Application of Bio-Economic Models

in the Management of the Dredge Fleet in Portugal

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A thesis submitted to Faculdade de Engenharia da Universidade do Porto
for the doctoral degree in Industrial Engineering and Management

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U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

2014

Everytime someone tells you that something is impossible just because,

don't take it too seriously.

Pretend you are an owl and blink wisely.

To my little rising star Johnny

Abstract

In Portugal, the bivalve dredge fishery is one of the most important artisanal activities within small-scale fisheries. It involves a large number of vessels and fishermen, and the amounts landed represent a large proportion of the total landings from artisanal fisheries, both in weight and in value. Over the last twenty years, the Portuguese artisanal dredge fleet has been facing a decrease in the number of vessels due to the reduction of the fishing yield. This reduction is a result of the dramatic increase in the production costs, mainly related to the escalation of fuel prices, which has not been compensated by an increase of the first-sale prices.

This fishery is regulated by administrative authorities (Directorate General of Natural Resources, Safety and Maritime Services) that are responsible for the implementation of management measures that aims the sustainability of the fishing fleet, the resources and the ecosystem. These regulatory measures include seasonal closures, intended to protect species during spawning and larvae settlement, as well as other measures intended to control fishing effort, namely, limited working hours and days per week, limitations to the number of licenses issued yearly and maximum fishing quotas established by species and vessel. These measures can cause a decrease on the profit of fishing vessels affecting, this way, the sustainability of coastal areas that often rely almost exclusively on artisanal fisheries activities. Therefore, it is extremely important to be able to properly anticipate their impact on local communities.

This thesis intends to apply frontier techniques, including Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA), to evaluate the performance of the dredge fleet and to contribute to the design of appropriate management policies to support the sustainable development of the dredge fisheries, taking into account economic, social and environmental aspects.

The four main research topics of this thesis are: 1) to explore the technical, allocative and revenue efficiency of the fleets operating in the Northwest, Southwest and South fishing areas of Portugal mainland using DEA models. The purpose of the analysis is to identify the characteristics of the vessels leading to superior performance, as well as the best-practices that should be followed to improve the fleets' performance; 2) to understand how the changes in quota regimes and the annual variations in the maximum quotas

allowed for each vessel affect the fleets' productivity. The methodology used was based on Directional Distance Function models and the Malmquist index. Both Northwest and Southwest areas, which are regulated by maximum weekly fishing quotas, were analyzed for a period of 13 years (from 1999 to 2011). For the South area, regulated by maximum daily quotas, it was evaluated a scenario with a different quota regime involving weekly quotas, providing important insights for future management actions; 3) to understand if the bivalve dredge fishery is subject to seasonality. With this purpose, the monthly fluctuations of fleets' revenue efficiency were analysed for the three bivalve fishing areas between 2006 and 2012. The mean wave height by fishing area was also included in the models in order to screen its effect on the fleets' efficiency. The methodology used was based on DEA models and Tobit regression; 4) the last topic addresses the effect of harmful algal blooms (HAB) on the revenue of the artisanal dredge fleet. The analysis was performed using SFA models to enlighten the phycotoxins impact on the fleet's performance.

Our results showed that the Northwest fishing area is, by far, the most affected by wave height, in such a way that the monthly seasonality effect explained 41.3% of the variability in vessels revenue efficiency (RE). In this fishing area, most of the catches are exported live to Spain throughout the year, and during December the demand for bivalve increases due to Christmas and New Year festivities. The shift from daily to weekly quota regime adopted in late 2007, improved the productivity of the fleet leading to a reduction in the number of fishing days (7.6%), and fuel consumption (8.7%). Despite, being technically close to the optimal operation, the monospecific characteristic of this fleet makes it more susceptible to external factors that jeopardize its performance.

In the Southwest fishing area, two substantial changes in management measures had impact on the productivity of this fleet, between 2006 and 2012. The productivity decreased due to an abrupt reduction of the daily fishing quota (800 kg per vessel), whilst the introduction of the weekly quota for the fishery had the opposite effect. In fact, the introduction of the weekly quota led to a reduction in the number of fishing days (15.4%) and fuel consumed (9.8%). In this area, the wave height also has a monthly effect, explaining 25.3% of the fleet's RE variability. Despite a quite stable bivalve demand, there is evidence of an increase in demand for bivalve in this region during Christmas and New Year festivities.

The hypothetical scenario designed for the South fleet, simulating a shift in the quotas regime from daily to weekly maximum quotas, predicted a reduction of about 10.8% in fishing days and 12.8% in fuel consumption for the year of 2011. These reductions would allow improvements in the fleets' productivity alongside the minimization of the impact of the fishery on the environment. Strong evidences of demand seasonality on fisheries performance was shown, with special emphasis during the summer months (June, July and August).

More recently, the HAB events became a phenomenon of concern due to the frequency, intensity and geographic spread. Their prevalence during the summer, affects particularly the dredge fleet in the South, where the market demand for bivalves is higher in this season. The hydrodynamics of the Portuguese coast explains the dispersion of the phenomenon in the West coast and its retention in the South coastline, where this phenomenon showed to be having the strongest effect on the vessels' revenue. Thus, the normal activity of this fleet in the South can seriously to be compromised with the phycotoxins prevalence, eventually dictating the end of this fishery.

Resumo

Em Portugal, a pesca da Ganchorra é uma das atividades artesanais mais importantes no quadro das pequenas pescarias artesanais. Esta pescaria envolve um grande número de embarcações e pescadores, e os montantes desembarcados representam uma elevada proporção do total da atividade da pesca artesanal Portuguesa, tanto em peso como em valor. Ao longo dos últimos vinte anos, a frota artesanal da Ganchorra tem assistido à diminuição do número de embarcações em virtude da redução do rendimento da pesca, em consequência do dramático aumento dos custos de produção, relacionados sobretudo com a escalada dos preços dos combustíveis, que não têm sido compensados pelo aumento do preço do pescado em lota.

A pesca da Ganchorra é regulada pelas autoridades nacionais (Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos) através da implementação de medidas de gestão que visam sobretudo a sustentabilidade dos recursos e dos ecossistemas e monitoramento do impacto da atividade tanto sobre os recursos naturais como sobre as condições socioeconómicas das comunidades pesqueiras. Estas medidas regulamentares incluem, entre outras, períodos de defeso com o objetivo de proteger as espécies durante a desova e a fixação larvar, bem como outras medidas destinadas ao controlo do esforço de pesca, impondo-se para tal limites ao horário de trabalho, ao número de dias de pesca por semana, ao número de licenças de pesca e montantes de captura através do estabelecimento de quotas máximas de captura, estabelecidas por espécie e por embarcação. Não obstante, desconhece-se o impacto que estas medidas podem ter na eficiência e rentabilidade das embarcações da frota da Ganchorra assim como nas comunidades piscatórias associadas a esta pescaria. Neste sentido, recorrendo à utilização de técnicas de fronteira de produção, tais como a Análise Envolvente de Dados (DEA) e a Análise de Fronteiras Estocásticas (SFA), pretendeu-se, com o presente estudo, avaliar o desempenho da frota de Ganchorra tendo em consideração não só aspetos económicos e biológicos (associados ao recurso) mas também sociais e ambientais, contribuindo desta forma, para a definição de políticas de gestão adequadas ao desenvolvimento sustentável da pesca de bivalves com Ganchorra.

Este estudo desenvolve-se em torno de quatro linhas de investigação, nomeadamente: 1) é explorada a eficiência técnica, alocativa e económica das frotas que operam nas áreas

de pesca do Noroeste, Sudoeste e Sul de Portugal continental, usando modelos DEA com o objetivo de identificar as características técnicas das embarcações que obtêm um desempenho superior, de modo a definir as melhores práticas que devem ser seguidas com vista a melhorar o desempenho da frota; 2) a segunda linha teve por objetivo compreender de que modo alterações no regime de quotas máximas de captura por embarcação e as suas variações anuais afetam a produtividade das frotas, utilizando-se para tal, modelos de função de distância direcionais e Índices de Malmquist. Embora este estudo tenha sido aplicado nas três áreas de pesca (Noroeste, Sudoeste e Sul) as análises foram direcionadas para as duas primeiras áreas (Noroeste e Sudoeste), ambas geridas por quotas máximas de captura semanais, para um período de 13 anos (1999-2011), sendo os resultados posteriormente transpostos e simulados para a Zona Sul, atualmente regulamentada por quotas máximas de captura diárias, de modo a avaliar os impactos de uma futura alteração de sistema de quotas nesta área; 3) com o terceiro tópico procurou-se compreender se existe sazonalidade na procura de bivalves e de que forma é que esta poderá condicionar a atividade da frota de pesca da Ganchorra. Neste sentido, foram analisadas as flutuações mensais da eficiência económica das frotas para as três áreas de pesca, entre 2006 e 2012, através da utilização de modelos DEA e regressão Tobit. A ondulação média por área de pesca também foi incluída nos modelos, de modo a rastrear o seu efeito no desempenho das frotas; 4) finalmente pretendeu-se avaliar o impacto dos blooms de microalgas tóxicas no desempenho da frota de Ganchorra aplicando-se para tal, modelos SFA.

Os resultados revelaram que numa perspetiva nacional, a Zona Norte é a região mais afetada pela ondulação média, sendo o fator mês responsável por 41.3% da variabilidade na eficiência económica das embarcações. Nesta região, grande parte das capturas é exportada ainda fresca para Espanha ao longo de todo o ano, registando-se um aumento na procura de bivalves durante as festividades do Natal e Ano Novo. A alteração no regime de quotas máximas de captura diárias para semanais no final de 2007, contribuiu para a melhoria da produtividade desta frota através de uma redução dos dias de pesca (7.6%), e combustível consumido (8.7%). Apesar de ser uma frota a operar tecnicamente próximo do óptimo, a monoespecificidade das suas capturas, deixa-a mais vulnerável a fatores externos à actividade que podem comprometer o seu desempenho.

Na área de pesca do Sudoeste, entre 2006 e 2012, duas alterações substanciais na legislação tiveram um impacto considerável na produtividade da frota que aqui opera: 1) a redução abrupta da quota máxima diária (800 kgs por embarcação) levou a uma perda de produtividade; 2) e a introdução da quota máxima semanal em meados de 2009 que teve um efeito oposto. Efectivamente, a introdução da quota semanal, em consonância com o que havia sido observado no Noroeste, levou igualmente à redução dos dias de pesca (15.4%) e do combustível consumido (9.8%). Nesta área de pesca, a ondulação média também exerce influência na atividade com o fator mês a explicar 25.3% da variabilidade da eficiência económica da frota. No Sudoeste não se registam grandes flutuações na procura de bivalves ao longo do ano, à excepção de um acréscimo durante as festividades do Natal e Ano Novo.

A simulação da aplicação de quotas máximas semanais na região Sul (em contraste com as diárias que se encontram em vigor) resultou numa redução hipotética de cerca de 10.8% nos dias de pesca e 12.8% no combustível consumido, só para o ano de 2011. Tais reduções teriam certamente contribuído para uma melhoria da produtividade desta frota, bem como para a minimização do impacto ambiental decorrente da exploração de bivalves nesta área. A região Sul é sem dúvida aquela em que mais se denota a sazonalidade na procura de bivalves e o seu impacto na eficiência económica da frota, com especial ênfase durante os meses de verão (Junho, Julho e Agosto).

Mais recentemente, os sucessivos *blooms* de microalgas tóxicas têm constituído motivo de grande preocupação devido à sua frequência, intensidade e dispersão geográfica. A sua prevalência durante o verão, afeta particularmente a frota da Ganchorra que opera no Sul, onde a procura de bivalves aumenta consideravelmente devido ao turismo na região. As condições hidrodinâmicas da costa Portuguesa explicam a dispersão do fenómeno na costa Ocidental e a sua retenção na costa Sul, onde o fenómeno tem vindo a registar um maior impacto na eficiência económica das embarcações. Desta forma, a normal atividade da frota do Sul, pode encontrar-se seriamente comprometida com a prevalência de microalgas tóxicas, ditando em extremo, o fecho desta pescaria na região.

Acknowledgments

When I was little and someone asked me what I wanted to become later on, I always answered the same… - I want to be self-sufficient, an independent woman!

The universe categorically denied me my wish. In its mysterious ways it showed me that human condition implicates life in society and unavoidable interpersonal relationships … In fact, my life was always fulfil of so many great, generous and wonderful people that it would be impossible to refer in so few lines. Thus, I will acknowledge the ones who somehow mostly contribute to this six year's project of my life – my PhD.

With a flowery chronologic order, I want to thank to the greatest parents in the world: mine! – I am what I am because of you! I also would like to thank my number one fans – my sister Ju and my brother-in-law Orlando – even though I could never understand why! (If only I was a nurse whom speak fluently Portuguese, English, German and Dutch). To my youngest sister Céu – I miss you a lot.

My next acknowledges goes to those who believed in my willpower to accomplish my own goals, Professor Fernando Taveira, Doctor José Pinto Paixão and my father-in-law Carlos. To my chief Doctor Graça Pestana and her successor Doctor Yorgos Stratoudakis, it was a pleasure to work with both of you! Thank you to even those who did not believe and yet allowed to be surprised, Professor Luis Gouveia please don't take it too personally, it happens all the time.

I am definitely grateful to my supervisors Doctor Ana Camanho e Doctor Miguel Gaspar! After all these years of co-work you are much more than that! Without your knowledge, expertise, pragmatism, patience and care, I would never have achieved my objective of add some valuable work to our artisanal fishing community.

The funding of this research through the scholarship SFRH/BD/77058/2011 from the Portuguese Foundation of Science and Technology (FCT) is gratefully acknowledged.

A special word to my friend and muse Miló – your wisdom and resilience are truly inspiring to me! And now the buddies, those who don't need any additional presentations to be the best buddies of all. Firstly, the girls: Alexandra Caetano, Filomena Correia,

Isabel Horta, Joana Martins, Mafalda Rangel, Sofia Almeida and Vera Miguéis. Secondly, the boys: João Aguiar, João Duarte, Miguel Boim and Nuno Ferreira.

I am no longer a child (or so it seems), life happen and I realised that the independence I sought for so many years, is a bunch of nothing! I married, had a child and changed my wish. Now, I just want to be happy! Luis, more than a husband you have been a partner in life, the father of my son, my listener and confident, my loyal friend! Let me depend on your love and care for the rest of our lives.

Eventually, no matter how magnificent we think we are, every single one of us needs someone, if nothing else, to says how bad we actually rule!

Therefore, be great, be grateful, be gentle and above all, be Happy!

Acronyms

AE – Allocative Efficiency

ASP – Amnesic Shellfish Poisoning

BCG – Boston Consulting Group

BPZ – Bivalve Production Zone

CI – Confidence Interval

CRS – Constant Returns to Scale

DCR – Data Collection Regulations

DDF – Directional Distance Function

DEA – Data Envelopment Analysis

DGPA – Portuguese General Directorate of Fisheries and Aquaculture

DGRM – Directorate General of Natural Resources, Safety and Maritime Services

DMU – Decision Maker Unit

DSP – Diarrheic Shellfish Poisoning

EC – Efficiency Change

ETP – Endangered, Threatened, or Protected

EU – European Union

FAO – Food and Agriculture Organization

FCT – Portuguese Foundation of Science and Technology

FMP – Fishing Management Plan

GD – Grid Dredge

GT – Gross Tonnage

HAB – Harmful Algal Bloom

INE – National Statistics Institute, Portugal.

INRB-L/IPIMAR – National Institute of Marine Research

IPMA – Portuguese Institute for the Ocean and the Atmosphere

K-W – Kruskal Wallis

MDFQ – Maximum Daily Fishing Quota

MI – Malmquist Index

MWFQ – Maximum Weekly Fishing Quota

MWH – Mean Wave Height

ND – North Dredge

NSP – Neurotoxic Shellfish Poisoning

PSP – Paralytic Shellfish Poisoning

RE – Revenue Efficiency

SCI – Science Citation Index

SFA – Stochastic Frontier Analysis

SSF – Small-Scale Fisheries

TC – Technological Change

TD – Traditional Dredge

TE – Technical Efficiency

VRS – Variable Returns to Scale

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CHAPTER 1. Introduction

1.1 General context

The importance of artisanal or small-scale fisheries (SSF) as a source of sustenance, income and employment for many coastal communities worldwide is undeniable. SSF represents an essential livelihood strategy for millions of families throughout developing countries, improving quality of life and reducing poverty (e.g. Pauly, 2006; Andrew *et al.*, 2007; Salas *et al.*, 2007; Schafer and Reis, 2008; Kronen *et al.*, 2010; Chuenpagdee, 2011; Silva *et al.*, 2013; Trimble and Johnson, 2013).

Compared to large-scale fisheries, SSF consume much less energy, require less capital per ton of product and are often ecologically less destructive (DuBois and Zografos, 2012). Furthermore, SSF are highly integrated in the local economies (Battaglia *et al.*, 2010), and are more efficient in the exploitation of near-shore resources, provide more employment opportunities, require less infrastructures (Colloca *et al.*, 2004), and are often less subsidized than industrial fisheries (Jacquet and Pauly, 2008).

Although the per capita investment for production is generally low, it has increased significantly in many SSF during the past three decades due to investments in more efficient fishing-gears and vessel motorization. However, the increase of fuel price in recent years has aggravated the production costs of this activity, and consequently affected fishermen income (FAO, 2005-2014).

The contribution of such fisheries in terms of global production is indisputable, representing more than half of the estimated wild harvest total of approximately 100 million tonnes per annum, providing employment to more than 31.5 million capture fishers in addition to more than 84 million people in associated activities (FAO, 2010). According to Macfadyen *et al.* (2011), SSF are estimated to represent 83% of the whole fleet in the European Union (EU) 27, involving approximately 90 thousand fishing crew members.

Notwithstanding, the knowledge of the three pillars of sustainable fisheries, including the well-being of the bio-ecological system, the human system and the management process, is generally limited in SSF. In fact, the artisanal fishing activity is commonly characterized by poor or even non-existent data collection in many countries worldwide. Illegal captures, the use of unlicensed gears, and the general disrespect for regulations are some of the problems frequently identified (Freire and García-Allut, 2000).

Unlike the long list of studies in literature addressing industrial fisheries (e.g. Pauly *et al.*, 2002; Chuenpagdee and Pauly, 2004; Chuenpagdee *et al.*, 2004; Bavinck *et al.*, 2005; Smith *et al.*, 2006; Chuenpagdee and Jentoft, 2007; Bundy *et al.*, 2008; Chuenpagdee *et al.*, 2008; Chuenpagdee and Jentoft, 2009; Jentoft and Chuenpagdee, 2009; Foley *et al.*, 2011; Griffin and Woodward, 2011; Dell'Apa *et al.*, 2012; Grimm *et al.*, 2012; Vázquez-Rowe and Tyedmers, 2013), those focusing on SSF are considerably less and frequently based on descriptive approaches due to the sparse or absent of economic data (e.g. Whitmarsh *et al.*, 2003; Guyader *et al.*, 2013; Garcia-Flórez *et al.*, 2014).

Indeed, in SSF the challenges related to efficiency assessment and management are still significant, despite several actions instigated in order to collect information of the fishing activity and biological resources, such as the EU Data Collection Regulations (DCR).

