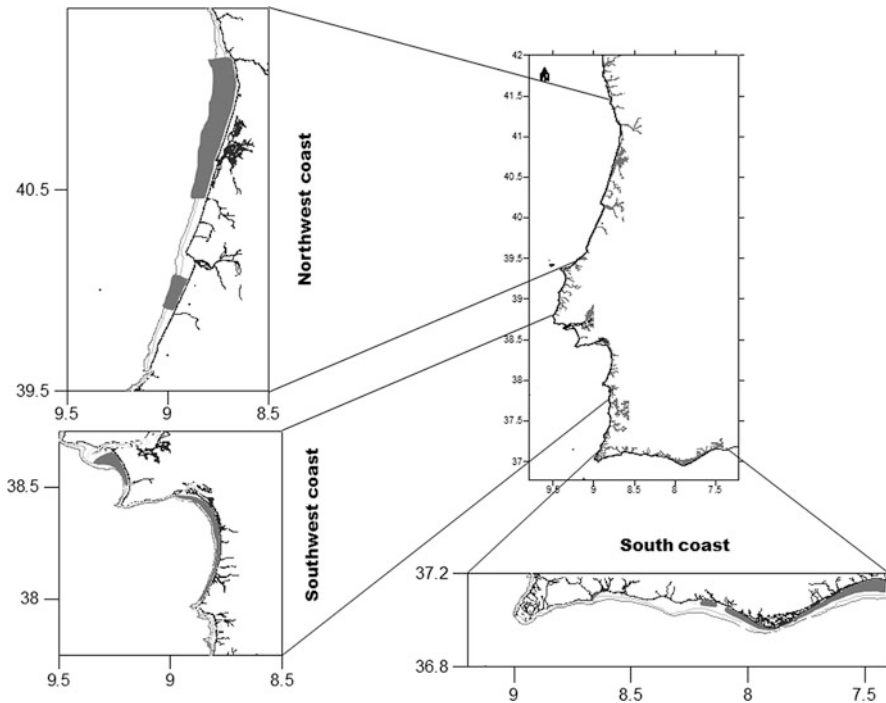
Fig. 1 Distribution of bivalve beds (*grey areas*) in the Northwest and Southwest fishing areas

the Portuguese Institute for the Ocean and Atmosphere (IPMA), and can be changed if necessary to adjust the catch to the status of the stocks (Oliveira et al. [21]).

4   Data

The dataset used in the present study was provided by the General Directorate of Natural Resources, Safety and Maritime Services (DGRM) and covers the period between January 2006 and December 2012. Of the dredge vessels that are currently licensed in the west coast (36 vessels) only 32 vessels were included in the analysis. The other 4 vessels (all from the Southwest dredge fleet) were excluded because in most of the years they used other fishing gears. Tables 1 and 2 present the average characteristics of the fleets that operated in the two areas, the mean fishing days per year, the biological stock indicator, the mean annual fishing quota per vessel, average yearly landings (in weight) and mean yearly price per kg at first sale. In the Southwest, price fluctuations do not occur (Table 2) since catches are sold through a contract that is established in the beginning of each year between the fishermen and the buyer. Therefore, although fishermen are obliged to pass the catches through the auction market, they are not obliged to sell them by auction. Thus, the selling price remains unchanged over the year. In the Northwest coast the price varies throughout the year because the species are sold at the auction (Table 1).