In Portugal, like in other countries, the importance of SSF as a source of income and employment for local communities is recognized, but often neglected by administrative authorities. Despite their importance, many SSF are often overlooked in fisheries management and development plans, mainly because fisheries policy, research attention and regulatory efforts are focused primarily on large-scale fisheries. In Portugal there are currently approximately six thousand fishermen operating in the artisanal fishing sector, and thousands more working in fisheries-related activities, such as fish processing and marketing, boat building and net making. Moreover, artisanal fleets account for more than 50% of fish production (source: Directorate General of Natural Resources, Safety and Maritime Services).

Among the Portuguese SSF, the bivalve dredge fleet is by far the most extensively studied (e.g. Gaspar *et al.*, 2002; Gaspar *et al.*, 2003; Oliveira, 2005; Oliveira *et al.*, 2009; Camanho *et al.*, 2010; Martins *et al.*, 2014). 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. Notwithstanding, likewise other SSF, the dredge fleet is regulated by management measures with the purpose to preserve the sustainability of the natural resources. Measures such as seasonal closures, fishing effort control and maximum fishing quotas surely compromise in some way the household income of the fishermen. Moreover, uncontrollable factors, such as sea conditions or phycotoxins presence, are matters of concern and certainly contribute to destabilize the normal fishing activity.

However, the impact of management measures or other factors on dredge fleets' performance has never been assessed before. Therefore, it is of utmost importance to understand the magnitude of the impact of managerial policies on the socioeconomic conditions of fishermen.

Motivated by the need to improve scientific and technical knowledge of artisanal fisheries, this research aims to be a constructive contribution for their sustainable development, preserving both the natural resources and the economic well-being of those who live on the fishing activity.

1.2 The Portuguese artisanal dredge fleet

1.2.1 Fishing areas, fish-landing ports and dredge fleet

According to current legislation (Diário da República, 2.ª série, N.º 182, Despacho n.º14515/2010), the Portuguese mainland coast is divided into three major fishing areas, regarding bivalve dredge fishery (Figure 1-1): the North Western zone (henceforth Northwest), from Caminha to the Pedrogão parallel (39º55'06'' N); South Western zone (henceforth Southwest), bounded in the North by Pedrogão and in the South by the parallel crossing through the lighthouse of Cabo de São Vicente (37º01'15'' N); and the South zone (henceforth South), bounded on the North by the São Vicente parallel mentioned above and on the West and East by the Portuguese marine territory. These three fishing areas have been defined taking into account the coastal morphology, the location of main fish-landing ports and the location of the main bivalve beds. The dredge fleet is distributed by several fishing ports along the coast. The main bivalve landing ports are Matosinhos and Aveiro in the Northwest, Setúbal, Sesimbra and Sines in the Southwest, and Quarteira, Olhão, Fuzeta, Tavira and Vila Real de Santo António in the South (Figure 1-1).

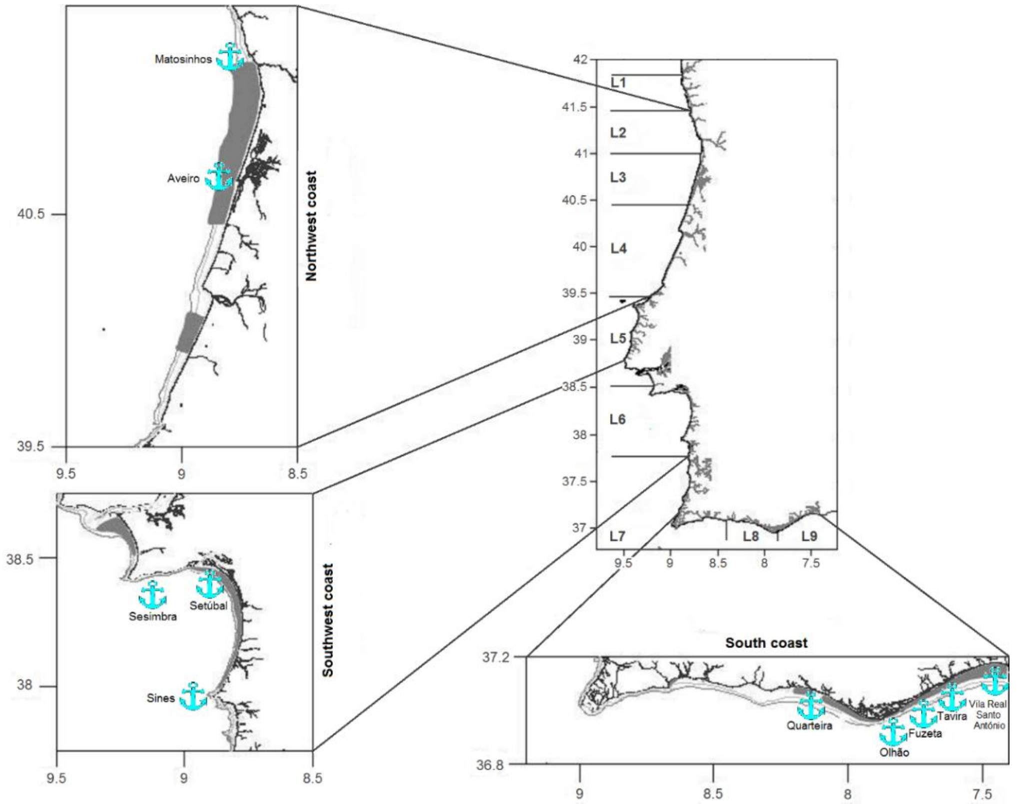

Figure 1-1. Portuguese bivalve dredge main landing ports and the bivalve production zones (L1 to L9) in the three main fishing areas.

The fishing vessels may be considered local or coastal, depending on their characteristics. Local vessels (Figure 1-2) are characterized by having low-powered engines and a maximum overall length less than or equal to 9 m and/or an engine power lower than 75 kW (=100 Hp) or 45 kW (=60 Hp), depending if the vessel has a cabin or not.

Local vessel © IPMA

Coastal vessel © IPMA

Figure 1-2. Vessels operating in the South fishing area of mainland Portugal.

Coastal vessels (Figure 1-2) have an overall length higher than 9 m, a gross tonnage (GT) lower than 180 ton and an engine power higher than 25 kW (=35 Hp). It is possible to distinguish the technical features of the fishing vessels operating in the three areas. The overall length, gross tonnage and engine power of the vessels decreases from the North to the South, as shown in Figures 1-3, 1-4 and 1-5. This is probably related to the harsher hydrodynamic conditions of the Northwest, such as strong swell, when compared to Southwest and South areas. Other factors, such as bathymetric distribution of bivalve populations and the distance of landing fishing ports with respect to fishing grounds should also be considered when explaining the different dimensions and motorization of vessels from different areas.

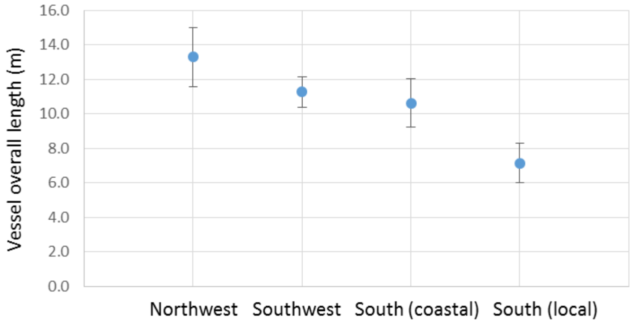

Figure 1-3. Mean overall vessel length per fishing area (data for the years 2006 to 2012). Bars represent Standard Deviation.

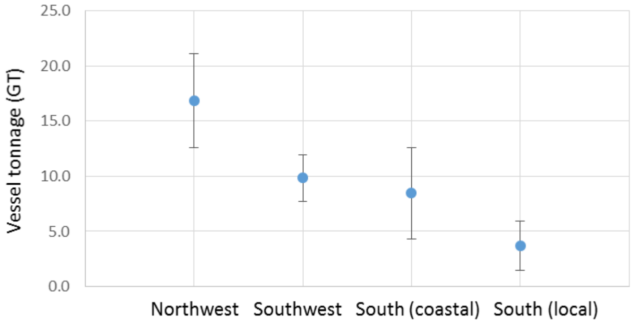

Figure 1-4. Gross tonnage per fishing area (data for the years 2006 to 2012).

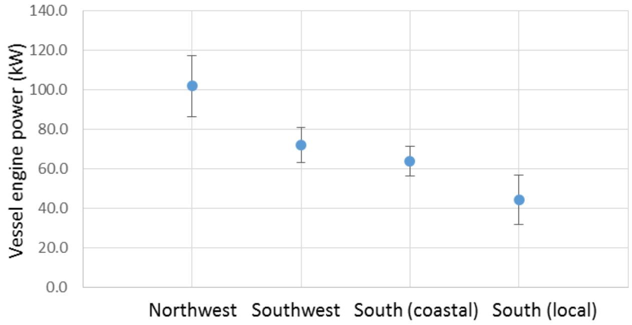

Figure 1-5. Mean vessels engine power per fishing area (data for the years 2006 to 2012). Bars represent Standard Deviation.

1.2.2 Target species

The target species of the artisanal dredge fleet are: the surf clam (*Spisula solida*), the smooth clam (*Callista chione*), the donax clam (*Donax* spp.), the striped venus (*Chamelea gallina*) and the pod razor clam (*Ensis siliqua*) (Figure 1-6).

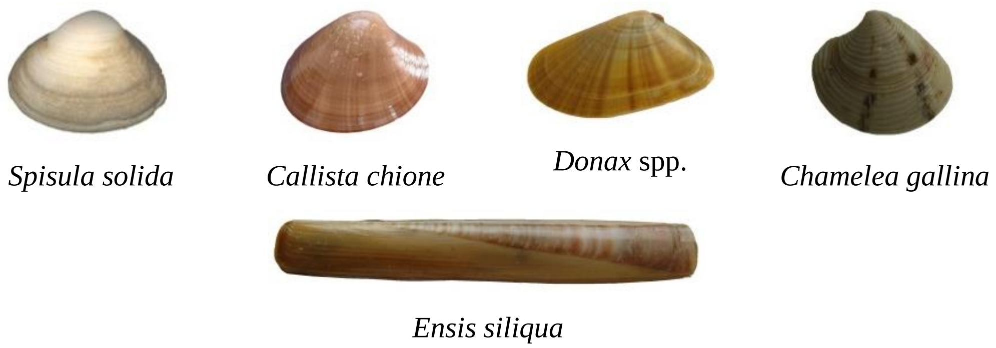

Figure 1-6. Target species of the artisanal dredge fleet. © IPMA

From the five species above, only the surf clam is caught along the entire coast. Moreover, it is the only species targeted by the Northwest fleet, despite the abundance of other species in this fishing area. The donax clam, the striped venus and the razor clam are exploited between Lisboa and Sines (Southwest), and between Lagos and Vila Real de Santo António (South). The smooth clam is only caught in the Southwest area, as its abundance is extremely low in the other two fishing areas.

Due to the sedentary nature of the bivalve species, a good year of exploitation may result in less favorable catches in the following year. Thus, it is often observed a recovery/ exploitation cyclic over the years for the abundance of the different species.

1.2.3 Fishing gears

In this fishery only mechanical dredges are allowed. Dredges are made up of a rigid iron structure with a toothed lower bar, and a collecting system. The main differences between the dredges used in the fishery relate to the shape (semi-circle or rectangular) and length of the dredge mouth, teeth length and the collecting system (mesh bag or metallic frame). The length of the teeth used in the dredges varies according to the target species and takes into account the maximum burrowing depth of the species being harvested. Usually, the length of the teeth used to catch clams does not exceed 20 cm, whilst in the case of the razor clam fishery, the tooth length may reach 60 cm.

Figure 1-7 illustrates the different types of dredges used in the bivalve fishery and Table 1-1 describes the main characteristics of the dredges (source: Leitão *et al.*, 2009).

Traditional Dredge (TD) | North dredge (ND) | Grid Dredge (GD)

Figure 1-7. Different types of dredges (Source: © IPMA).

Table 1-1. Main characteristics of the dredges used by the Portuguese bivalve dredge fleet.

Gear specifications	TD	ND	GD
Weight (kg)	40	95	80
Dredge mouth			
Length (cm)	64	193.5	64
Height (cm)	54	28.5	54
Tooth bar			
Tooth length (cm)	15	12	15
Tooth spacing (cm)	2.2	2	2.2
Retention			
Net bag length (cm)	250	450	-
Mesh size (cm)	2.5	2.5	-
Grid spacement (cm)	-	-	0.8
Mesh shape	diamond	diamond	-

Until 1999, the Northwest dredge fleet only operated with the North dredge (ND) and the Southwest and South dredge fleets with the traditional dredge (TD). In 2001, a new dredge design (grid dredge - GD) was introduced into the fishery and since then the majority of the fleet operating along the Southwest and South coasts of Portugal started using this new gear. This dredge employs a metallic grid instead of a net bag to retain the catch.

Small boats usually work with one dredge, whereas large vessels operate with up to four dredges, which can be deployed and hauled together or individually. Dredges are towed with a cable normally at a 3:1 warp depth ratio. The duration of each tow varies between 1 and 20 minutes depending on the target species (Gaspar *et al.*, 1999).

1.2.4 Catch Handling

Catch handling is an important step in the dredge fishery since the survival of discards can be affected by the on-board processing of the catch and the time that organisms are exposed on the deck of the vessel. The dredges are usually emptied directly onto the deck. The catch is then shoveled into rotary sieves to separate large individuals from empty shells and juveniles, which pass through the grids of the sieve and are returned to the sea (Figure 1-8). The remainder of the catch is collected to baskets or boxes that are emptied on a sorting table and hand-sorted by the crew (Figure 1-8).

Catch shovelling © IPMA

Collection in baskets © IPMA

Figure 1-8. Catch handling procedures undertaken by the Portuguese bivalve dredge fleet.

After sorting procedures, the discards are thrown overboard. In small vessels, the dredge is brought aboard by hand or by a powered winch, and lifted from the rear so that the catch can be dumped out through the mouth. The catches are collected in boxes on the deck. During the next tow, fishers sort the catch manually or using manual sieves. In the razor clam fishery, catches are put into boxes placed on the deck. These boxes are then emptied on a sorting table and sorted by the crew. The discards are collected in baskets and then returned to the sea.

1.2.5 Fishery management

The responsibility for implementing domestic fisheries policy lies with the Ministry of Agriculture, Rural Development and Fisheries, delegated to the Deputy State Secretary for Fisheries, which is assisted by the Directorate General of Natural Resources, Safety and Maritime Services (DGRM). The Portuguese Institute of the Ocean and the Atmosphere (IPMA) has the role of proposing management measures to the Administration in order to protect and maintain fish stocks. The Portuguese dredge fishery is managed at a regional level. With this purpose, three Regional Committees (one for each fishing area) were constituted in the late 90's, with representatives of DGRM, IPMA and fishermen associations. These Committees only have an advisory role in the decision-making process, and meet whenever necessary to discuss management issues related to the dredge fishery. The final decision on the implementation of management measures belongs to the Deputy State Secretary for Fisheries.

In the dredge fishery, the management measures in place intend to reduce or contain effective fishing effort (input controls) as well as to restrict the total catch into predefine limits (output controls). Management input controls include restricted entry to fishery (limited number of fishing licenses), maximum engine power and maximum fishing days per week. Management output controls comprise daily/weekly catch quota per vessel. The quotas are reviewed on an annual basis and can be changed whenever necessary to adjust the fishing effort to the status of the stocks of the target species (Oliveira *et al.*, 2010).

In addition to the control measures above described, other technical measures are also in place, namely limits on gear specifications, minimum landing sizes and seasonal closures (between the 1st of May and the 15th of June) to protect the species during spawning and larvae settlement. Although the majority of the management measures are similar in all three fishing areas (Northwest, Southwest and South), there are differences in terms of number of licenses and daily/weekly quotas.

The exploitation of subtidal bivalve beds along the Portuguese coast is relatively recent, and started only in the late 1960 (Gaspar *et al.*, 2003). Prior to 1986 on Fishing Management Plan (FMP) existed for the dredge fishery and the only management measure in place was the minimum landing sizes definition. Owing to the increase in landings, fishing power and resource conservation concerns, IPMA started a Bivalve Research Program aiming to evaluate stock status. Based on that data, a FMP was designed and a set of management measures were implemented in the fishery in 1986. Apart from technical regulations, such as gear restrictions and fishing seasons, other measures intended to control fishing effort were introduced, namely, maximum engine power and limitation of the number of licenses. Since 1986, based on scientific studies carried out by IPMA, several proposals were suggested to the Administration in order to improve the management of the dredge fishery.

These included the adjustment of some technical characteristics of the gear to the biology and ecology of the target species (see review of Gaspar and Chícharo, 2007). In 1997, the stocks showed signs of overexploitation, which led to the implementation of daily quotas *per* vessel. In that year, a project aiming to quantify and minimize the adverse effects of dredging on the ecosystem was developed.

This research has culminated with the development of a new dredge (the GD already mentioned above in the section "Fishing gears") that proved to be more efficient and selective than the traditional one (the TD also mentioned above in the section "Fishing gears") (Gaspar *et al.*, 2001; Gaspar and Chícharo, 2007). In 2000, the GD was introduced in the fishery. The management measures that regulate the dredge fishery have remained unchanged since then. As aforementioned, the exception is the quotas *per* vessel that (in Northwest and Southwest fleets) has passed from daily to weekly quotas in 2007 and 2009, respectively. The catch quota is reviewed on a yearly basis, taking into consideration the status of the stocks.

In the Northwest, three periods were established, namely: the introduction of maximum daily fishing quotas (MDFQ) (1999 to 2001); the implementation of a maximum weekly fishing quota (MWFQ) during the winter months remaining the MDFQ in the rest of the year (between 2001 and 2007); and the introduction of a MWFQ throughout the whole year (since 2007).

Concerning the Southwest, three significant changes in regulation were identified from 1999 to 2011. These involved: the implementation of MDFQ; the introduction of a new dredge, a drastic reduction in the MDFQ in the end of 2000; and, the implementation of the MWFQ in 2009. The introduction of the MDFQ intended to control catches, adjusting them to the status of the resources, whilst MWFQ *per* vessel aimed at controlling catches but at the same time increasing the profitability of the fishing vessels without compromising the sustainability of the resources. Indeed, MWFQ sought to minimize both the effect of the difficult winter atmospheric conditions, and the constant raises of production costs (particularly the abrupt rise of fuel prices) that were not compensated by the first sale price of the catches at.

A significant change in vessels' operating conditions was the introduction of the new, more efficient type of dredge (GD) that allowed the capture of the same fishing quota in less time (Gaspar *et al.*, 2001, 2003; Gaspar and Chícharo, 2007). Since its use was not mandatory, only the fleets operating in the Southwest and South areas adopted it.

1.3 The assessment of performance

In fisheries, as in most economic activities, resources and materials (inputs) are used to produce goods and services (outputs). The relationship between the amounts of output produced and the inputs used is known as the technology of production. This technology can be defined as being the maximum feasible amount of output which can be obtained from a given set of inputs, or alternatively the minimum feasible amount of inputs that allows obtaining a given set of outputs.

Although several techniques have been developed over the past forty years to estimate the technology of production, frontier techniques are by far the most widely applied in fisheries performance studies. In essence, these techniques consist of estimations of a frontier that envelops all observations considered in the analysis. The distance of an individual observation from the efficiency frontier (the best practice reference which is formed from the fully efficient observations of the data set) enables to quantify a measure of efficiency. Such measure is obtained comparing the observed values of the unit under assessment with the optimal values corresponding to a point on the frontier.

1.3.1 Efficiency measurement

The methods to assess efficiency have evolved following two parallel research lines, namely: parametric and non-parametric methods. The main difference between them relies in the way the frontier is specified and estimated.

The parametric approach specifies the frontier with a precise mathematical form, usually the Translog or the Cobb-Douglas function, which must be selected a priori. The non-parametric approach specifies the frontier based on a set of axioms (Banker, 1984; Banker and Thrall, 1992; Färe and Grosskopf, 2005), without imposing any assumptions related to the functional form of the frontier.

Both methods can further be divided into stochastic and deterministic. In the former method, deviations from the estimated frontier (assessed with the use of statistical techniques) can be explained both by Decision Making Units' (DMUs) inefficiency and noise or measurement error in the data. Concerning the deterministic method, it assumes that the entire deviation from the frontier is caused by DMUs' inefficiency. In this approach, the production frontier is estimated using mathematical programming techniques, which according to Fried *et al.* (2008) is an advantage since this avoids confounding functional form misspecification with inefficiency effects. The different variants of production frontier methods are presented in Figure 1-9.

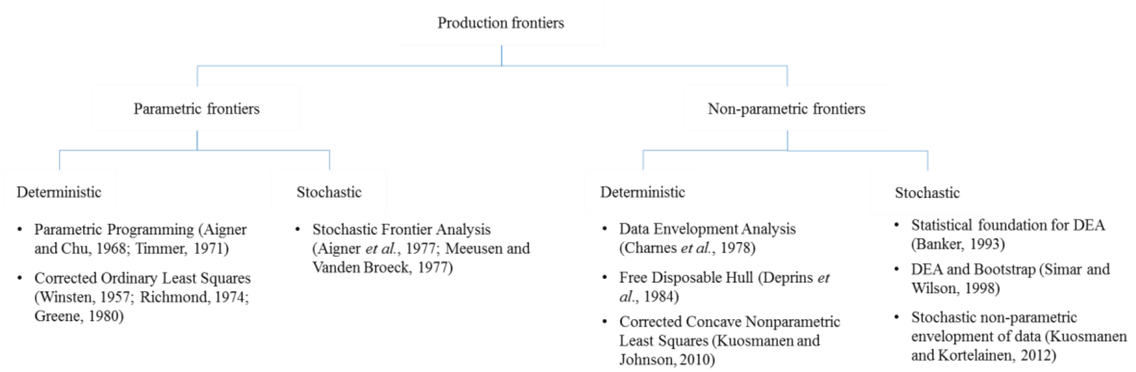

Figure 1-9. Different variants of parametric and non-parametric frontiers. Source: Zanella (2014).

From those, the most commonly used methods in the fisheries literature are Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA).

1.3.1.1 Data Envelopment Analysis

Measuring efficiency with DEA allows the incorporation of multiple inputs and outputs directly in the analysis, and does not require the specification of a structural form for the relationship between the inputs and the outputs, leading to greater flexibility in the frontier estimation.

DEA is a linear-programming based technique that constructs an envelopment production frontier, which from an output oriented perspective 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. For inefficient DMUs, DEA identifies efficient input and output targets and a reference set (or peer group) corresponding to the subset of efficient DMU with which they were compared.

Based on the seminal work by Farrell (1957), the basic DEA model was operationalized and popularized by Charnes *et al.* (1978):

$$
\begin{aligned}
&Max\ \{\delta| \\
&\delta y_{rj_0} \leq \sum_{j=1}^{n} \lambda_j y_{rj} \quad r = 1, \dots, s \\
&\mathrm{x}_{ij_0} \geq \sum_{j=1}^{n} \lambda_j x_{ij} \quad i = 1, \dots, m \\
&\lambda_j \geq 0, \qquad \forall_j \}
\end{aligned}
\tag{1}
$$

In model (1) above, the index j (j =1,...,n) specifies the DMUs that use the inputs x_{ij} (x_{1j},...,x_{mj}) ∈ $\mathbb{R}_+^m$ to obtain the outputs y_{rj} (y_{1j}, ..., y_{sj}) ∈ $\mathbb{R}_+^s$ and δ is a factor representing the proportional improvement to outputs that is required for the DMU j_0 under assessment to reach the frontier of production. This factor is the reciprocal of the efficiency measure. This linear programming model is solved for each DMU under assessment, where $\frac{1}{\delta}$ indicates the efficiency level of that DMU compared with the a virtual producer, located on the efficient frontier (corresponding to a linear combination of other DMUs in the sample, obtained using the multipliers λ_j). As the first restriction defines how much the outputs of the DMU under assessment can be equiproportionally expanded to achieve the levels of the virtual producer, this formulation is called output oriented. The second restriction imposes that the virtual producer uses the same or less of each input than the DMU under assessment.

The DEA model can also be specified with an input orientation, as follows:

$$
\begin{aligned}
&Min\ \{\theta| \\
&\theta \mathrm{x}_{ij_0} \geq \sum_{j=1}^{n} \lambda_j x_{ij} \quad i = 1, \dots, \mathrm{m} \\
&y_{rj_0} \leq \sum_{j=1}^{n} \lambda_j y_{rj} \quad r = 1, \dots, s \\
&\quad \lambda_j \geq 0, \qquad\qquad \forall_j \}
\end{aligned}
\tag{2}
$$

In this case, the first restriction allows determining the minimum levels of inputs for the DMU under assessment that correspond to efficient production levels. The second restriction imposes that the virtual DMU located on the frontier must have at least the same level of each output as the DMU under assessment. The efficiency level of the DMU under assessment is obtained by comparison with a virtual producer, located on the efficient frontier obtained from model (2), and is given by the value of θ, which can vary from 0 (totally inefficient) to 1 (totally efficient). Models (1) and (2) assume the existence of Constant Returns to Scale (CRS), such the efficiency scores obtained using the different orientations are identical, i.e., $\theta = \frac{1}{\delta}$.

1.3.1.2 Stochastic Frontier Analysis

Stochastic Frontier Analysis is a parametric approach that specifies the frontier as a function with a precise mathematical form. Thus, a SFA model requires a priori the specification of the functional form representing the frontier. Aigner *et al.* (1977) and Meeusen and van den Broek (1977) were the first to propose, independently, the stochastic frontier production model as follows:

$$
\ln(y_j) = x'_{ij}\beta_i + v_j - u_j \tag{3}
$$

The DMUs were indexed by j ($j = 1,\dots,n$) and $y_j \in \mathbb{R}_+$ measures the quantity of output of the j^{th} DMU, x_{ij} are the inputs x_{ij} $(x_{1j},\dots,x_{mj}) \in \mathbb{R}_+^m$, and β_i represents the parameters to be estimated.

In model (3), the error term $v_j - u_j$ has two distinct components for each DMU. The v_j component (also known as random error) is similar to that of a traditional regression model and accounts for statistical noise (random variation in output due to factors beyond control of the DMU, such as measurement errors in dependent variables or explanatory variables eventually omitted). Likewise, it is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$. Due to the output values of the model defined in (3) being bounded from above by the stochastic variable $e^{(x'_{ij}\beta_i + v_j)}$, this formulation is called a stochastic frontier. Thus, the random error v_j can be positive or negative varying the stochastic frontier around the values ($e^{(x'_{ij}\beta_i)}$) of the deterministic part of the model (Coelli *et al.*, 2005). The error term u_j is a non-negative random variable, accounting for the existence of technical inefficiency in production. u_j is a non-negative random variable, distributed as half-normal $u_j \sim |N(0, \sigma_u^2)|$.

The SFA is mostly directed towards the prediction of the inefficiency effects being the most common output-oriented measure of technical efficiency, the ratio of the observed output to the corresponding stochastic frontier output (Coelli *et al.*, 2005). Thus the technical efficiency of DMU j is defined by expression (4):

$$TE_j = \frac{y_j}{e^{(x'_{ij}\beta_i + v_j)}} = \frac{e^{(x'_{ij}\beta_i + v_j - u_j)}}{e^{(x'_{ij}\beta_i + v_j)}} = e^{-u_j} \qquad (4)$$

The TE_j value ranges between 0 and 1, measuring the output of the j^{th} DMU relatively to the output that could be produced with the same inputs by a fully-efficient DMU.

1.3.2 Assessment of productivity over time

Efficiency analysis is frequently performed for a specific time period, but changes in productivity over time period is also an issue that should be considered. The change in productivity over time can be analysed when a dataset containing observations on multiple variables observed over multiple time periods is available. Several indexes are used in the literature to measure the changes in productivity over time. Essentially, an index is defined as a real number which measures the changes in a set of related variables, which is used to explore if their values changed over time, over place or both.

Several different approaches are available to perform the assessment of productivity over time, such as the Hicks-Moorsteen, the Törnqvist or Fisher indices, requiring behavioural assumptions of cost minimisation or revenue maximisation, availability of price data for input or output factors, and the specification of a functional form for the production function. The Malmquist index (MI) is an alternative approach that, compared with the other indices, offers a more general picture of productivity change due to the possibility of representing multiple inputs and outputs scenarios without requiring data on input and output prices. In addition, it offers the possibility of exploring the components of productivity change, and thus this technique has become the standard approach to productivity change measurement, with numerous applications reported in the literature.

1.3.2.1 Malmquist Productivity Index

In recent years, the MI, introduced by Caves *et al.* (1982), has become the standard approach to productivity measurement within the non-parametric literature. It was named after Sten Malmquist, who proposed the calculation of indexes using distance functions. The MI approach to productivity measurement has many advantages: (i) it is based on multi input–output frontier representations of the production technology; (ii) the results are obtained using mathematical programming techniques (DEA) that rely on minimum assumptions regarding the shape of the production frontier; and (iii) the index decomposes into multiple components to give insights into the root sources of productivity change.

Caves *et al.* (1982) define a MI relative to a single technology ϕ^t (in (5)) or ϕ^{t+1} (in (6)), considering *n* DMU in time period *t* that use inputs $x^t \in \mathbb{R}_+^m$ to produce outputs $y^t \in \mathbb{R}_+^s$, as follows:

$$M_O^t = \frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)} \tag{5}$$

$$M_O^{t+1} = \frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^t, y^t)} \tag{6}$$

$D_O^t(x^t, y^t)$ is the output distance function, which is defined on the technology ϕ^t as the reciprocal to the maximal feasible expansion of y^t producible from input x^t. The values of M_O^t and M_O^{t+1} may be greater, equal or smaller than one, depending on whether productivity growth, stagnation or decline has occurred between periods *t* and *t+1.* In general, M_O^t and M_O^{t+1} yield different productivity numbers since their reference technologies are different.

The MI was treated only theoretically until its enhancement by Färe *et al.* (1994). A major contribution of this paper was to relax the efficiency assumption and use DEA models (Charnes *et al.*, 1978) for the calculation of the distance functions embodied in the MI. Note that an output distance function coincides with the DEA measure of technical efficiency.

Therefore, linear programming models can be used to compute the MI. Färe *et al.* (1994) defined an output-oriented productivity index as the geometric mean of the two Malmquist indexes referring to the technology at time periods t and $t+1$, (5) and (6) respectively, yielding the following Malmquist measure of productivity:

$$I^{t+1,t} = \sqrt{\left(\frac{D_O^t(x^{t+1},y^{t+1})}{D_O^t(x^t,y^t)} \cdot \frac{D_O^{t+1}(x^{t+1},y^{t+1})}{D_O^{t+1}(x^t,y^t)}\right)} \tag{7}$$

Another major achievement of Färe *et al.* (1994) was to show how to decompose the index (7) into an index of technical efficiency change and an index reflecting the change in the frontier of the production possibility set, *i.e.*, an index of technological change. These components are obtained by rewriting the index (7) as follows:

$$I^{t+1,t} = \frac{D_O^{t+1}(x^{t+1},y^{t+1})}{D_O^t(x^t,y^t)} \cdot \sqrt{\left(\frac{D_O^t(x^t,y^t)}{D_O^{t+1}(x^t,y^t)} \cdot \frac{D_O^t(x^{t+1},y^{t+1})}{D_O^{t+1}(x^{t+1},y^{t+1})}\right)} \tag{8}$$

The ratio outside the square root measures the technical efficiency change between time periods t and $t+1$. The geometric mean of the two ratios inside the square root captures the technological change (or shift in technology) between the two periods, evaluated at the input–output levels at $t(x^t, y^t)$ and at $t+1(x^{t+1}, y^{t+1})$. Overall, improvements (decline) in productivity yield MI ($I^{t+1,t}$) with values greater (smaller) than unity.

The output-oriented MI requires the estimation of within-period and mixed-period efficiency scores using DEA models. Whilst the single period distance function is always less than or equal to one, in the mixed-period assessments required for the estimation of the MI, the value of the output distance function may be smaller or greater than unity. This is because the input–output combination observed in one period may not be feasible within the technology in another period. This corresponds to the super-efficiency concept proposed by Andersen and Petersen (1993). The DEA models required for the estimation of the MI can be found in Coelli *et al.* (1998). For a review of the literature on the theoretical developments and applications on the MI see Färe *et al.* (1998).

1.4 Review of the literature on performance assessment in fisheries

Ultimately, fisheries management has the task to ensure sustainable development. The three pillars of fisheries sustainability are based on economic, social and ecologic dimensions. From an economic perspective, the resources available should be well used. One of the most studied issues in worldwide fisheries is the capacity utilization applied to industrial fleets in order to analyse the availability of the resources and their adequacy to the abundance (or catch quotas) of the target species (e.g. Dupont *et al.*, 2002; Kirkley *et al.*, 2003; Tingley *et al.*, 2003; Vestergaard *et al.*, 2003; Pascoe and Herrero, 2004; Tingley and Pascoe, 2005a). Notwithstanding, a capacity study can also be carried out as an approach to highlight possible non-declared landings. Basically, if a vessel is systematically underutilizing its capacity, it is important to explore the factors that may be contributing to this fact.

Another issue frequently analysed in fisheries under an economic perspective is the efficiency level. Most studies focused on technical efficiency, evaluating vessels' ability to use the right level of resources to produce the outputs. Some others are focused on the ability of the vessel to maximize the revenue obtained from the catch, given the resources available, the fishing effort (inputs), and the prices of the target species (output prices). These output oriented studies are known as revenue efficiency studies (e.g., Lindebo *et al.*, 2007), but studies focusing on cost efficiency, with an input orientation but a similar interpretation are also available (e.g. Alam and Murshed-e-Jahan, 2008). When data of input and output prices are available, the analysis can also be directed to profit efficiency (e.g. Pascoe and Tingley, 2006).

Performance can also be analysed over a predefined time window. The assessment of productivity change over time is frequently approached in the fisheries literature. At times, the analysis aims to clarify the factors behind the inefficiency of the fleets. In fact, different factors that can cause disruptions to production, such as fishing experience, fishermen skills, effort, management policies, among others (e.g. García del Hoyo *et al.*, 2004; Solis *et al.*, 2012; Shen, 2012; Onumah and Acquah, 2010; Kareem *et al.*, 2012; Jamnia *et al.*, 2013).

From a methodological perspective and regarding the analysis of productivity's change over time, the techniques used vary according the data available. Several studies have analysed it of fishing fleets using Total Factor Productivity techniques (e.g. Jin *et al.*, 2002; Hannesson, 2007; Eggert and Tveteras, 2013), profit index decomposition methods (e.g. Fox *et al.*, 2003, 2006), a transformation function production model (Felthoven *et al.*, 2009), and the Malmquist Index (e.g. Hoff, 2006; Walden *et al.*, 2012).

On other hand, the nonparametric DEA models are mostly applied to estimate efficiency levels, and are also widely applied to estimate fleet's capacity. The use of DEA can combine in the same model different types of inputs, such as vessel characteristics, fishing effort, operational resources and stock abundance indices (e.g. Sharma and Leung, 1999; Kirkley *et al.*, 1995, 1998; Pascoe and Coglan, 2002). Concerning the output factors, most studies, both in single and multispecies fisheries, use the landed weight of the catches (e.g. Sharma *et al.*, 1999; Pascoe and Herrero, 2004; Hoff, 2006; Lindebo *et al.*, 2007; Pascoe *et al.*, 2013) or the value of the catches (e.g. Maravelias and Tsitsika, 2008; Idda *et al.*, 2009).

The use of parametric SFA models in the fisheries context is mostly directed towards the explanation of the inefficiency levels, due to the assumption that deviations from the production frontier may not be entirely under the control of the DMU (i.e., vessel) and explained by contextual factors.

The combined use of SFA and DEA has also been reported by some authors to test the robustness of the results by the comparison of both parametric and nonparametric approaches for the measurement of technical efficiency and productivity (e.g. Pascoe and Mardle, 2003; Kim *et al.*, 2011; Ghee-thean *et al.*, 2012; Collier *et al.*, 2014).

Regardless the amount and variety of studies in the fisheries literature, few of them focused on SSF (e.g. Colloca *et al.*, 2004; Oliveira, 2005; Idda *et al.*, 2009; Oliveira *et al.*, 2009). In fact, several issues remain unclear concerning SSF. Especially, in those cases where the fishery is regulated by quotas or other technical restrictions, such as gear features, number of licenses available, closure periods during which the fishing activity must be stopped, to be best of our knowledge there are no studies reflecting the effects of such measures in the efficiency of the fleets. Furthermore, in SSF, the performance assessment models rarely include data on social and environmental aspects of the ecosystem, due to the lack of data available. This thesis intends to fill this gap, by the development of models that can help fisheries managers to design better policies to guide SSF towards sustainable development, taking into account economic, social and ecological aspects associated to the coastal areas where these fisheries take place.

1.5 Motivation and research objectives

The sustainability of SSF is desirable for a balanced social, economic and ecologic development of coastal areas. In this context, it is extremely important to develop new management tools and models that integrate not only biological parameters of the resources exploited but also social and economic variables. However, studies about artisanal fleets and fisheries are quite scarce, mostly due to data unavailability for this particular segment of fishery.

The main purpose of this thesis is to contribute to the long-term sustainability of the artisanal bivalve dredge fleet that operates in mainland Portugal. In order to accomplish this, four distinct objectives were addressed, as follows:

- To identify the characteristics of the vessels and the best-practices to be followed in local and coastal fleets in order to improve the results from the fishing activity (chapters 2 and 3).

- To understand how the changes in vessel's yearly quota and shifts in the quota regime may affect vessels' productivity (chapter 4).

- To explore the existence of demand seasonality and its effects on the performance of the fleet at a national level (chapter 5).

- To investigate the effect of Harmful Algal Blooms (HAB) on the revenue of the dredge fleet (chapter 6).

Throughout the research, an effort was made to ensure that the models and methodologies developed in the context of the artisanal dredge fishery could be applied to other artisanal fisheries (especially those managed by a quota regime).

1.6 Thesis summary

This thesis was written in the format of papers' collection (commonly called a compilation thesis). The papers follow the research objectives described in the previous section, and the thesis is divided into seven chapters, which can be summarised as follows.