Concerning the variables defined for the DEA analysis, it was used one output for the Northwest area and four outputs for the Southwest areas, corresponding to total amount landed by species per year (Tables 1 and 2). To estimate the revenue efficiency of the fishing activity, it was collected data on the value of landings per species and vessel. For each area, the average price for each of the target species was calculated by dividing the landed value by the amount (kg) landed by each vessel. The input variables used were: overall vessel length (m), GT (ton), engine power of the vessel (kW), a biomass stock indicator for each of the target species (g per 5 min tow dredging) (fixed factors), and the effective days at sea (variable factor). The biomass stock indicator was obtained from bivalve research surveys conducted by IPMA, specifically designed to evaluate the conservation status of the commercial species. The surveys are carried out in a yearly basis onboard the IPMA research vessels. Details on both sampling design and procedures can be found in Rufino et al. [26]. The annual fishing quota per vessel (kg) was used as a contextualizing factor that bounds the output expansion allowed for each vessel and it was calculated by multiplying the daily/weekly quota for all target species and the effective days at sea/weeks per year for each vessel. The efficiency assessment models considered 73 DMUs for the Northwest fleet and 131 DMUs for the Southwest fleet. Since the potential differences in the operating conditions between the years are essentially related to stock abundance, and the models already incorporate the stock level as an input, the unit of analysis was the vessel's operation in a given year, run for a pooled sample with vessels from all years together.

Table 1 Profiling of the Northwest fleet (average values between 2006 and 2012)

	Northwest fleet (means)						
	2006	2007	2008	2009	2010	2011	2012
Inputs							
Overall length (meters)	13.3	13.3	13.3	13.3	13.4	13.4	13.4
GT (ton)	16.5	16.5	16.5	16.5	17.3	17.3	17.3
Engine power (kw)	103.3	103.3	103.3	103.3	103.2	103.2	103.2
No. days at sea	123.8	92.6	72.2	77.4	92.4	85.8	71.3
Surf clam stock (g per 5 min tow dredging)	33.4	16.9	11.1	28.5	45.9	54.3	55.6
Contextualizing factor							
Annual fishing quota per vessel kg)	62,400.0	62,400.0	62,400.0	62,400.0	62,400.0	72,000.0	72,000.0
Outputs							
Capture of surf clam (kg)	39,550.6	11,639.2	11,811.7	23,936.6	35,492.2	36,765.9	35,535.9
Output prices							
Prices of surf clam (€)	2.92	3.12	2.76	1.95	2.05	2.91	2.88

Table 2 Profiling of the Southwest fleet (average values between 2006 and 2012)

	Southwest fleet (means)						
	2006	2007	2008	2009	2010	2011	2012
Inputs							
Overall length (meters)	11.1	11.3	11.3	11.4	11.4	11.4	11.3
GT (ton)	9.5	9.7	9.7	10.0	10.0	10.0	9.7
Engine power (kw)	71.7	71.8	71.8	73.0	73.0	73.0	71.8
No. days at sea	147.6	144.2	144.1	149.1	89.2	77.6	122.3
Surf clam stock (g per 5 min tow dredging)	43.7	36.5	100.3	81.7	39.5	34.2	36.1
Smooth clam stock (g per 5 min tow dredging)	386.1	171.6	182.4	325.5	195.4	214.2	232.1
Donax clam stock (g per 5 min tow dredging)	29.5	81.5	100.9	107.5	63.0	102.3	110.6
Razor clam stock (g per 5 min tow dredging)	108.3	49.1	70.2	127.4	143.5	131.0	140.2
Contextualizing factor							
Annual fishing quota per vessel (kg)	88,533.3	86,490.0	86,430.0	99,000.0	99,000.0	99,000.0	99,000.0
Outputs							
Capture of surf clam (kg)	1375.0	1533.8	661.7	1195.9	585.7	196.7	1762.3
Capture of smooth clam (kg)	14,723.6	11,131.0	9288.5	9501.6	12,339.7	15,555.0	14,579.6
Capture of donax clam (kg)	2185.3	3040.4	5541.2	3166.4	1573.6	2057.0	4352.6
Capture of razor clam (kg)	8297.5	6064.6	4118.8	3415.4	2598.4	1067.4	2379.2
Output prices							
Prices of surf clam (€)				1.50			
Prices of smooth clam (€)				1.00			
Prices of donax clam (€)				2.50			
Prices of razor clam (€)				2.50			