Chapter 1 describes the general context of the thesis research and introduces the Portuguese artisanal dredge fleet. It provides a description of the fishing areas, technical characteristics of the vessels, target species, fishing gears, catch handling, and fishing management practices. The different methodological approaches to the evaluation of fisheries performance were also reviewed, as these underlie the analysis used in this thesis to pursue the research objectives. Finally, the specific research objectives of the thesis are outlined.

In Chapters 2 and 3, the technical, allocative and revenue efficiency of the dredge fleets operating in the different fishing areas along the coast of mainland Portugal were explored. Chapter 2 is focused on the South fishing area between 2005 and 2007 whereas Chapter 3 replies the study to the Western coast between 2006 and 2012. The main purpose of these chapters was to identify the best-practices to be followed in all fleets, including the specification of the most appropriate features of the vessels in terms of inputs. DEA models were used to assess the efficiency of each vessel, considering fixed and variable inputs (vessel power, overall length, tonnage, an indicator of stock biomass and number of fishing days). Being a fishery controlled by maximum fishing quotas, an annual quota per vessel was also included in the model as a contextual factor. A two-dimensional graphical representation of vessel's performance enabled to identify the benchmark vessels, not only in terms of those that maximized the weight of the catch for the landed species (considering their inputs), but also the vessels that selected the most appropriate target species, maximizing the revenue of the fishing activity (considering output prices). The definition of targets for inefficient vessels was also addressed.

Chapter 4 investigated the effects on productivity levels of changes in quota regimes and limits to captures attributed to each vessel. In order to accomplish this, bootstrapped Malmquist indices, complemented with an efficiency assessment using a directional distance function, were used to quantify productivity change for the fleets operating in the Western coast. With the results obtained, a hypothetical scenario was explored for the South fleet, intending to analyse the impact of changes in the quota regime in this area, consisting of the specification of weakly quotas instead of daily quotas.

Chapter 5 studied the impact of seasonality on fleets' performance along the year. The monthly fluctuations of fleets' revenue efficiency (RE) were studied in the three fishing areas. The monthly seasonality impact on fleets' revenue efficiency was explored using Tobit regression, taking also into account the mean wave height in the different fishing areas to screen any effects of this factor on the RE of the fleets.

Chapter 6 addresses a very important and actual issue: the effect of HAB on the performance of the Portuguese artisanal dredge fleet. A SFA model was used with data on daily activity of vessels from each of the three fleets analysed (Northwest, Southwest and South) for a seven year period. The phycotoxins presence and intensity was modeled as an index that indicates, by fishing area and on a daily basis, the sum of interdicted species by bivalve production zone.

Chapter 7 integrates all the results obtained through the different chapters/papers and present them in a managerial perspective. Thus, each fishing area is globally analysed, and suggestions of management policies to be adopted in the light of the results obtained are put forward. In addition, the scientific contributions of the thesis for the performance measurement literature are also described, highlighting the innovations of the models used, as well as the main additions to the literature on performance evaluation in fisheries. At the end of the chapter, an agenda for future research is proposed.

CHAPTER 2. Technical and economic efficiency analysis of the Portuguese artisanal dredge fleet[1]

Abstract: An efficiency analysis of the commercial dredge fleet operating along the South coast of Portugal between 2005 and 2007 sought to determine the efficiency of the vessels using data envelopment analysis models, considering fixed inputs (vessel power, length, tonnage, and an indicator of stock biomass) and a variable input (number of days at sea). The annual quota per vessel was also included in the model as a contextual factor. In the technical-efficiency (TE) analysis, outputs were defined by the catch weight for each of the three target species (bivalves). Using price data for each species in the wholesale market, revenue efficiency was also estimated to complement the TE analysis. The advantage of the approach lies in the ability to separate technical aspects from allocative aspects in the efficiency assessment, allowing two-dimensional graphic representation of vessel performance. The procedure allows the identification of benchmark vessels, which maximized the catch weight of the species landed, given their inputs, as well as the vessels that selected the appropriate target species to maximize the revenue of the fishing activity, given output prices. The approach also allowed the specification of targets for inefficient vessels that correspond to the catch by species, permitting revenue maximization from fishing.

Keywords: artisanal fishing, clam fishery, data envelopment analysis, dredge fleet, revenue efficiency, technical efficiency.

[1] Oliveira, M.M., Camanho, A.S., and Gaspar, M.B. (2010). Technical and economic efficiency analysis of the Portuguese artisanal dredge fleet. ICES Journal of Marine Science, 67(8):1811-1821.

2.1 Introduction

Interest in studying the efficiency of fisheries has gained momentum in recent years. During the past two decades, experts from distinct areas of research, such as marine biology, economics, and management, have explored this topic, often in collaboration with fishing communities. Multidisciplinary studies were carried out in an attempt to understand fishing activity. However, fisheries are complex systems involving several variables that interact with each other, and whose causal relationships and feedback loops are often difficult to model. The unit of analysis of fisheries efficiency studies is usually the vessel, the efficiency of which has a direct impact on the catching ability of a fleet, which itself depends on the state of the resources being exploited. The impact of fishing activity on those resources requires regulation by restricting access and harvest to guarantee sustainability of the fisheries. The restrictions will be reflected in the behaviour and strategy adopted by fishers to deal with the regulations.

Previous fisheries efficiency studies aimed at estimating fishing capacity, determining the potential catch from the fleet, or an optimal catch composition. Different types of data have been collected and analysed to bring insights to the issues identified. However, unlike the case of efficiency analysis in an industrial context, where it is generally possible to identify a production process for individual outputs, fishing activity is often characterized by joint input–output production (Kirkley and Squires, 2003). In other words, a combination of different types of output, i.e. the catch of different species, is obtained from a given set of inputs (fishing effort). The inputs could be of different types, but often, existing data availability constrains the selection of the variables used in the models.

From an output-orientated perspective, the technical efficiency (TE) of a vessel results from a comparison between landed catches and some ideal or potential catches. The estimate of TE for each vessel is based on a measure of distance between the actual landings (output) and a point at the frontier (limit) of the production possibility set, corresponding to the maximum catch levels. When the production of a vessel is at that frontier, it is considered efficient. If not, the distance between its production and the frontier will define how technically inefficient the vessel is compared with other vessels in the fleet. Enhancing this efficiency assessment can lead to the estimation of revenue efficiency, which requires information on output prices.

Revenue efficiency measures the ability of the vessel to maximize the revenue obtained from the catch, given the resources available, the fishing effort (inputs), and the prices of the target species (output prices). Therefore, revenue efficiency requires vessel production to be located at the frontier of the production possibility frontier, i.e. TE, as well as a good choice of the catch composition in light of the prices of target species (i.e. allocative efficiency). More formally, it can be stated that revenue efficiency is the product of two components, corresponding to TE and allocative efficiency.

Data envelopment analysis (DEA), a non-parametric, linear programming method, estimates a production frontier from the best-practice observed in a sample, estimates the distance of every decision-making unit (DMU) to this frontier, and allows multiple inputs and outputs to be included in the analysis. This is an advantage in fisheries, because a catch is often multispecies. It is also possible to model cases where price and cost data are not available, or when it is inappropriate to assume that the DMU assessed (vessels) are cost minimizers or revenue maximizers. Therefore, DEA has been successfully applied not only in estimating TE, but also in capacity utilization in fisheries worldwide (Dupont *et al.*, 2002; Kirkley *et al.*, 2003; Tingley *et al.*, 2003; Vestergaard *et al.*, 2003; Pascoe and Herrero, 2004; Tingley and Pascoe, 2005a, b). More recently, revenue maximizing (Lindebo *et al.*, 2007) or profit maximizing behaviours (Pascoe and Tingley, 2006) have been explored in the assessments.

Productivity change over time is also an issue that has been explored in fisheries using Malmquist indices, which can be calculated using the DEA models. The study by Hoff (2006) was the first to use the Malmquist index in fisheries, and it analysed the fleet of Danish seiners operating in the North Sea and Skagerrak between 1987 and 1999. That study was followed by others, such as that of Oliveira *et al.* (2009), who first applied this method to artisanal fisheries.

Efficiency studies require data on input factors such as vessel characteristics, fishing effort, or operational costs. Sharma and Leung (1999) analysed the longline fishery in Hawaii and used crew size (number of persons), trip length (days per trip), and operational costs (e.g. fuel, bait, and ice) as inputs. Kirkley *et al.* (1995, 1998) analysed the US Mid-Atlantic sea scallop fishery and used days at sea, crew size, and stock abundance as inputs.

In another study involving mobile fishing gears, Pascoe and Coglan (2002) selected as inputs a measure of boat size (deck area), engine power, number of hours fished, and a stock abundance index. In that case, crew size was not used as an input because it was argued that the size of the boat and the number of crew were correlated, i.e. bigger boats have more fishers on board. The output from fishing is not just a function of the resources employed by the fishers, but also depends on the biological stock available for the target species. Most of the species exhibit variations in seasonal abundance during and between years and between different areas.

However, the lack of a stock-biomass indicator is a common problem in fisheries. For that reason, most studies assume a constant level of stock biomass; for example, Sharma and Leung (1999) used cross-sectional data for 1 year and did not include a measure of stock because it was assumed to be constant during that year. Some authors adopted different approaches to overcome the problem related to the lack of stock indicators. Kirkley *et al.* (1995, 1998) derived a stock index from a fishery-independent survey of the scallop fishery, and Coglan *et al.* (1998) used a series of dummy variables to represent changes in stock conditions during and between years.

In relation to the output variables of efficiency analysis, most studies in both single and multispecies fisheries use the landed weight of the catch (Sharma *et al.*, 1999; Pascoe and Herrero, 2004; Hoff, 2006; Lindebo *et al.*, 2007). In some cases, however, the outputs specified were the value of the catches (Tingley *et al.*, 2005; Maravelias and Tsitsika, 2008; Idda *et al.*, 2009). As argued in Herrero and Pascoe (2003), revenue and total catch weight in single-species fisheries are often proportional, resulting in similar efficiency measures.

However, in multispecies fisheries, the different approaches to the specification of the outputs reflect different purposes of the study. Assuming that a fisher's effort is directed to maximizing revenue, then the efficiency assessment must take into account both the quantities captured as well as their relative prices. To assess vessel efficiency in terms of the ability to maximize revenue, Färe *et al.* (1994) suggested that instead of defining outputs as the measures of revenue and evaluating the efficiency using the standard DEA model of Charnes *et al.* (1978), which only searches for equiproportional augmentation of the outputs, a more appropriate specification of the model would be to separate the revenue data into quantity and prices. This permits inclusion of the output corresponding to the catch weight per species in the constraint set of the linear-programming model, such that the production possibilities in terms of catch weight for each species are enforced and include information on output prices per species in the objective function. This is the approach followed here, and it assumes revenue-maximizing behavior and distinguishes technical aspects of catch weight from allocative aspects that are determined by the relative prices of the different species.

Despite the long list of studies published on efficiency assessment in fisheries, few have been directed towards the artisanal fleet segment. This specific commercial fleet segment is characterized by poor or even non-existent data collection in many countries.

Illegal captures, the use of unlicensed gears, and the general disrespect for regulations are some of the problems identified frequently. However, the importance of these fleets and their social role cannot be disregarded. Although the income achieved is quite low compared with industrial fishing fleets, artisanal fisheries and fishing-related activities often support entire coastal communities. In Portugal, more than 6000 fishers operate in artisanal fisheries, and direct and indirect jobs generated by fishing-related activities can be three times this number. More than analyzing their efficiency, it is critical to understand the measures that need to be implemented to promote sustainability of this activity.

The current study explores the technical, allocative, and revenue efficiency of the artisanal bivalve dredge fleet that operated along the South coast of Portugal between 2005 and 2007. The fishery is considered to be one of the most important artisanal ones, because of the number of fishers and vessels involved and the volume and high value of the catches. The main objective of the study was to identify the characteristics of the vessels and the best-practices to be followed in the local and the coastal fleets that would improve the results from the fishing activity.

2.2 Material and methods

DEA is a linear-programming, non-parametric technique for measuring the relative efficiency of a fairly homogeneous set of DMU in their use of multiple inputs to produce multiple outputs. It identifies a subset of efficient "best-practice" DMU; for the others, the magnitude of their inefficiency is derived by comparison with a frontier constructed from best-practice. DEA derives a single summary measure of efficiency for each DMU.

For inefficient DMU, DEA identifies efficient input and output targets and a reference set (or peer group) corresponding to the subset of efficient DMU with which they were compared directly. Based on the seminal work by Farrell (1957), the DEA model was operationalized and popularized by Charnes *et al.* (1978). There are several extensions of the original model, from which we selected a formulation with upper-bound constraints on the outputs (Cooper *et al.*, 2000, p. 224) to use in the study. These models are particularly useful for evaluating quota-managed fisheries because, in such cases, a vessel may not be able to expand its output fully because its catches are capped by regulation.

Therefore, the quota needs to be considered as the upper bound for the output variables representing catch weight. Consider *n* Decision Making Units (DMU), defined by *j* ($j = 1,...,n$), which use the inputs x_{ij} $(x_{1j},...,x_{mj}) \in R_+^m$, to obtain the outputs y_{rj} $(y_{1j}, ..., y_{sj}) \in R_+^s$. Assume that the maximum value of the sum of all outputs is bounded by the quota limit Q_{j0} for each DMU_{j0}. The efficiency of each DMU_{j0} is given by the reciprocal of the factor (δ) by which the outputs of the DMU_{j0} can be expanded, obtained from the following model based on Cooper *et al.* (2000):

$$\begin{aligned}
&max\{\delta \mid \\
&x_{ij_0} \geq \sum_{j=1}^{n} \lambda_j x_{ij}, \quad i = 1, \dots, m \\
&\delta\, y_{rj_0} \leq \sum_{j=1}^{n} \lambda_j y_{rj}, \quad r = 1, \dots, s \\
&\sum_{r=1}^{s} \sum_{j=1}^{n} \lambda_j y_{rj} \ \leq Q_{j_0}, \\
&\lambda_j \ \geq 0, \ \forall_j \}
\end{aligned} \tag{1}$$

The DEA model used in this paper is output oriented, since we assume that the vessels analysed try to maximise daily catches given the resources available. The value of $\frac{1}{\delta^*}$ is a measure of the technical efficiency (TE) of DMU_{j0}, which assumes the existence of constant returns to scale (CRS).

The main difference between model (1) and the formulation proposed by Cooper *et al.* (2000) 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 efficiency assessments concerns the specification of peers (i.e. benchmarks) and targets for inefficient units. The benchmarks for the DMU$_{j0}$ under assessment are the units with values of λ_j^* greater than zero in the optimal solution to model (1). Since the vessels were analysed with an output oriented perspective, the estimation of output targets for each DMU$_{j0}$ 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).

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

According to Koopmans (1957, 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.* (2000, p.45).

Next we introduce the DEA model for the estimation of economic efficiency, following Farrell (1957) concepts. Farrell (1957) described a cost minimization assessment, corresponding to the assumption that the DMU intend to produce current outputs at minimum cost, given the input prices.

The concept of economic efficiency can be generalised to an output oriented assessment, corresponding to the measurement of revenue efficiency, whose definition is as follows: revenue efficiency measures the ability of a DMU 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$_{j0}$, 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 (3).

The model follows the formulation originally proposed by Färe *et al.* (1985), but has additional restrictions to reflect the fact that the captures are bounded by the quotas (Q_{j_0}) imposed by fisheries regulatory conditions.

$$
\begin{aligned}
& max\left\{\sum_{r=1}^{s} p_{rj_0}\, y_r^0 \;\middle|\right. \\
& \sum_{j=1}^{n} y_{rj}\,\lambda_j \geq y_r^0, \quad r = 1,\dots,s \\
& \sum_{r=1}^{s}\sum_{j=1}^{n} \lambda_j y_{rj} \;\leq Q_{j_0,} \\
& \sum_{j=1}^{n} x_{ij}\,\lambda_j \leq x_{ij_0}, \;\; i = 1,\dots,m \\
& \lambda_j \;\geq 0, j = 1,\dots,n \\
& \left. y_r^0 \;\geq 0, i = 1,\dots,m \right\}
\end{aligned}
\tag{3}
$$

In the formulation above, p_{rj0} is the price of output r for the DMU$_{j0}$ under assessment. In this paper we specified the output prices for each vessel as the average price for each species in the vessel's port of landing. y_r^0 is a variable that, at the optimal solution, gives the amount of output r to be produced by DMU$_{j0}$ in order to maximise the revenue, subject to the technological restrictions imposed by the existing production possibility set. Note that this model assumes that the price data for each output (i.e., in our case the price payed for the species captured by each vessel) is known. This price may vary between vessels.

Revenue efficiency is then obtained, for each DMU$_{j0}$, as the ratio of current revenue observed at DMU$_{j0}$ to the maximum revenue estimated by the optimal solution to model (3), 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 captured. 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:

$$\text{Revenue efficiency } j_0 = \text{Technical efficiency } j_0 \times \text{Allocative efficiency } j_0 \qquad (5)$$

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 (1). 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.

In order to provide a graphical illustration of these efficiency concepts, consider a set of DMU that produce two types of outputs (Y_1 and Y_2) using a single resource (X), as shown in Figure 2-1. In the context of fisheries analysis, the outputs could represent the amounts (kg) of two different species captured, and the resource could be the operational costs, measured in euros.

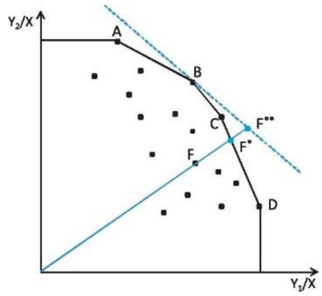

Figure 2-1. An Illustration of the efficiency measures.

Figure 2-1 represents in the axes the captures per unit of resources consumed, to enable a two dimensional representation of the production possibility set. The segments linking DMU A, B, C and D form the technical efficient production frontier. DMU F will be used to illustrate the efficiency concepts. Technical efficiency is given by the ratio $\frac{OF}{OF^*}$. A ratio smaller that one indicates that it is possible to increase proportionally the quantities captured of both species without requiring an increase in the consumption of resources.

Looking beyond technical efficiency, it is also possible to measure revenue efficiency, assuming a revenue maximisation behaviour. This requires the specification of an isorevenue line, i.e., a line in which all points have the same revenue value (the dashed line in Figure 2-1). Its slope is equal to the observed prices ratio at the DMU F under assessment (i.e., $-\frac{P_1}{P_2}$, where P_1 is the price paid for output 1 and P_2 is the price paid for output 2). Comparing points F^* and B on the production frontier, although they both exhibit 100% technical efficiency, the revenue at F^* is only a fraction $\frac{F^*}{F^{**}}$ of the revenue at F^{**}. This ratio is defined as the output allocative efficiency of F.

Output allocative efficiency attempts to capture the inefficiency arising solely from the wrong choice of technically efficient output combinations given output prices, i.e., measures the extent to which a DMU produces the various outputs in the best proportions in the light of their prices. If DMU F were perfectly efficient, both technically and allocatively, its revenue would increase in relation to the current level. The ratio gives $\frac{F}{F^{**}}$ is a measure of economic efficiency. It indicates the extent to which the DMU is obtaining the maximum revenue given the resources consumed and the existing prices.