5 Results and Discussion

5.1 Catch Composition

Figures 2 and 3 show the evolution of total landings during the period studied, for dredge vessels operating in the Northwest and Southwest areas, respectively. Since in the Northwest coast the fishery is monospecific (single species) the total amount landed reflects the conservation status of the *Spisula solida* stock (Table 1). In the case of the Southwest area it can be observed from Fig. 3 that although the catch composition varied among years, the total amount landed only changed slightly over the years. Since no significant changes in quotas occurred in the years studied, we believe that the changes observed in catch composition are only related to changes in the biomass stock or changes in demand of the bivalve market.
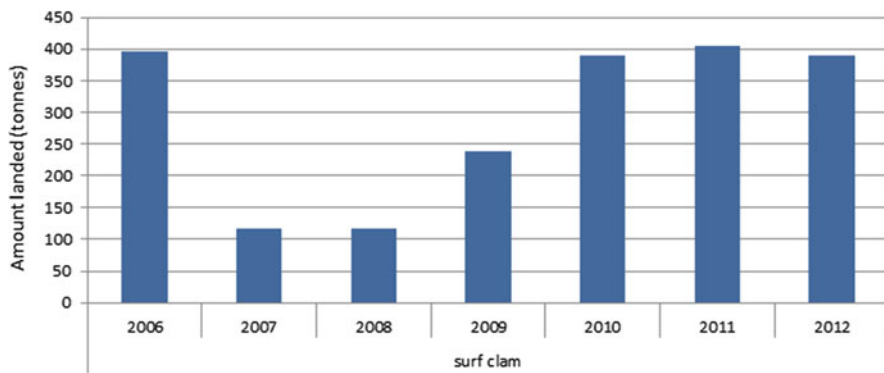

Fig. 2 Northwest fleet. Total landed from dredge vessels between 2006 and 2012
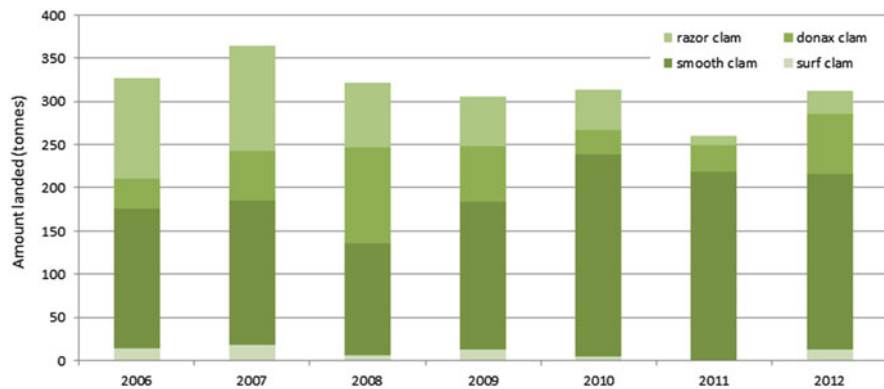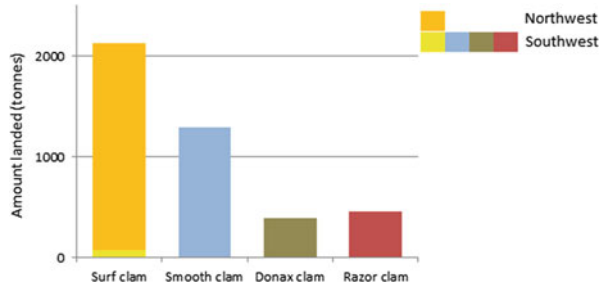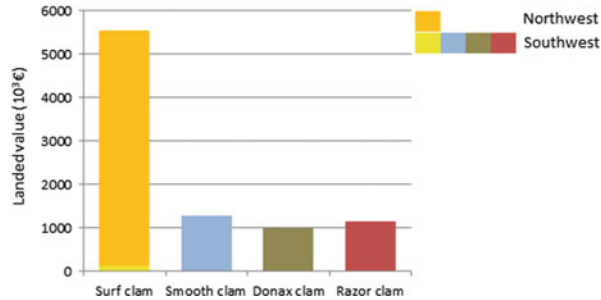

Fig. 3 Southwest fleet. Landed catch composition from dredge vessels between 2006 and 2012

Fig. 4 Comparison of total landings per species in weight (tonnes) from Northwest and Southwest dredge vessels between 2006 and 2012

Fig. 5 Comparison of total landings per species in values (10^3€) from Northwest and Southwest dredge vessels between 2006 and 2012

Figures 4 and 5 show the total catch landed, in weight (tonnes) and in value (10^3€), respectively, for the species caught by the Northwest and Southwest dredge fleets. Despite harvesting only one species (surf clam) and having only half of the vessels of the Southwest fleet, it is important to highlight that the Northwest fleet achieved, on average, about 48 % of the total catch landed in both areas (in tonnes, see Fig. 4) and 60 % of the total income (Fig. 5) in this particular period of time (i.e., between 2006 and 2012). This could be related to the fleet ownership profile. In fact, in the Portuguese artisanal dredge fishery the skipper is usually the ship-owner. However, in the Southwest area, the ship-owners usually have several vessels and therefore can manage the activity of their vessels according to the oceanographic conditions and market demand. Indeed, the ship-owner can decide when and which vessels can fish to accomplish the order lists by species received on land before they sail.

5.2 Technical and Revenue Efficiency Analysis

Tables 3 and 4 summarise the efficiency results (geometric means, standard deviation and the number of efficient DMUs) for the Northwest and Southwest fleets between 2006 and 2012, respectively. The allocative efficiency is not presented for the Northwest fleet because as this fleet only harvests one species, the weight and value of the catches are proportional, and thus technical and revenue efficiency results are identical (Herrero and Pascoe [11]).

Table 3 Efficiency results for the Northwest fleet

	Technical efficiency			Revenue efficiency		
	Geometric mean	St. dev	No. eff. DMUs	Geometric mean	St. dev	No. eff. DMUs
2006	0.944	0.073	3	0.944	0.073	3
2007	0.498	0.168	0	0.498	0.168	0
2008	0.761	0.207	2	0.761	0.207	2
2009	0.717	0.148	0	0.717	0.148	0
2010	0.699	0.242	2	0.699	0.242	2
2011	0.782	0.171	0	0.782	0.171	0
2012	0.830	0.169	3	0.830	0.169	3

Concerning revenue efficiency, it was observed that Northwest vessels have an average efficiency score significantly higher (K-W, $p = 0.001$) than the Southwest vessels (0.735 and 0.631, respectively). Is important to underline that the efficiency scores of each fleet were calculated with reference to fleet-specific frontiers, as the sample of Northwest fleet vessels and Southwest fleet vessels were analysed separately. Therefore it cannot be concluded that higher efficiency scores represent better performance levels. Indeed, this result only indicates that the performance of Northwest vessels is more homogeneous than that of Southwest vessels, as the average distance to the efficient frontier is smaller.

In the Southwest fleet, it can be concluded that most inefficiencies are due to technical causes. The comparison of the technical and the allocative efficiency levels obtained through the 7 years, showed that in general the composition of the catches was good but the volume of the catches could have been improved, especially since 2009. In an attempt to explore whether scale inefficiency has a significant impact on artisanal dredge fisheries in these areas, it was undertaken a hypothesis test firstly proposed by Banker [2] for determining the type of returns to scale of the DMUs' activity. If the efficiency distributions obtained using the CRS and variable returns to scale (VRS) models (Banker et al. [3]) were similar, it would mean a scale inefficiency almost nonexistent, and thus there would not enough evidence to support the hypothesis that the DMUs' activity exhibited VRS. In these cases, the differences in the shape of the production frontier using CRS and VRS models may be due to random variations and not to the intrinsic VRS properties of DMUs' activities. The existence of VRS in vessels' activities was formally tested using the K-W test. For both fleets, the null hypothesis was rejected ($p = 0.044$ and $p = 0.000$ for Northwest and Southwest fleets, respectively) which indicates that the vessels are likely to operate under variable returns to scale, emphasizing that an increase in the resources does not always cause a proportional increase in the catches. The decomposition of technical efficiency (CRS estimate) into pure technical efficiency (VRS estimate) and scale efficiency components for both fleets is shown in Tables 5 and 6.