2.2.1 The dredge fleet

The artisanal dredge fleet studied operates along the South coast of Portugal. Its vessels can be classified into two categories: local and coastal. The first group has a low level of motorization, limited or even absent hauling equipment, overall length 9 m, and an average crew of two. Such vessels can only operate in the area of the home port of registry or adjacent home ports. Coastal vessels have an overall length of 9–14 m, operate all along the coast of the Algarve, and generally have a crew of three or four. The gross tonnage (GT, the measurement by which restrictions on catch by species and vessel are applied) of local vessels varies between 1.18 and 9.41 and between 3.19 and 23.64 in coastal vessels. Dredge vessels that operate along the Algarve have mostly glass fibre hulls and their engine power is below the national average of the dredge fleet as a consequence of the hydrodynamic characteristics of the coast along which they operate. The bivalve beds along the Algarve coast are located in the area of jurisdiction of four ports of registry: Faro, Olhão, Tavira, and Vila Real de Santo António (Figure 2-2). Although Fuzeta is not a port of jurisdiction, some vessels also depart from there, so it is also shown on the map.

Figure 2-2. Main fishing home ports and the locations of bivalve banks along the South coast of Portugal.

The type of gear used in the fishery is the grid dredge (Figure 2-3). All vessels use dredges with similar width, and a detailed description of the gear is given by Gaspar *et al.* (2003). The target species of the dredge fleet along the Algarve coast and considered here are the surf clam (*Spisula solida*), the donax clam (*Donax trunculus*), and the striped venus clam (*Chamelea gallina*). In a single trip, effort may be directed at all three species, but their sedentary nature means that fishing does not rely on chance fishing alone. Limited to a greater or lesser extent by the type of vessel they own, fishers know exactly where to head when they leave port, taking into account the type of species they intend to capture.

Figure 2-3. The dredge used in the Portuguese clam fishery.

Fishing activity is subject to regulation, and the main conditions that have to be adhered to are (i) an annual temporal closure to protect the species during spawning and larvae settlement (the seasonal closure is imposed from 1st May to 15th June), and (ii) daily fishing quotas per vessel tonnage and per species.

2.2.2 Input and output variables

The data used in this study were provided by the Portuguese General Directorate of Fisheries and Aquaculture (DGPA) and the National Institute of Marine Research (INRB-L/IPIMAR) and focused on the dredge fleet operating along the South coast of Portugal between 2005 and 2007. The vessels were divided into local and coastal subsegments. In total, 28 local vessels operated in 2005, but the analysis reported in this paper excluded one of them, because it was considered to be an outlier in that year. One of the vessels from the fleet did not operate in 2006 and 2007, so in all the years considered, the number of vessels analysed was 27.

The number of coastal vessels was 25 in 2005, but the number decreased to 20 in 2006 and 2007. All models were applied to both subsets separately, and the results reflect this split. The differences in vessel characteristics and limits on their operation along the coast motivated this split. Both fleets direct their fishing effort at different species, and the differences in the capture composition reflect differences in the fishing strategy adopted.

In relation to the variables defined for the DEA analysis, three outputs were used, corresponding to the total quantity landed by species in the year analysed (Table 2-1). To estimate the revenue efficiency of the fishing activity, the analysis required collecting data for all vessels on the landed value of each species.

For each port, the average price for each of the target species was calculated by dividing the landed value by the quantity (kg) landed. The input variables used were, as fixed factors, overall vessel length (m), GT, vessel engine power (kW), and a stock-biomass indicator for each target species (g *per* 5-min dredge tow), and as the variable factor, effective days at sea.

Table 2-1. Profiles of the local and the coastal fleets, 2005–2007.

	Local fleet (means)			**Coastal fleet (means)**		
	2005	2006	2007	2005	2006	2007
Inputs						
Overall length (meters)	7.2	7.3	7.3	10.8	10.9	10.9
GT (ton)	3.9	4.1	4.1	9.0	9.6	9.6
Engine power (kw)	61.3	62.5	62.5	88.5	87.2	87.2
No. days at sea	135.5	112.8	143.4	155.2	139.9	172.1
Surf clam stock (g per 5 min tow dredging)	170.0	73.0	113.0	170.0	73.0	113.0
Donax clam stock (g per 5 min tow dredging)	51.0	42.0	42.0	51.0	42.0	42.0
Striped venus stock (g per 5 min tow dredging)	361.0	291.0	113.0	361.0	291.0	113.0
Contextualizing factor						
Annual fishing quota per vessel (kg)	39667.4	32504.2	42615.9	61596.5	54616.0	67119.0
Outputs						
Capture of surf clam (kg)	213.1	109.6	409.2	21505.8	6335.9	9461.0
Capture of donax clam (kg)	8041.2	5828.2	5907.4	6781.9	5127.4	5742.5
Capture of striped venus (kg)	7288.9	5545.3	2471.2	14069.0	12077.0	5412.9
Output prices						
Prices of surf clam (€)	0.50	0.50	0.51	0.50	0.50	0.51
Prices of donax clam (€)	1.62	1.62	1.66	1.52	1.52	1.53
Prices of striped venus (€)	1.50	1.50	1.50	1.50	1.50	1.50

The stock-biomass indicator was obtained from bivalve research surveys specifically aimed at evaluating the conservation status of commercial species. Such surveys are conducted annually on board IPIMAR research vessels. Details on sampling design and operational procedures are given by Rufino *et al.* (2010).

The annual fishing quota per vessel (kg) was used as a contextualizing factor that bounded the output expansion allowed for each vessel. The annual fishing quota was calculated by multiplying the daily quota for all species captured (*per* GT) and the effective days at sea of each vessel. The number of effective days at sea was taken as the number of days on which a vessel landed a catch. This is a realistic measure for days at sea because in this fishery, each vessel can only make one trip per day, and each trip always implies some catch, because the target species are in known, fixed locations.

From Table 2-1, it is clear that the catch composition varies between years. In 2005, the main target species were surf clam and striped venus (38 and 37% of total catches, respectively), in 2006, the main target species was striped venus (50% of total catches), and in 2007, surf clam and donax clam were the main target species (34 and 40%, respectively). The catch composition is related to species abundance and the regulations on catch quota. As there were no significant changes in quotas during the years considered, it is our opinion that catch composition is driven by changes in stock biomass.

To be able to obtain significant results for the efficiency assessment, we decided to run models where the unit of analysis was the vessel operation in a given year, but the models were run for a pooled sample with vessels from all years combined. This is a reasonable comparison, because the potential differences in operating conditions between years are related to stock abundance, which is accounted for in the model by defining stock level as an input. In summary, efficiency was estimated with 81 DMU for the local fleet and 65 DMU for the coastal fleet.

Although the number of inputs and outputs used in the DEA model is large (seven inputs and three outputs), the use of a pooled sample with 81 vessels for the local fleet and 65 vessels for the coastal fleet allowed us to generate sufficient discriminatory power in the assessment. The rules concerning the relationship between the total number of DMU and the total number of variables included in the DEA model proposed by Banker *et al.* (1989), i.e. the number of DMU should be at least threefold more than the sum of the number of inputs and outputs, and Dyson *et al.* (2001), i.e. the number of DMU should be at least twofold more than the product of the number of inputs and outputs, were both satisfied.

In terms of the prices paid for each species, perhaps the local fleet achieved a better wholesale price than the coastal fleet for donax clam. This apparent advantage for local vessels can be explained partly by the auction system (descent price); clams landed first are sold at a higher price. Operating nearer the coast, local vessels can arrive first at the wholesale market.

2. 3 Results and discussion

2.3.1 Catch composition

Figures 2-4 and 2-5 show the landed catch composition for local and coastal vessels, respectively. The different choices of target species are well demonstrated and result directly from the characteristics of the vessels. The small length and low engine power allow the local fleet to operate only in very shallow water, where the most abundant species is the donax clam. The coastal fleet has a different capture pattern, as shown in Figure 2-5. That fleet has more powerful engines, more equipment, and a larger operational area. Vessels expend more fuel to reach the fishing grounds, but they also have a different catch composition. It is easier for those vessels to manage the order lists by species received on land before they sail and to deal with adverse atmospheric conditions, biological restrictions, and bivalve-bed location.

Figures 2-6 and 2-7 show the total landed catch by weight (t) and value (10^3€), respectively, for the species caught by the local and the coastal fleets. Despite their smaller capacity, operational area, and fishing effort, the local fleet achieved, on average, ~42% of the total income (Figure 2-7) from 2005 to 2007. However, the larger operational area of the coastal fleet and its ability to diversify catch composition yielded more income for the same fishing effort.

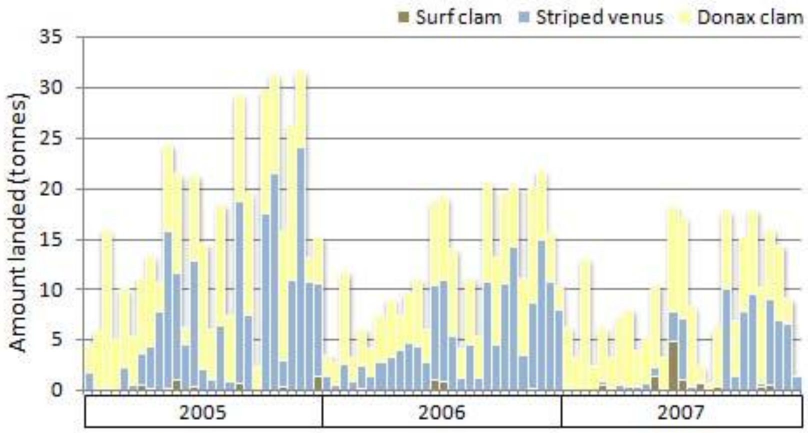

Figure 2-4. Composition of the landings of vessels in the local fleet.

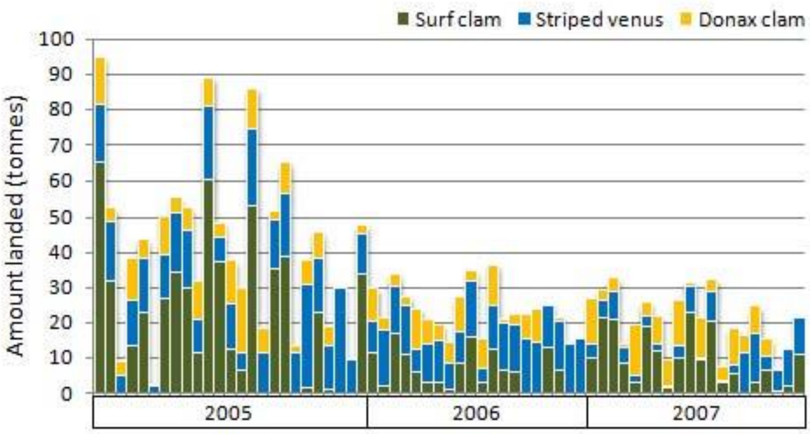

Figure 2-5. Composition of the landings of vessels in the coastal fleet.

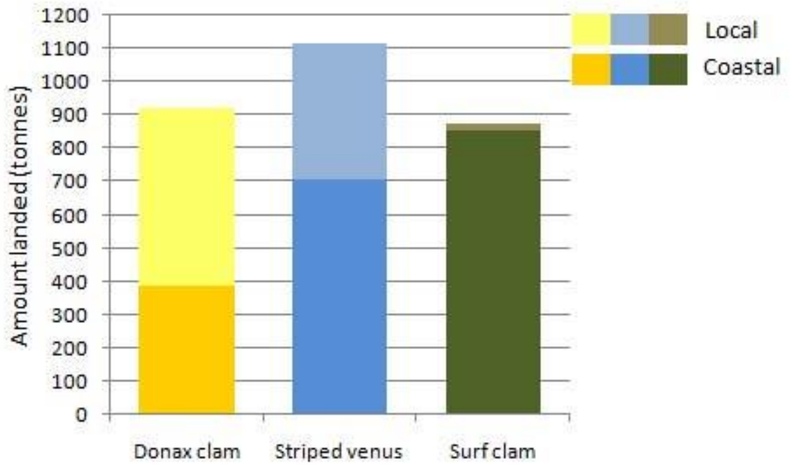

Figure 2-6. Comparison of species landings in weight (t) from local and coastal vessels, 2005–2007.

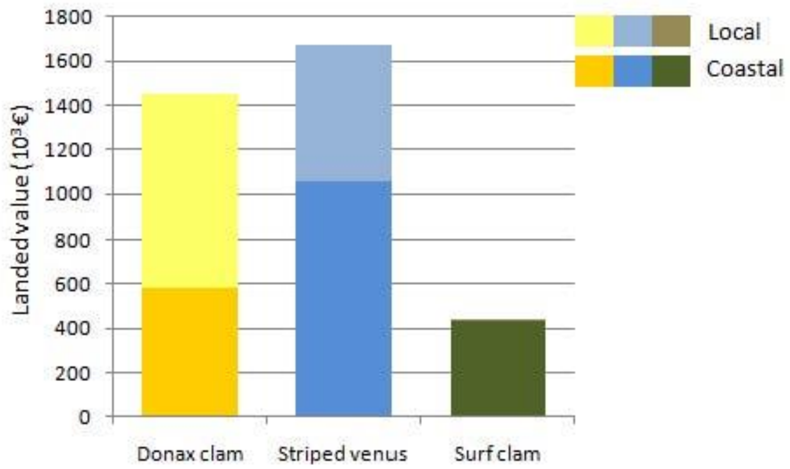

Figure 2-7. Comparison of species landings by value (10^3€) from local and coastal vessels, 2005–2007.

2.3.2 Technical and revenue efficiency analysis

Tables 2-2 and 2-3 respectively summarize the efficiency results for the local and the coastal fleets between 2005 and 2007. In terms of revenue efficiency, the average efficiency score for coastal vessels was higher than that of local vessels. Nevertheless, using a nonparametric Kruskal–Wallis (K–W) test, no statistically significant differences were observed between the two fleets ($p = 0.0648$).

Table 2-2. Efficiency results for the local fleet.

	Technical efficiency			Allocative efficiency			Revenue efficiency		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
geometric mean	0.742	0.656	0.583	0.845	0.918	0.795	0.626	0.602	0.464
st. dev	0.216	0.275	0.285	0.119	0.070	0.154	0.234	0.278	0.292
no. eff. dmus	8	9	6	4	5	4	4	5	4

Table 2-3. Efficiency results for the coastal fleet.

	Technical efficiency			Allocative efficiency			Revenue efficiency		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
geometric mean	0.805	0.914	0.790	0.850	0.838	0.783	0.684	0.766	0.619
st. dev	0.172	0.114	0.225	0.111	0.117	0.116	0.181	0.159	0.226
no. eff. dmus	7	11	9	3	2	1	3	2	1

Therefore, it is concluded that the hypothesis that the local and the coastal fleets have a distribution of revenue efficiency with the same median cannot be rejected. Note that the efficiency scores of each fleet were calculated about fleet-specific limits, because the samples of coastal and local fleet vessels were analysed separately. This implies that one cannot conclude that higher efficiency scores represent better performance. The results just indicate that the performance of coastal vessels is more homogeneous than that of local vessels, because the average distance to the efficient frontier is smaller.

In relation to the technical and allocative components of revenue efficiency, we conclude that most inefficiencies in the local fleet are attributable to technical reasons, whereas allocative and technical inefficiency levels are similar in the coastal fleet, so that both represent importance sources of inefficiency. Comparing the TE levels of the local and the coastal fleets, TE is higher in the coastal fleet than in the local fleet, by a statistically significant factor (K–W test, $p = 0.0026$). In terms of allocative efficiency, no significant differences between the fleets could be detected (K–W test, $p = 0.0920$). The next step of the analysis attempted to explore whether scale inefficiency has a significant impact on the artisanal dredge fisheries. It was, *a priori*, unclear whether vessel activity demonstrated constant or variable returns to scale (VRS). Banker (1993) proposed using hypothesis tests to determine the type of returns to scale of DMU activity. If the efficiency distributions obtained using the CRS and VRS models (Banker *et al.*, 1984) are similar, then scale inefficiency is almost non-existent, and there is insufficient evidence to support the hypothesis that DMU activity exhibits VRS. In those cases, differences in the shape of the production frontier using the CRS and VRS models may be attributable to random variation and not to the intrinsic VRS properties of DMU activities. The existence of VRS in vessel activities was formally tested using a K–W test.

For the local fleet, the null hypothesis was rejected ($p = 0.0001$), indicating that the vessels are likely to operate under VRS. Conversely, for the coastal fleet, there is no evidence that scale size affects the efficiency levels (K–W test, $p = 0.1169$). The decomposition of TE (CRS estimate) into pure TE (VRS estimate) and scale-efficiency components for the local fleet is shown in Table 2-4.

Table 2-4. VRS and scale efficiency for the local fleet.

	VRS efficiency			Scale efficiency		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**
geometric mean	0.843	0.772	0.799	0.879	0.850	0.730
st. dev	0.183	0.247	0.227	0.154	0.201	0.260
no. eff. dmus	9	11	10	15	17	13

For the local fleet, the best-practice vessels in terms of revenue efficiency in the 3-year period were larger than the local segment average (with 7.9 m length and 71.4 kW engine power). A possible explanation lies in the fact that the daily quota established per species is related to vessel tonnage. The higher the tonnage, the higher the daily quota per species.

Although all local fleet vessels have similar area restrictions, the larger ones can catch more. In addition, the larger tonnage may permit easier access to more remote areas, such that catch composition and total catch weight per trip may be optimized. As a result, local fleet vessels may experience increasing returns to scale.

Although there is no statistically significant evidence that scale size affects the efficiency levels of the coastal fleet, we found that the best-practice vessels of that fleet in terms of revenue efficiency are slightly smaller than the coastal-segment average (with 10.6 m length and 83.3 kW engine power). The VRS efficiency and scale-efficiency estimates for the coastal fleet are summarized in Table 2-5.

Table 2-5. VRS and scale efficiency for the coastal fleet.

	VRS efficiency			Scale efficiency		
	2005	2006	2007	2005	2006	2007
geometric mean	0.922	0.985	0.925	0.873	0.928	0.854
st. dev	0.154	0.038	0.150	0.132	0.101	0.196
no. eff. dmus	8	15	10	12	13	12

Note that the differences between the scale-efficiency results for the local and the coastal fleets were also tested. The K–W test revealed that the differences are significant ($p = 0.0021$), confirming that scale efficiency is more prevalent in the local fleet than in the coastal fleet.

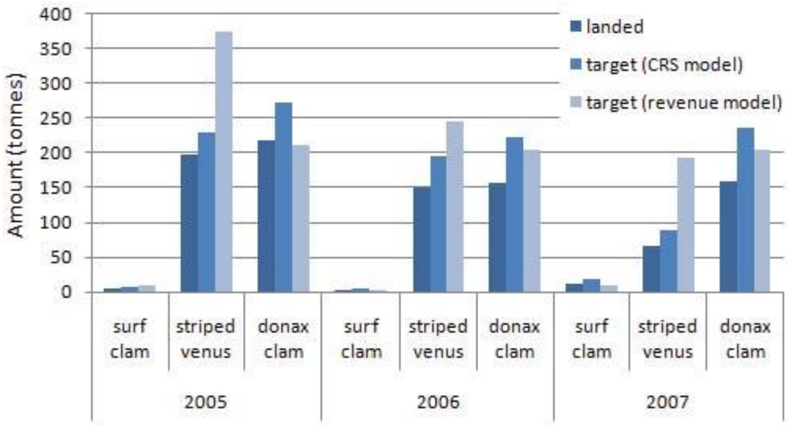

Figure 2-8. The quantity landed vs. the target landings for the local fleet.