For the Northwest fleet, the best practice vessels in terms of revenue efficiency in the 7 year period were found to be slightly smaller than the fleet's average (with

Table 4 Efficiency results for the Southwest fleet

	Technical efficiency			Revenue efficiency			Allocative efficiency		
	Geometric mean	St. dev	No. eff. DMUs	Geometric mean	St. dev	No. eff. DMUs	Geometric mean	St. dev	No. eff. DMUs
2006	0.886	0.124	7	0.764	0.154	2	0.862	0.121	2
2007	0.878	0.170	10	0.766	0.208	6	0.872	0.118	6
2008	0.834	0.134	6	0.702	0.130	0	0.841	0.108	0
2009	0.615	0.194	2	0.510	0.141	1	0.829	0.132	1
2010	0.711	0.173	4	0.621	0.197	3	0.873	0.110	3
2011	0.620	0.210	2	0.530	0.235	2	0.854	0.131	2
2012	0.725	0.245	7	0.577	0.227	1	0.797	0.142	1

Table 5 VRS and scale efficiency for the Northwest fleet

	VRS efficiency			Scale efficiency		
	Geometric mean	St. dev	No. eff. DMUs	Geometric mean	St. dev	No. eff. DMUs
2006	0.950	0.065	3	0.994	0.011	4
2007	0.598	0.177	1	0.832	0.226	1
2008	0.956	0.068	7	0.796	0.211	2
2009	0.791	0.133	0	0.907	0.047	0
2010	0.702	0.246	3	0.995	0.011	6
2011	0.821	0.168	1	0.952	0.121	8
2012	0.892	0.113	4	0.930	0.163	9

Table 6 VRS and scale efficiency for the Southwest fleet

	VRS efficiency			Scale efficiency		
	Geometric mean	St. dev	No. eff. DMUs	Geometric mean	St. dev	No. eff. DMUs
2006	0.964	0.087	13	0.919	0.099	8
2007	0.951	0.095	14	0.923	0.127	11
2008	0.913	0.101	9	0.914	0.101	6
2009	0.655	0.203	2	0.939	0.074	2
2010	0.813	0.163	7	0.875	0.121	4
2011	0.802	0.195	6	0.773	0.194	2
2012	0.895	0.142	11	0.810	0.228	7

12.9 m length and an engine power of 96.3 kW), whereas in the Southwest fleet, the overall length and the engine power of the best practice vessels did not differ from the fleet's average (with 11.3 m length and an engine power of 71.8 kW). Statistically significant differences ($p = 0.005$) between the scale efficiency results of both fleets were observed confirming that scale efficiency is more prevalent in the Northwest fleet than in the Southwest fleet. A vessel is considered to be scale efficient when the combination of spent resources and volume of catches is optimal so that any modifications on this combination will result in efficiency loss. Thus the scale efficiency value is obtained by dividing the CRS efficiency by VRS efficiency. This means that despite the bivalve dredge fishery is monospecific in Northwest area, the fleet is technically close to the optimal operation.