Figures 2-8 and 2-9 compare target landings (t) 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 quantity landed per species, whereas the revenue model allows changes to the mix of species caught. In particular, revenue maximization would require an increase in striped venus catch of 179 t in 2005, 95 t in 2006, and 126 t in 2007 for the local fleet. For the coastal fleet, the model would require an increase in surf clam catch of 351 t in 2005 and 223 t in 2006. However, in 2007, a different picture emerges; the best strategy to maximize revenue would be to increase the catch of striped venus by 150 t, which could require a small decrease in the catch of the other species.

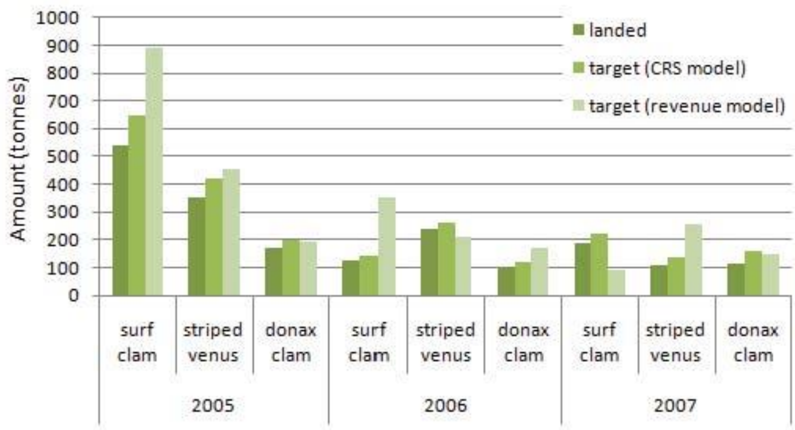

Figure 2-9. The quantity landed vs. the target landings for the coastal fleet.

2.3.3 A strategic approach with DEA

The idea of analysing the performance of an organization based on a portfolio of business, corresponding to different dimensions than can be represented in a matrix, dates back to a technique to support a strategic-option formulation proposed in the 1960s and known as the growth–share matrix, developed by the Boston Consulting Group (BCG). This matrix was adapted by Boussofiane *et al.* (1991) to the context of efficiency vs. profitability analysis. The efficiency–profitability matrix can be divided into four quadrants in which different profiles of units are likely to exist, although the precise boundary positions between quadrants are subjective.

Adapting the growth–share or efficiency–profitability matrix to this study, this section explores the relationship between the technical-efficiency measure obtained from a DEA analysis, considering three outputs corresponding to the quantities captured for the target species, and the allocative-efficiency measure, obtained as a by-product of the DEA analysis with a revenue maximization model. Figure 10 illustrates the relationship between allocative efficiency and TE for local vessels. A similar analysis could be carried out for the coastal fleet, but the results are not detailed here.

The analysis of the allocative-efficiency–technical-efficiency matrix is an alternative way to identify best-performing vessels, corresponding to those located in the top corner of each matrix. The vessels located in that quadrant can be considered the “stars”. For the local fleet, there are 13 vessels located in the “star vessel” quadrant at least once in the 3 years analysed. One of those vessels was fully efficient, both technically and allocatively, in all years considered (no. 19), two vessels were fully efficient in 2 years (23 and 26), and six vessels (3, 10, 14, 17, 25, and 28) were only fully efficient in one of the years.

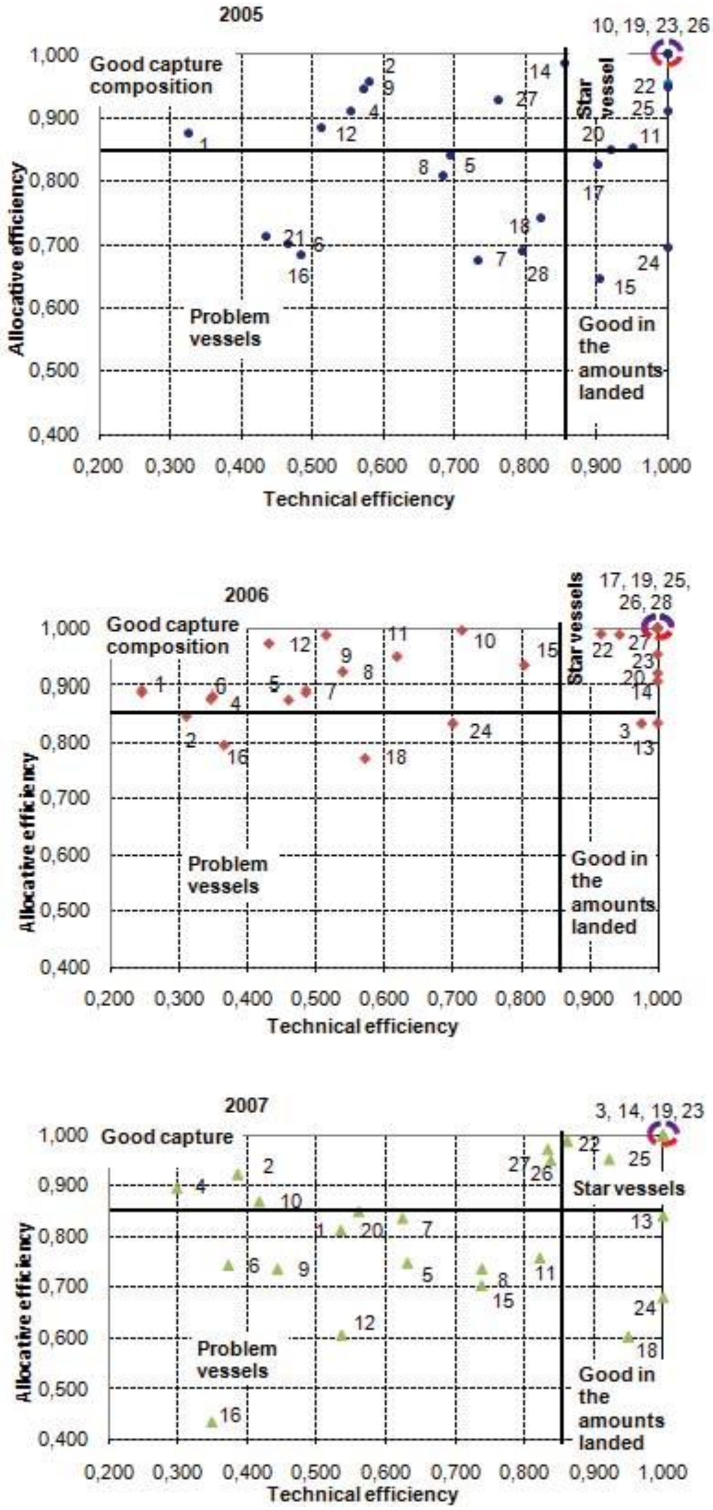

Figure 2-10. Allocative efficiency vs. TE matrix for the local fleet, for each of the study years 2005–2007.

The other four vessels (11, 20, 22, and 27) achieved high efficiency scores in all years, despite never achieving the maximum efficiency level. Those vessels are registered in three home ports (three at Fuzeta, three at Olhão, and seven at Tavira).

The analysis in Figure 2-10 also reveals a significant number of vessels located in the "problem-vessel" quadrant, particularly in 2005 and 2007, suggesting scope for efficiency improvements. Vessels located in the "problem-vessel" quadrant have the potential for both greater technical- and allocative-efficiency levels, meaning they should alter the proportions of species captured, as well as increase the total quantities landed. Only one vessel is consistently located in this quadrant over the years (no. 16).

In addition, six vessels were classified as "problem vessels" in 2 years (5, 6, 7, 8, 18, and 28), so their activity needs to be monitored carefully to identify the practices that need to be modified to improve performance.

The number of vessels in the "good-in-the-amounts-landed" quadrant is small compared with the number of vessels in the "good-capture-composition" quadrant, suggesting that fisher behavior focuses on capturing the species that maximize revenue rather than aiming at capturing large quantities of bivalves, as would be expected. Vessels located in the "good-capture-composition" quadrant need to focus on increasing the quantities landed while maintaining the current proportions of target species in the catch. Vessels located in the "good-in-the-amounts-landed" quadrant have an inappropriate choice of target species, such that it may be possible to increase their profits by redirecting effort to other species.

2.4 Conclusions

This study has clarified some issues about the performance of both the local and the coastal dredge fleets. The technical-efficiency analysis revealed that the quantities landed are considerably below the efficient levels. It was possible to verify an average TE larger in the coastal fleet than in the local fleet. The most successful vessels in the fishery seem to be, on average, 7.9 m long with 71.4 kW of engine power in the local fleet and 10.6 m long and 83.3 kW engine power in the coastal fleet. The best-practice vessels in the local fleet were larger than the average of all the local vessels, and in the coastal fleet slightly smaller than the average of all coastal vessels, suggesting the existence of increasing returns to scale only for the local fleet. A possible explanation for this is related to the fact that the daily quota per species is established in relation to vessel tonnage, so larger vessels have a larger daily quota. Moreover, although all vessels from the local fleet are similarly restricted in terms of area, the larger vessels may be able to operate farther from the coast and reach a greater range of fishing beds.

The targets proposed by the revenue-efficiency model suggest, for the local fleet, an increase in striped venus catch. In relation to the coastal fleet, the surf clam catch in 2005 and 2006 should have been larger to increase revenue, but in 2007, the best strategy to improve revenue would have been to catch more striped venus.

Adapting the BCG growth–share matrix to a fisheries context, the relationship between allocative efficiency and TE was explored graphically for local fleet vessels. The main management challenge concerns the vessels located in the "problem-vessel" quadrant. They did not operate close to efficient levels in either technical or allocative terms. To make fishing activity more profitable, they need to alter the balance between species caught, as well as increase the amount they land. Vessels in the "good-capture-composition" quadrant need to increase the quantities landed to become "stars" and attain higher profits. Vessels in the "good-in-the-amounts-landed" quadrant need to redirect their fishing effort to catch a different mix of species. As they are close to operating efficiently in technical terms, profitability can only be increased by altering the mix of species caught. Their activity needs to be redesigned to emulate the best-practices observed in the benchmark vessels of the same fleet.

Our intention in future is to extend this study to other years and other fleets operating in Portugal. It would also be of value to compare the different approaches with the artisanal dredge fishery for clams in the Atlantic arc area. In that case, the method proposed by Charnes *et al.* (1981), known as "programme efficiency", to compare the performance of different sets of DMU whose performance is affected by their association with specific regimes or exogenous conditions, may be the topic to explore. If data become available, it would also be important to redefine the input set to include the total costs of fishing in the efficiency analysis, costs such as fuel, crew, and maintenance for vessels and fishing equipment.

CHAPTER 3. Assessing technical and economic efficiency of the artisanal dredge fleet in the Portuguese west coast[2]

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.

Keywords: Data Envelopment Analysis, Technical efficiency, Revenue efficiency, Allocative efficiency, Artisanal fishing, Bivalve dredge fleet

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[2] Oliveira, M.M., Camanho, A.S., Gaspar, M.B., 2014. Assessing technical and economic efficiency of the artisanal dredge fleet in the Portuguese west coast. Post APDIO Congress volume, CIM Series in Mathematical Sciences, Springer-Verlag, (*in press*).

3.1 Introduction

The estimation of a Decision Making Unit (DMU) efficiency, according to Farrel (1957) 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.*, 2013)). The factors most frequently used as inputs are vessel characteristics, fishing effort, operational costs and stock abundance indices (e.g. Sharma and Leung, 1999; Kirkley *et al.*, 1995, 1998; Pascoe and Coglan, 2002). Concerning the output factors, most studies in both single and multispecies fisheries use the landed weight of the catches (e.g. Sharma *et al.*, 1999; Pascoe and Herrero, 2004; Hoff, 2006; Lindebo *et al.*, 2007) or the value of the catches (e.g. Tingley *et al.*, 2005; Maravelias and Tsitsika, 2008; Idda *et al.*, 2009). As argued by Herrero and Pascoe (2003), 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 DMU. The efficiency of the remaining DMU 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.*, 2002; Kirkley *et al.*, 2003; Tingley *et al.*, 2003; Vestergaard *et al.*, 2003; Pascoe and Herrero, 2004; Tingley and Pascoe, 2005a,b), revenue efficiency (e.g. Lindebo *et al.*, 2007; Oliveira *et al.*, 2010, 2014), profit efficiency (*e.g.* Pascoe and Tingley, 2006) and cost efficiency (*e.g.* Alam and Murshed-e-Jahan, 2008).

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.

3.2 Methodology

The DEA models were first proposed by Charnes *et al.* (1978). 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.*, 2000, 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* DMU, defined by *j* (j =1,...,n), which use the inputs x_{ij} (x_{1j},...,x_{mj}) ∈ R^m_+, to obtain the outputs y_{rj} (y_{1j},..., y_{sj}) ∈ R^s_+ . Assume that the maximum value of the sum of all outputs is bounded by the quota limit Q_{j0} for each DMU$_{j0}$. The efficiency of each DMU$_{j0}$ is given by the reciprocal of the factor (δ) by which the outputs of the DMU$_{j0}$ can be expanded, obtained from the following model based on Cooper *et al.* (2000):

$$
\begin{aligned}
& max\{\delta \mid \\
& x_{ij_0} \geq \sum_{j=1}^{n} \lambda_j x_{ij}, \quad i = 1, \dots, m \\
& \delta\, y_{rj_0} \leq \sum_{j=1}^{n} \lambda_j y_{rj}, \quad r = 1, \dots, s \\
& \sum_{r=1}^{s} \sum_{j=1}^{n} \lambda_j y_{rj} \leq Q_{j_0,} \\
& \lambda_j \geq 0, \ \forall_j \}
\end{aligned}
\tag{1}
$$

Model (1) 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$_{j0}$. Comparing the formulation of model (1) and the one proposed by Cooper *et al.* (2000), 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$_{j0}$ under assessment are the units with values of λ^*_j greater than zero in the optimal solution to model (1). Since the vessels were analysed with an output oriented perspective, the estimation of output targets for each DMU$_{j0}$ 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 (1957, 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.* (2000, 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 (1957) concepts. This author described a revenue maximization assessment, corresponding to the assumption that the DMU 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_{j0}, given the current level of resources consumption, the quota limit Q_{j0} and the output prices, is estimated solving the linear programming problem shown in (3). The model follows the formulation originally proposed by Färe *et al.* (1985), with an additional constraint to reflect the fact that the catches are bounded by the quotas (Q_{j0}) imposed by fisheries regulatory conditions.

$$\begin{aligned}
& max\left\{\sum_{r=1}^{s} p_{rj_0}\, y_r^0 \;\middle|\right. \\
& \sum_{j=1}^{n} y_{rj}\, \lambda_j \geq y_r^0, \quad r = 1, \dots, s \\
& \sum_{r=1}^{s}\sum_{j=1}^{n} \lambda_j y_{rj} \;\leq Q_{j_0,} \\
& \sum_{j=1}^{n} x_{ij}\, \lambda_j \leq x_{ij_0}, \;\; i = 1, \dots, m \\
& \lambda_j \;\geq 0, j = 1, \dots, n \\
& \left. y_r^0 \;\geq 0, i = 1, \dots, m \right\}
\end{aligned} \tag{3}$$

In the formulation above, p_{rj0} is the price of output r for the DMU_{j0} under assessment and y_{0r} is a variable that, at the optimal solution, gives the amount of output r to be produced by DMU_{j0} 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_{j0}, as the ratio of current revenue observed at DMU_{j0} to the maximum revenue estimated by the optimal solution to model (3), as follows:

$$Revenue\ efficiency_{j_0} = \frac{\sum_{r=1}^{s} p_{rj_0}\, y_{rj_0}}{\sum_{r=1}^{s} p_{rj_0}\, y_r^{0*}} \qquad (4)$$

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:

$$\text{Revenue efficiency}_{j0} = \text{Technical efficiency}_{j0} \times \text{Allocative efficiency}_{j0} \qquad (5)$$

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 (1). 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 were undertaken using SPSS®.

3.3 Dredge fleets that operate 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) (Figure 3-1). 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 four to five 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*).

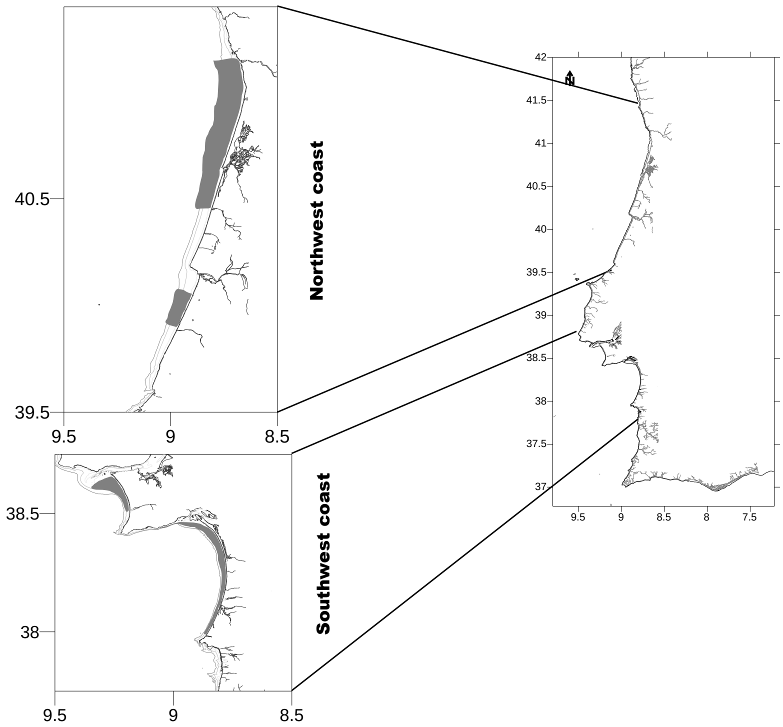

Figure 3-1. Distribution of bivalve beds (grey areas) in the Northwest and Southwest fishing areas.

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 the Portuguese Institute for the Ocean and the Atmosphere (IPMA), and can be changed if necessary to adjust the catch to the status of the stocks (Oliveira *et al.*, 2013).

3.4 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 3-1 and 3-2 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.

Table 3-1. 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)	62400.0	62400.0	62400.0	62400.0	62400.0	72000.0	72000.0
Outputs							
Capture of surf clam (kg)	39550.6	11639.2	11811.7	23936.6	35492.2	36765.9	35535.9
Output prices							
Prices of surf clam (€)	2.92	3.12	2.76	1.95	2.05	2.91	2.88

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 3-1). In the Southwest, price fluctuations do not occur (Table 3-2) since catches are sold through a contract that is established in the beginning of each year between the fishermen and the buyer.

Table 3-2. 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)	88533.3	86490.0	86430.0	99000.0	99000.0	99000.0	99000.0
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)	14723.6	11131.0	9288.5	9501.6	12339.7	15555.0	14579.6
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						

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 3-1 and 3-2). 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.* (2010). 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 DMU for the Northwest fleet and 131 DMU 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.

3.5 Results and discussion

3.5.1 Catch composition

Figures 3-2 and 3-3 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 3-1).

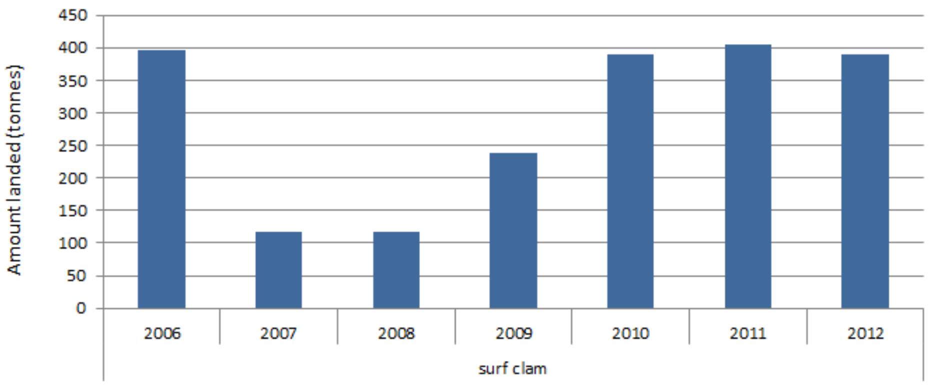

Figure 3-2. Northwest fleet. Total landed from dredge vessels between 2006 and 2012.

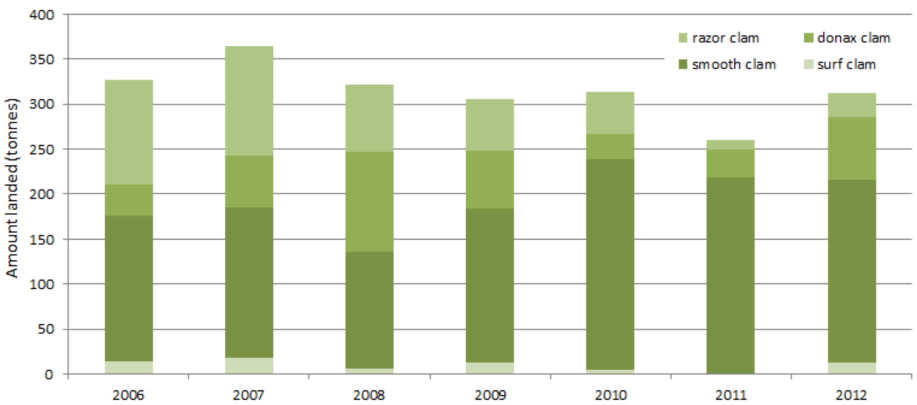

Figure 3-3. Southwest fleet. Landed catch composition from dredge vessels between 2006 and 2012.

In the case of the Southwest area it can be observed from Figure 3-3 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.

Figures 3-4 and 2-5 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 Figure 3-4) and 60% of the total income (Figure 3-5) in this particular period of time (i.e., between 2006 and 2012).

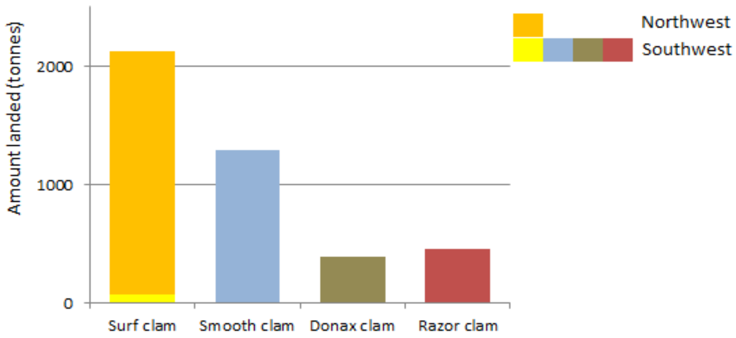

Figure 3-4. Comparison of total landings per species in weight (tonnes) from Northwest and Southwest dredge vessels between 2006 and 2012.

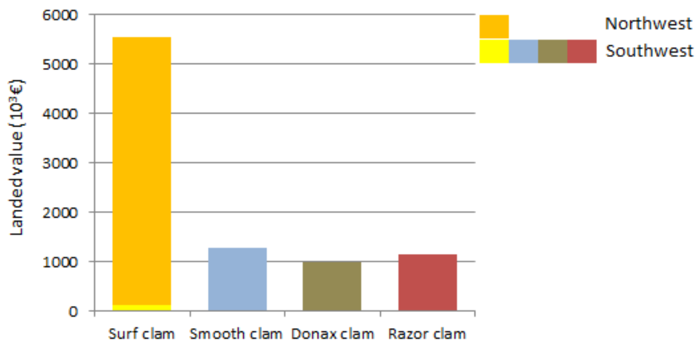

Figure 3-5. Comparison of total landings per species in values (10^3€) from Northwest and Southwest dredge vessels between 2006 and 2012.

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.

3.5.2 Technical and revenue efficiency analysis

Tables 3-3 and 3-4 summarise the efficiency results 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, 2003).

Table 3-3. 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

Table 3-4. 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

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 seven 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 (1993) for determining the type of returns to scale of the DMU' activity. If the efficiency distributions obtained using the CRS and variable returns to scale (VRS) models (Banker *et al.*, 1984) were similar, it would mean a scale inefficiency almost nonexistent, and thus there would not enough evidence to support the hypothesis that the DMU' 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 DMU' 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 3-5 and 3-6.

Table 3-5. 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 3-6. 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

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

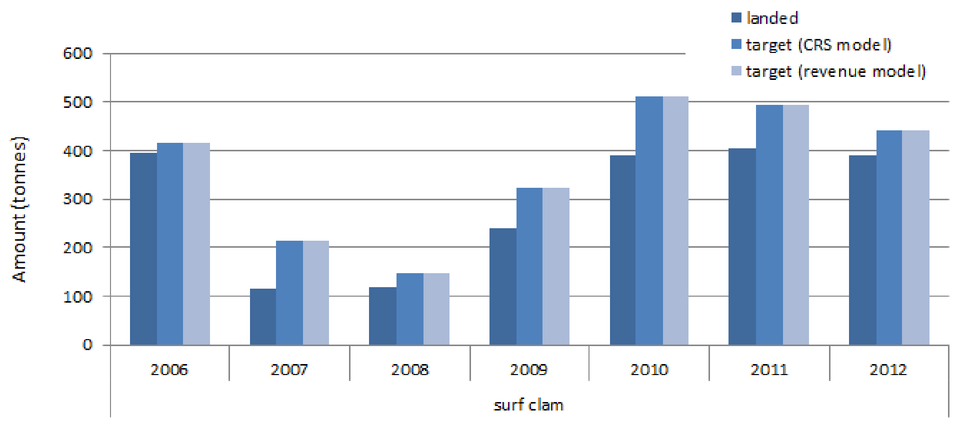

Figure 3-6. Amount landed versus target landings for Northwest fleet

Figures 3-6 and 3-7 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 (Figure 3-6). 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.

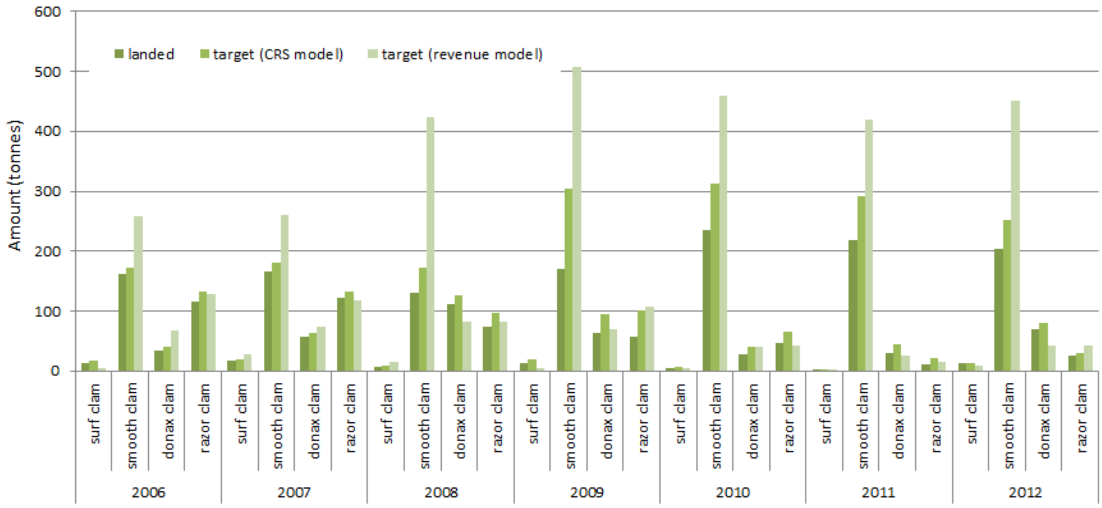

Figure 3-7. Amount landed versus target landings for Southwest fleet

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).

3.5.3 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.* (1991). 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 three years of the study and the quadrants boundaries used were identical to those proposed by Oliveira *et al.* (2010). 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 3-8 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 three years analysed. One of these vessels was fully efficient, both technically and allocatively, in two 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 Figure 18 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).

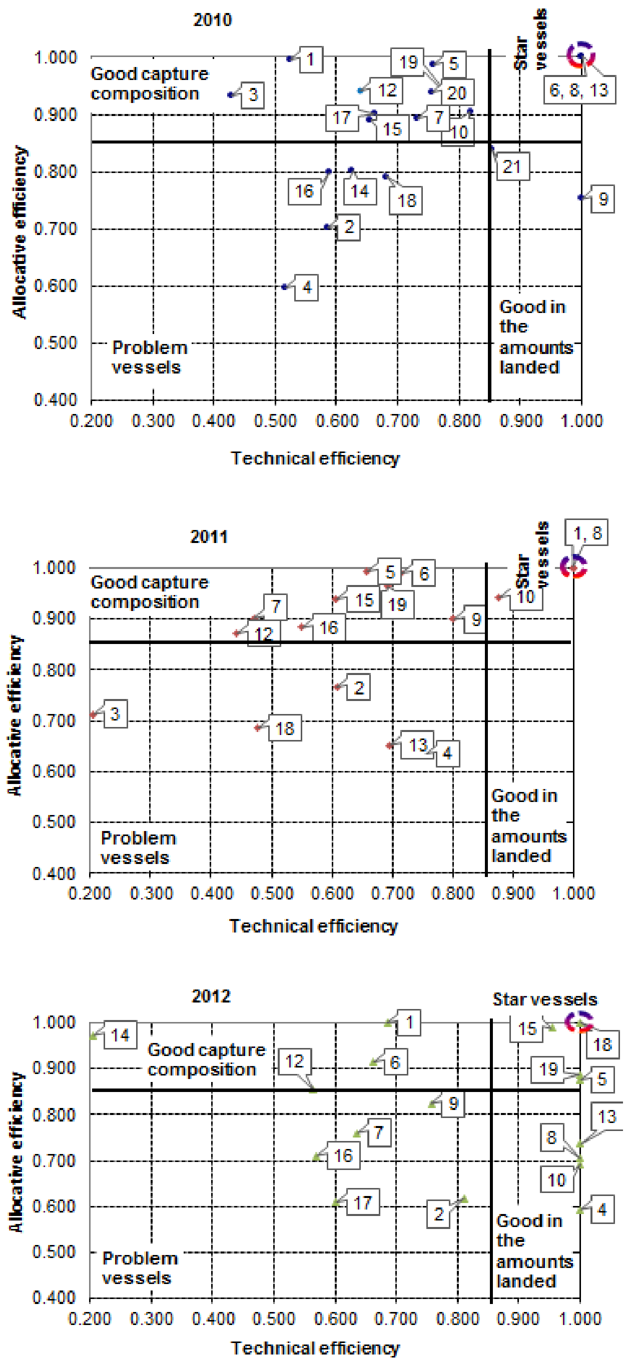

Figure 3-8. Allocative efficiency versus technical efficiency matrix for the Southwest fleet

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

3.6 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 is 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 three 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.

CHAPTER 4. The influence of catch quotas on the productivity of the Portuguese bivalve dredge fleet[3]

Abstract: Among the Portuguese artisanal fishing fleets, the bivalve dredge fleet is one of the most profitable. In the last decade, after the implementation of a quotas system, the management of this fishery has been largely focused on adjusting catch to the conservation status of the resources exploited. The present work aims to understand how changes in the amount of quota attributed to each vessel each year and shifts in the quota regime affected vessel productivity. Bootstrapped Malmquist indices, complemented with an efficiency assessment using a directional distance function, were used to quantify productivity changes between 1999 and 2011 for the fleets operating in two areas along the Portuguese coast (Northwest and Southwest). The results showed that the implementation of a weekly quota, as opposed to a daily quota, led to a significant improvement in productivity. This was mainly due to the decrease in fishing days and fuel consumption. It is predicted that the implementation of weekly quotas in the South area would lead to an overall reduction of about 12% in fishing days and fuel consumption, even though the variation in fuel consumption may be affected by the status of the resources. The results achieved provide important insights for future management actions and showed the potential advantages of applying this type of management to other fisheries worldwide, mainly those using active gear.

Keywords: bivalve fisheries, bootstrap, data envelopment analysis, directional distance function, dredge fleet, Malmquist index.

[3] Oliveira, M.M., Camanho, A.S., Gaspar, M.B., 2013. The influence of catch quotas on the productivity of the Portuguese bivalve dredge fleet. ICES Journal of Marine Science, 70(7): 1378-1388.

4.1 Introduction

In the Portuguese fishing sector, artisanal or small-scale fisheries have a significant social relevance, both at regional and local level. In 2011, the artisanal fleet represented 87% of the Portuguese fleet in terms of the number of vessels. Despite the low volume of captures relative to the national context [15% of total landings in mainland Portugal, source: Directorate General of Natural Resources, Safety and Maritime Services (DGRM)], artisanal fisheries are very important in socio-economical terms, as they promote the establishment and development of coastal communities (Guyader *et al.*, 2013). Fishing frequently represents the main economic activity of these communities, and it also has a positive impact on other sectors, such as tourism, food and beverage services, manufacturing industry, nautical industry, fishing gear manufacture and maintenance, and the commercialization of landings (Monteiro, 2010).

Therefore, artisanal fisheries foster economic development as they generate considerable employment in communities that generally face difficulties in finding other sources of employment or diversification (Guyader *et al.*, 2013).

Among the Portuguese artisanal fishing fleets, the bivalve dredge fleet is one of the most profitable. This fleet carries out its activity along three fishing areas (Northwest, Southwest and South areas), and the fishery is managed by a set of output controls, input controls and technical measures. Although most of the management measures that regulate the fishery are common to the three fishing areas, output controls differ among them since they are managed as separate units. In the last decade, after the implementation of a quotas system, the management of this fishery has largely focused on adjusting catch to the conservation status of the resources exploited. Whereas in the South area the quota regime has remained unchanged, in both the Northwest and Southwest areas it changed from maximum daily fishing quotas (MDFQ) to maximum weekly fishing quotas (MWFQ).

The objective of the present study is to understand how changes to the amount of quota attributed to each vessel each year and shifts in the quota regime affect vessel productivity. The Northwest and Southwest areas were used as case studies, and the results obtained from the analysis of a period of 13 years (between 1999 and 2011) provide important insight for future management actions.

Vessel productivity is a key performance indicator and is defined as the ratio between its outputs (landings) and inputs (resources) employed in the production process (the fishery activity) (Coelli *et al.*, 1998). In multidimensional settings, such as the fishing activity, the vessels use multiple inputs to obtain multiple outputs, and thus these variables have to be aggregated using weighting systems prior to the calculation of the productivity indicator (i.e. ratio of outputs to inputs). The technique most often used for estimating the weights and deriving a productivity measure is Data Envelopment Analysis (DEA) (Charnes *et al.*, 1978).

Changes in vessel productivity over time can be estimated using the Malmquist index (MI) introduced by Caves *et al.* (1982). This technique offers a more general picture of productivity change compared with other indices (such as the Hicks–Moorsteen, the Törnqvist or Fisher indices) essentially due to the possibility of representing multiple inputs and outputs scenarios without requiring data on input and output prices, and the possibility of exploring the components of productivity change (Färe *et al.*, 1994).

Several studies have analysed the productivity of fishing fleets using Total Factor Productivity techniques (*e.g.* Jin *et al.*, 2002; Hannesson, 2007; Eggert and Tveteras, 2013), profit index decomposition methods (*e.g.* Fox *et al.*, 2003, 2006) and a transformation function production model (Felthoven *et al.*, 2009), but few used the MI. To date, only Hoff (2006), Oliveira *et al.* (2009) and Walden *et al.* (2012) have applied this technique to fisheries. Hoff (2006) was the first to apply the MI, complemented with bootstrapping, to evaluate the productivity of the fleet of Danish seiners operating in the North Sea and the Skagerrak. Oliveira *et al.* (2009) were the first to apply the MI to study artisanal fisheries. Walden *et al.* (2012) explored changes in vessel productivity under an individually transferable quota management system in the surf clam and ocean quahog fisheries in the USA.

One innovative feature of the analysis of productivity described in this study concerns the use of a particular formulation of the DEA model, based on the use of a directional distance function (DDF), developed by Chambers *et al.* (1996, 1998), that allows for a simultaneous reduction of inputs and expansion of outputs variables. The use of this approach to assess the effects of changes in management on vessel productivity and efficiency, as well as the extrapolation of the results obtained to a different fishing context (South area), are the main contributions of this paper.

In fisheries, a DDF has essentially been used to measure efficiency and capacity in the presence of undesirable outputs such as discarded or endangered, threatened, or protected (ETP) species (*e.g.* Färe *et al.*, 2006, 2011; Kjærsgaard *et al.*, 2009). Weninger and Waters (2003) also applied DDF models to estimate the economic benefits of replacing controlled access with tradable harvest permits in the northern Gulf of Mexico reef fish fishery.

4.2 Bivalve dredge fishery

4.2.1 Dredge fleet

The artisanal dredge fleet dedicated to bivalve fishing differs in features and operability along the Portuguese coast, and comprises 93 vessels (11, 25 and 57 vessels operating on the Northwest, Southwest and South coast, respectively). Over the past 20 years, this fleet, like many others in Portugal, has experienced significant size reductions. In the nineties, the Northwest dredge fleet dropped from 94 to 11 vessels as a result of the depletion of the bivalve stocks (Sobral *et al.*, 2001). The fishing vessels are classified according to the area in which they operate. Local vessels can only operate near the homeport or adjacent fishing ports, and comprise boats with an overall length smaller than or equal to 9 m, a GT between 1.18 and 9.41 tons, and an engine power up to 75 kW. Coastal vessels can fish within the fishing area for which they are registered, and comprise boats with an overall length of 9 m, a GT ranging between 3.19 and 23.64 tons, and an engine power up to 130 kW. Due to the distance of the bivalves' beds from fishing ports, as well as the hydrodynamic conditions, only coastal vessels operate in the Northwest and Southwest fishing areas.

The target species are caught using mechanical dredges. These gears comprise a metallic frame with a toothed lower bar, and the catch is retained in a mesh bag or in a rectangular metallic grid box (for detailed gear specifications see Gaspar *et al.*, 1999, 2003). The length of the teeth varies according to the target species, ranging between 10 and 60 cm, corresponding to the donax and razor clam fisheries, respectively. For other clam species, tooth length does not exceed 20 cm. Boats can work with up to two dredges.