Figures 6 and 7 compare the target landings (in tonnes) obtained as by-products of the technical efficiency and revenue efficiency models, respectively. The technical efficiency model suggests for each vessel a proportional increase in the amount landed for each species, whereas the revenue model allows changes to the mix of species captured. For the Northwest fleet both technical and revenue efficiencies suggest the same increment in each year, which is explained by the fact that this fleet only harvest one species (Fig. 6). The higher increments are required for the years 2007, 2010 and 2011 (99, 120 and 90 tonnes, respectively). These increments were coincident with the first year in which the biological stock indicator fell and the years of its recover.
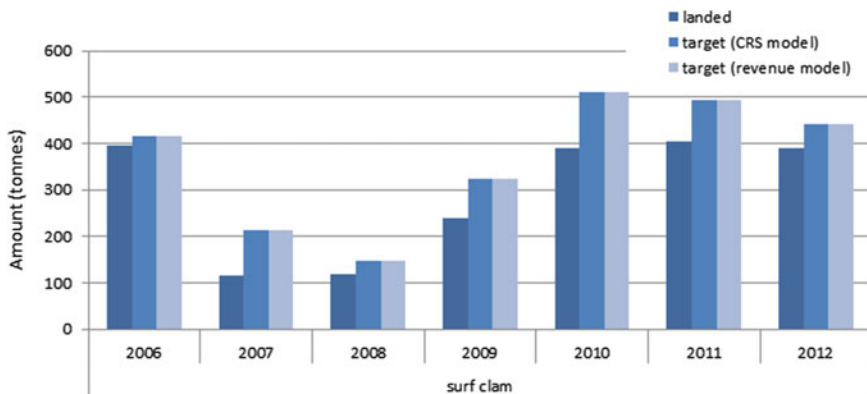
Fig. 6 Amount landed versus target landings for Northwest fleet
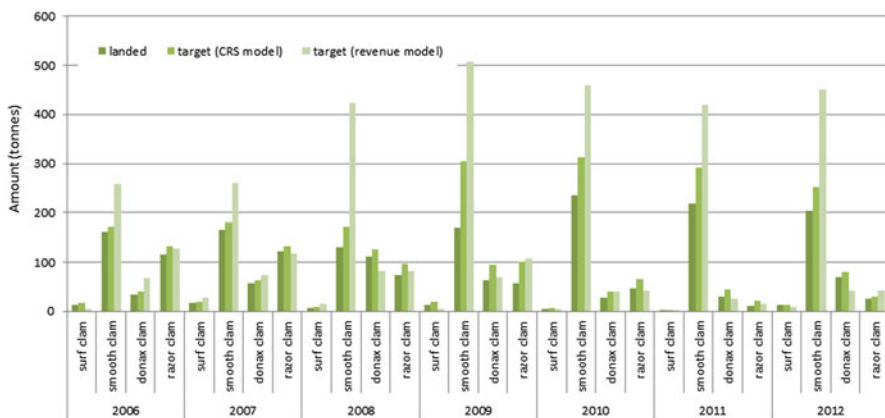

Fig. 7 Amount landed versus target landings for Southwest fleet

In the Southwest fleet, the species in which is required more often an increment in a revenue maximisation perspective is by far the smooth clam (94, 294, 337, 226 and 246 tonnes in 2007, 2008, 2009, 2010 and 2012, respectively). For the donax clam was also required an increment of 33 tonnes in 2006. A better strategy to maximize revenue also involves harvesting less quantities of three species, namely surf clam (9 and 8 tonnes, in 2006 and 2009, respectively), razor clam (4 tonnes in 2007 and 2010) and donax clam (27, 6 and 26 tonnes in 2008, 2011 and 2012). From a technical perspective a different scenario is presented. No reductions to catches are suggested, and the higher increments needed correspond to the smooth clam (133 and 48 tonnes in 2009 and 2012, respectively).

5.3   A Strategic Approach with DEA

The performance analysis of an organisation based on a portfolio of business, corresponding to different dimensions represented in a matrix, dates back to the 1960s. This technique, known as the growth-share matrix, was developed by the Boston Consulting Group (BCG) to support strategic options formulation. This technique was later adapted to the context of efficiency and profitability analysis by Boussofiane et al. [4]. The efficiency-profitability matrix is divided into 4 quadrants, where different profiles of units are likely to exist, although the precise boundary positions between quadrants are subjective. This approach was applied to the Southwest dredge fleet for the last 3 years of the study and the quadrants boundaries used were identical to those proposed by Oliveira et al. [20]. It is intended to explore the relationship between the technical-efficiency measure obtained from a DEA analysis and the allocative-efficiency measure, obtained as a by-product of the DEA analysis with a revenue maximization model.

Figure 8 illustrates the relationship between allocative efficiency and technical efficiency for the Southwest dredge vessels. The analysis of the allocative efficiency versus technical efficiency matrix is an alternative way to identify best-performing vessels, corresponding to those located in the top corner of each matrix that can be considered the "stars". There are nine vessels located in the "star vessels" quadrant at least once in the 3 years analysed. One of these vessels was fully efficient, both technically and allocatively, in 2 years (no. 8), and four vessels (no. 1, 6, 13 and 18) were only fully efficiency in one of the years. The other four vessels (no. 5, 10, 15 and 19) achieved high efficiency scores in all years, despite never achieving the maximum efficiency level.

The analysis of Fig. 8 also shows that every year there are five vessels located in the "problem vessels" quadrant. This suggests that there is scope for efficiency improvements in this fleet. Vessels located in the "problem vessels" quadrant have the potential for achieving greater technical and allocative efficiency levels, indicating that they should change the proportion among the species captured and, at the same time, they should increase the total amounts landed. Only one vessel is consistently located in this quadrant over the years (no. 2). In addition, three vessels (no. 4, 16 and 18) were classified as "problem vessels" in two of the years, so their activity should be carefully monitored, to identify the practices that need to be modified to improve their performance. The number of vessels in the "good capture composition" quadrant is higher compared with the number of vessels located in the "good in the amounts landed" quadrant. This suggests that fishermen behaviour focuses on capturing the species that can maximise revenue rather than only aiming at capturing large quantities of bivalves. Vessels located in the "good capture composition" quadrant need to focus on incrementing the amounts landed, keeping the current proportion among the target species harvested. Vessels located in the "good in the amounts landed" quadrant have an inappropriate choice of target species, and thus it may be possible to increase profits by redirecting captures towards other species. In certain cases, vessels previously referred as "star vessels"
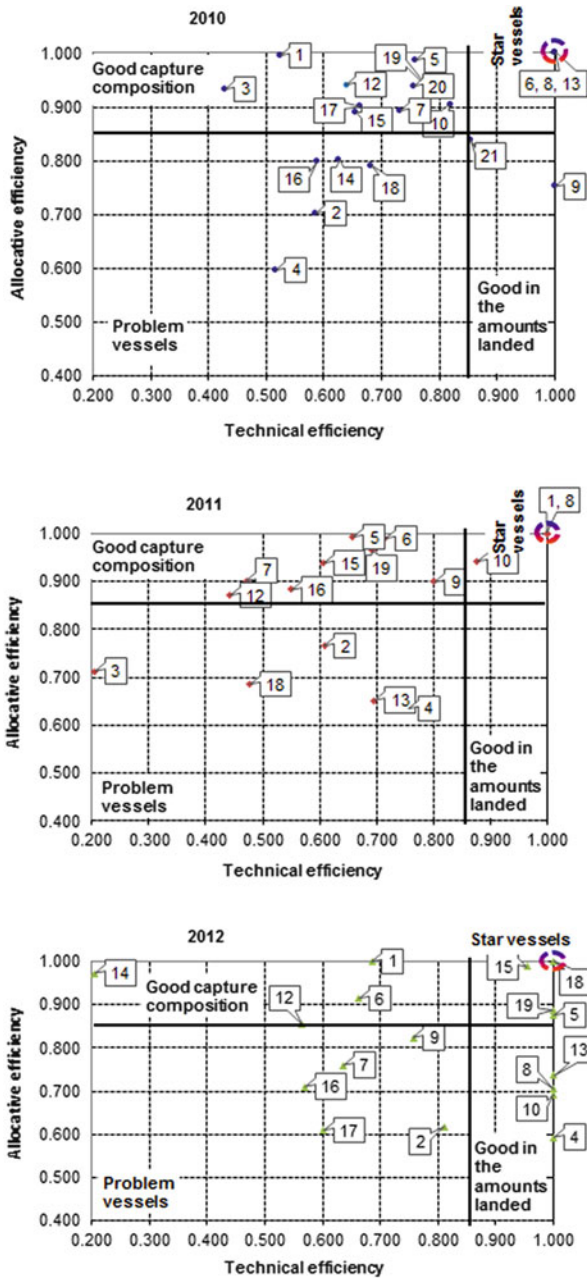
Fig. 8 Allocative efficiency versus technical efficiency matrix for the Southwest fleet

(e.g. no. 8 and 13) decreased their allocative or/and technical efficiency and fell in the "good in the amounts landed" quadrant.

6 Conclusions

The present study allowed clarifying same interesting issues about the performance of both Northwest and Southwest dredge fleets between 2006 and 2012. Concerning the composition of the catches, the amount landed in the Northwest area are directly related to stock since in this area the fishery is monospecific. In the Southwest the changes observed in catch composition are not only related to changes in the stock but also to changes in bivalve market demand since no significant changes in quotas occurred in the years considered. During the period studied, and despite harvesting only the surf clam species and having only half the vessels of the Southwest fleet, landings from the Northwest dredge fleet accounted for 48 % of the total catch landed in both areas, and 60 % of the total income. This result reflects the differences in the ownership profile. In contrast to the common in the artisanal dredge fishery where the skipper is usually the ship-owner, as it is the case of the dredge fleet that operates in the Northwest area, in the Southwest area, the ship-owners usually have several vessels, and manage their activity as a whole, according to the oceanographic conditions and market demand, instead of treating independently the different vessels. During periods of low demand, some vessels may remain inactive during several weeks decreasing, this way, their efficiency. This justifies the reason why the performance of the Northwest fleet is more homogeneous than the Southwest fleet. The analysis of returns to scale allowed concluding that both fleets are operating under variable returns to scale, meaning that in this fishery a possible increase in the resources could not imply a proportional increment in the catches landed. The BCG growth-share matrix constructed for the Southwest fleet allowed to explore graphically the relationship between allocative efficiency and technical efficiency for the last 3 years. The main management challenge concerns the vessels located in the "problem vessels" quadrant. They are not operating close to efficient levels neither in technical or allocative terms. In order to make the fishing activity more profitable, these vessels should change the balance between the species captured and the amounts landed. The vessels located in the "good capture composition" quadrant should increment the quantities landed in order to become "stars" and attain higher profits. The vessels located in the "good in the amounts landed" quadrant should redirect the fishing effort to capture a different mix of species. As they are close to operating efficiently in technical terms, the profitability can only be increased by changing the mix of species captured. Their activity should be redesigned in order to emulate the best-practices observed in the benchmark vessels of the same fleet. The present study emphasizes the importance of assessing efficiency in artisanal fishery. The results achieved allowed to better understanding fishing operation and how the fleets achieved their performance. In face of that and from a management perspective, the Northwest fleet should start diversifying the catch by targeting the

other bivalve species with commercial interest that occurs in the area in order to maximize their revenue, since in terms of the resources employed no changes are needed. Being restricted to a single species, the performance of the fleet is extremely dependent of the status of the stock.

Concerning the Southwest fleet, the improvement of the performance of the fleet is more difficult to achieve due to the ownership profile. Nevertheless, the results revealed, on general, that although the composition of catches is appropriate, the amount landed could be improved. Our suggestion would be to increase the catches of all species, perhaps directing the effort to those that have a higher market price. The results from the BCG growth-share matrix could also be useful if a vessels scrapping plan is put in place in this area aiming to adjust fishing effort to the status of the exploited stocks. Therefore, the vessels that should be scraped from the fishery should be those that are located in the "problem vessels" quadrant.

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