Five species are targeted along the Portuguese coast, namely the surf clam (*Spisula solida*), the donax clam (*Donax trunculus*), the smooth clam (*Callista chione*), the striped venus (*Chamelea gallina*) and the razor clam (*Ensis siliqua*). The first is caught along the entire coast while the donax clam, the striped venus and the razor clam are caught between Lisboa and Sines (Southwest area), and between Sagres and Vila Real de Santo António (South area). The smooth clam is only exploited in the Southwest area, since in the other two fishing areas its abundance is extremely low (Figure 4-1).

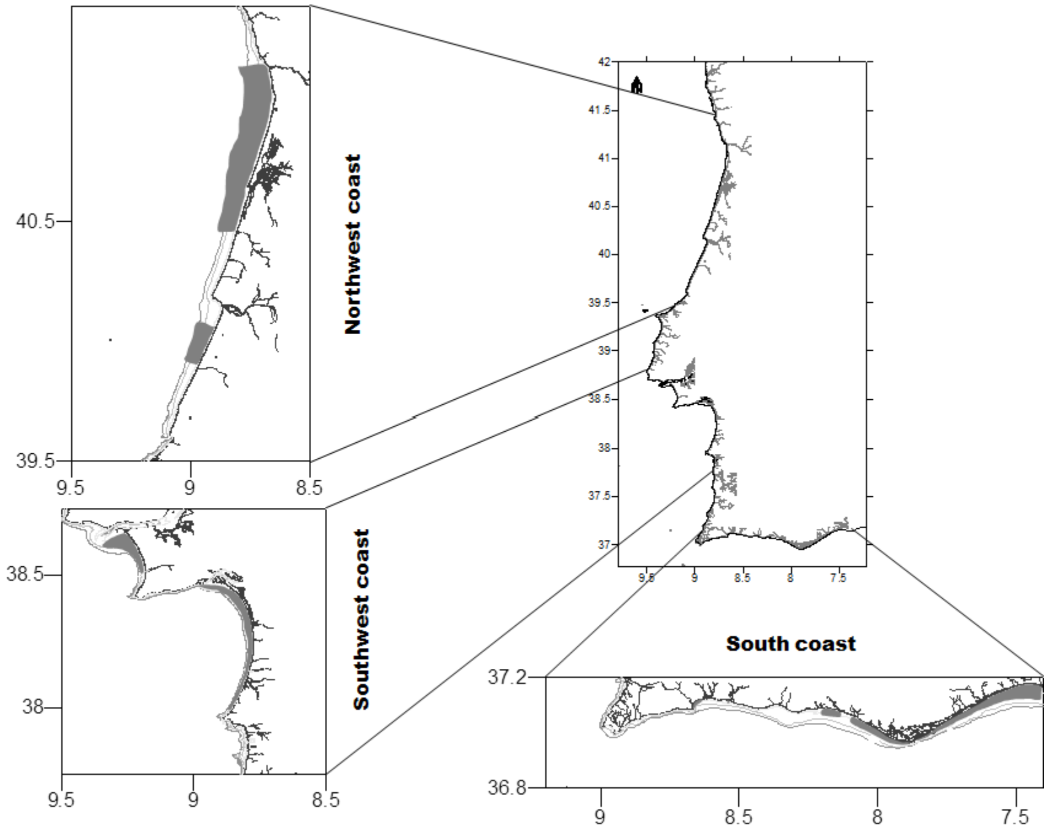

Figure 4-1. Distribution of bivalve beds (grey areas) in the three fishing areas of mainland Portugal.

4.2.2 Fisheries management

The exploitation of subtidal bivalve beds along the Portuguese coast is relatively recent, and started only in the late 1960s (Gaspar *et al.*, 2003). Prior to 1986 no Fishing Management Plan (FMP) existed for the dredge fishery, and the only management measure in place was minimum landing sizes. Owing to the increase in landings, fishing power, and resource conservation concerns, the Portuguese Institute for the Ocean and the Atmosphere (IPMA) started a Bivalve Research Program aiming to evaluate stock status. Based on these results, an FMP was designed and a set of management measures was implemented in the fishery in 1986. Apart from technical regulations, such as gear restrictions and fishing seasons, other measures intended to control fishing effort were introduced, namely, maximum engine power and limitation of the number of licenses.

In 1987 a seasonal closure was introduced. Since then, based on scientific studies carried out by IPMA, several proposals were suggested to the Administration in order to improve the management of the dredge fishery. These included the adjustment of some technical characteristics of the gear to the biology and ecology of the target species, such as minimum mesh sizes, maximum width of the dredge mouth, maximum tooth length and maximum tooth spacing. In addition, the seasonal closure was set for the period from 1st May to 15th June (see review of Gaspar and Chícharo, 2007). In 1997, the stocks showed signs of overexploitation, which led to the implementation of maximum fishing days per week and MDFQ.

This latter management measure aimed to adjust catches to the status of the resources and was first set by vessel and then split by species. In that year, a project was started aiming to quantify and minimize the adverse effects of dredging on the ecosystem. This research culminated in the development of a new dredge that proved to be more efficient and selective than the traditional one (Gaspar *et al.*, 2001; Gaspar and Chícharo, 2007). Therefore, in 2000, this new dredge was introduced into the fishery. However, since its use was not mandatory it was only adopted by fleets operating in the Southwest and South areas.

The management measures that regulate the dredge fishery have remained unchanged since then, with the exception of the quotas regime, which has changed from MDFQ to MWFQ in both Northwest and Southwest fishing areas. The introduction of the MWFQ aimed to control catches to ensure the sustainability of the resources, but at the same time increase the profitability of the fishing vessels. One of the advantages of MWFQ compared with MDFQ is that fishermen are free to decide when to fill it, based on weather conditions and other preferences, whereas in the case of MDFQ if the vessel stays in the fishing port, the quota of that day is lost. Moreover, as MWFQ is usually reached within 2–3 days, less fuel is spent as the number of fishing trips between the fishing port and clam beds decreases.

Although the majority of the management measures are similar in all three fishing areas, there are differences in terms of number of licenses and quotas regime. The quotas are reviewed on an annual basis and can be changed if necessary to adjust the catch to the status of the stocks of the target species (Oliveira *et al.*, 2010). The main changes in quota management registered for the Northwest and Southwest areas during the time-window studied are summarized in Table 4-1. In the Northwest area, three main periods were considered, namely: the existence of MDFQ (1999–2001); the existence of MWFQ during the winter months and MDFQ in the rest of the year (between 2001 and 2007); and the existence of an MWFQ throughout the whole year (after 2007).

Table 4-1. Main changes in the quota management between 1999 and 2011 for the Northwest and Southwest areas.

Area	Period	From - To	Allowed
	1	January 1999 - June 2001	daily maximum fishing quota per vessel
Northwest area	2	July 2001 - May 2007	weekly maximum fishing quota per vessel (during four winter months)
	3	Since June 2007	weekly maximum fishing quota per vessel
	1	January 1999 - September 2000	daily maximum fishing quota per vessel
Southwest area	2	Since October 2000	daily maximum fishing quota per vessel reduction (800kg) (new dredge)
	3	Since August 2009	weekly maximum fishing quota per vessel

Concerning the Southwest area, three significant changes in regulation were identified, namely: the implementation of MDFQ in 1999; a drastic reduction in the MDFQ and the introduction of a new dredge at the end of 2000; and finally, the implementation of the MWFQ in 2009.

4.3 Material and methods

4.3.1. Data

The data used in the present study were provided by the DGRM and IPMA and cover the period from January 1999 to December 2011. The vessels included in the study (11 in the Northwest and 25 in the Southwest area, respectively) were active during the entire time window analysed.

This implies that the number of observations considered in the study is identical in all years. The inputs included in the study of vessel productivity were vessel overall length, gross tonnage, engine power, fishing days and fuel consumption per vessel and week, and a biomass stock indicator. The output variable used was the sum of the landings, measured in weight, of all species captured per vessel per week. The time-series of biomass stock indicator was derived from IPMA bivalve research surveys carried out on a yearly basis, that are specifically designed to evaluate the conservation status of the commercial species (details on both sampling design and procedures can be found in Rufino *et al.*, 2010). Table 4-2 presents the average characteristics of the fleets that operated in the Northwest and Southwest areas, as well as the mean fishing days per year, mean fuel consumption per year and average yearly landings (during the whole time-window). Trends in the biological stock indicator, fishing days and fuel consumption for the period studied and per fishing area can be observed in Figure 4-2.

Table 4-2. Fleets' profile in both areas.

	Northwest fleet (11 vessels)				Southwest fleet (25 vessels)			
Inputs	min	max	mean	± SD	min	max	mean	± SD
Vessel overall length (m)	10.2	15.8	13.3	1.6	9.2	13.7	11.2	1.0
Vessel tonnage (GT)	9.1	22.1	16.6	3.7	5.6	14.7	9.6	2.3
Vessel power (kW)	72.9	128.0	103.9	14.7	46.2	96.9	72.2	9.5
No. fishing days (per year)	88.1	111.8	100.2	8.5	53.8	154.0	112.3	26.7
Fuel consumption (kl per year)	14.3	22.7	18.5	2.8	14.8	45.9	28.8	8.6
Output								
Landings (tons per year)	23.6	34.7	30.3	3.6	7.2	34.4	19.9	7.2

min = minimum; max = maximum; mean = aritmetic mean; SD = standard deviation

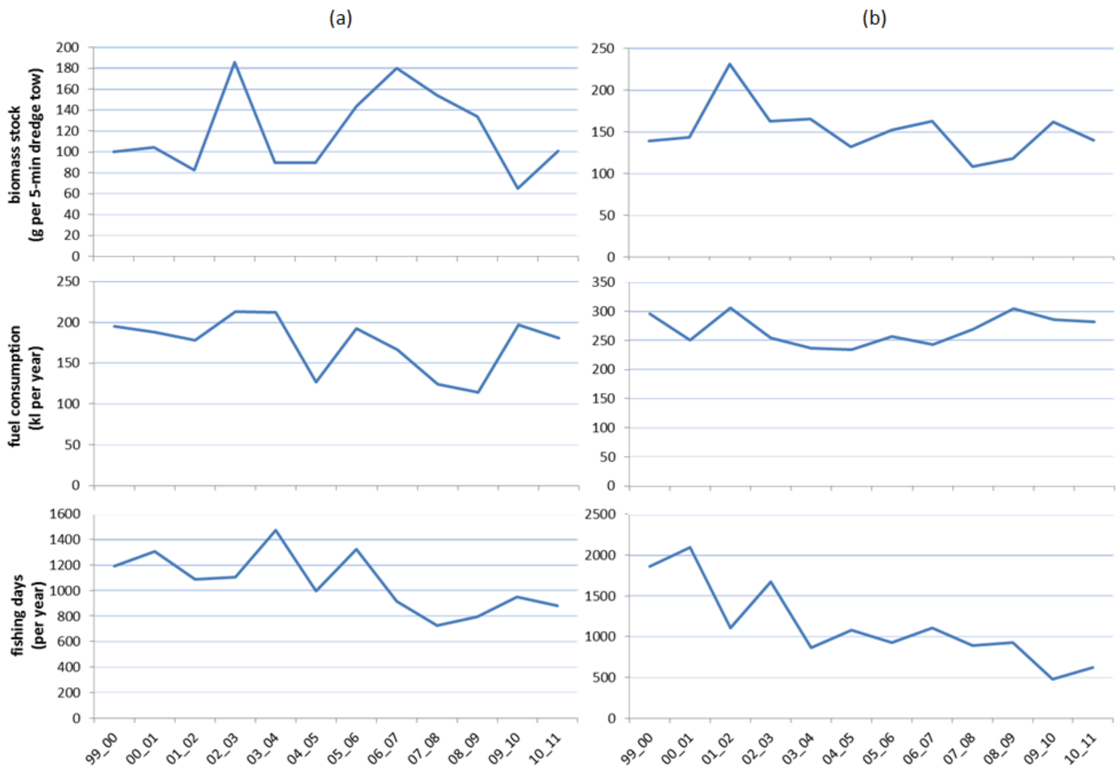

Figure 4-2. Variables' trend in the Northwest (a) and Southwest (b) fishing areas.

The input selection criteria followed the common procedure used in the literature on fisheries efficiency measurement and took into account the availability of data (*e.g.* Hoff, 2006; Walden *et al.*, 2012). In this fishery the trips only last between 7 and 12 h, so the fishing days are equivalent to trips. Despite the high correlation between the variables GT and vessel overall length, both were included in the models following the recommendation in Dyson *et al.* (2001).

4.3.2 Data analysis

In the production process each production unit can be referred as a Decision Maker Unit (DMU) that produces Y outputs using X inputs. If the productivity of each DMU is a ratio between its outputs and inputs, the efficiency of a DMU is the comparison between observed and optimal values of its outputs and inputs.

The purpose of using DEA methodology is to construct a nonparametric envelopment production frontier which maps out the greatest output (least input) for a given level of input (output) based on observed outputs and inputs of the DMU such that all observed points lie on or below this frontier (Figure 4-3). Thus, the production frontier or the "best-practices frontier" is constructed with the DMU that lie on it (highest efficiency). The efficiencies of the remaining DMU that lie below it are measured by the distance relative to this frontier.

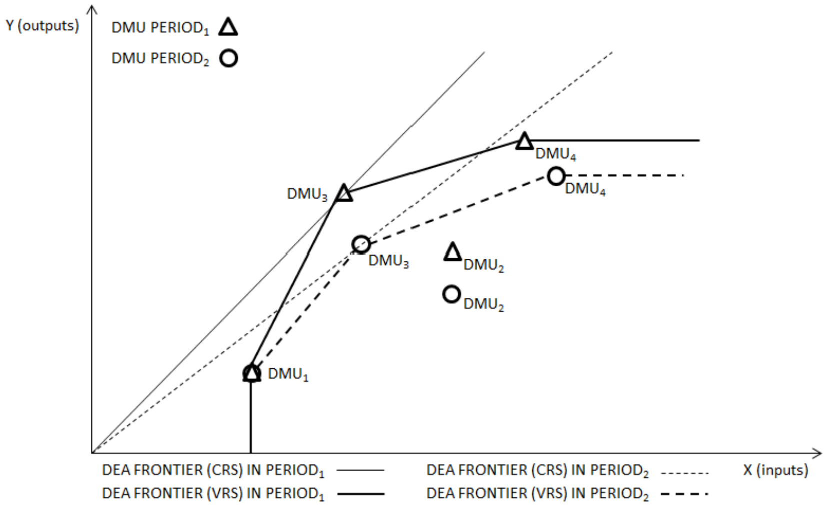

Figure 4-3. A hypothetical case for illustration purposes. DEA production frontiers under constant returns to scale (CRS) and variable returns to scale (VRS) in two different periods.

The MI, which is based on non-parametric distance functions (evaluated with DEA), is employed to estimate productivity changes over time. Notwithstanding the fact that the productivity is defined as the ratio of all output produced by a DMU to all inputs employed by the DMU, the MI assessment requires the calculation of four distance functions in order to enable its decomposition into two components, namely efficiency change (EC) and technological change (TC). The EC reflects whether the DMU's efficiency has changed relative to the total sample of observed DMU, whereas the TC reflects whether the maximum obtainable output (productivity) of the DMU has changed because of movements in the production frontier (more extensive explanation can be found in the Supplementary data online).

In the MI assessment one of three different types of production frontiers (Tulkens and Vanden Eeckaut, 1995) can be considered. In this case, the contemporaneous frontier was implemented which was constructed for each period t, from the observations made in that period only. For instance, considering a period as a year, the contemporaneous frontier assumption means that each DMU will be represented (with a single observation) just once in each year (Figure 4-3). With this type of frontier technological regress may occur since productivity could be lower in more recent years than in previous ones. The registered upward and downward shifts (that could be associated with technical progress or regress, respectively) can occur either due to the changes in operating conditions enforced by management or the status of the fishing resources.

For the purpose of the present study, a vessel's fishing activity in a particular week was considered as a DMU. The use of weekly data greatly increased the size of the sample, thus avoiding the problem of lack of discriminatory power in DEA models. In this context, 45 weeks of operation per vessel and per year were considered, removing the first and the last weeks, as well as the six weeks of seasonal closure.

The MI was calculated separately per area, for all pairs of years between 1999 and 2011 (*e.g.* week 1 of year 1999 for vessel 1 vs. week 1 of year 2000 for the same vessel) totaling 540 observations per vessel over the 13 years analysed.

The MI referring to the productivity change of each DMU between time period t-1 and t, can be obtained as follows (Färe *et al.*, 1994):

$$\mathrm{MI}^{\mathrm{t,t\text{-}1}} = \frac{\mathrm{E}^{\mathrm{t}}(\mathrm{x}^{\mathrm{t}},\mathrm{y}^{\mathrm{t}})}{\mathrm{E}^{\mathrm{t\text{-}1}}(\mathrm{x}^{\mathrm{t\text{-}1}},\mathrm{y}^{\mathrm{t\text{-}1}})} \times \sqrt{\frac{\mathrm{E}^{\mathrm{t\text{-}1}}(\mathrm{x}^{\mathrm{t\text{-}1}},\mathrm{y}^{\mathrm{t\text{-}1}})}{\mathrm{E}^{\mathrm{t}}(\mathrm{x}^{\mathrm{t\text{-}1}},\mathrm{y}^{\mathrm{t\text{-}1}})} \times \frac{\mathrm{E}^{\mathrm{t\text{-}1}}(\mathrm{x}^{\mathrm{t}},\mathrm{y}^{\mathrm{t}})}{\mathrm{E}^{\mathrm{t}}(\mathrm{x}^{\mathrm{t}},\mathrm{y}^{\mathrm{t}})}} = \mathrm{EC} \times \mathrm{TC} \tag{1}$$

where, $E^t(x^t, y^t)$ corresponds to the efficiency measure of each DMU at time period t considering its outputs (y) and inputs (x), compared with all DMU observed in the same time period t; $\mathrm{E}^{\mathrm{t\text{-}1}}(\mathrm{x}^{\mathrm{t\text{-}1}}, \mathrm{y}^{\mathrm{t\text{-}1}})$ corresponds to the efficiency measure of each DMU at time period t-1. Likewise, $\mathrm{E}^{\mathrm{t}}(\mathrm{x}^{\mathrm{t}-1}, \mathrm{y}^{\mathrm{t}-1})$ and $\mathrm{E}^{\mathrm{t}-1}(\mathrm{x}^{\mathrm{t}}, \mathrm{y}^{\mathrm{t}})$ are the efficiency measures of each DMU at time period t-1 and t related to the production frontier of time period t and t-1, respectively. In this expression, the first part of the equation (outside the square root) corresponds to EC and represents the change between two time periods in the DMU position relative to the frontier of the respective time period whereas the second part (inside the square root) corresponds to TC and represents the change in the frontier position between the two periods. The MI (or its components) may reach a value greater, equal or smaller than one, depending on whether a progress, stagnation or regress in the vessel performance between two consecutive time periods was observed.

The MI was estimated assuming constant returns to scale (CRS), as recommended in Färe and Grosskopf (1996), Färe *et al.* (1997, 1998) and Griffel-Tatjé and Lovell (1995). According to Griffel-Tatjé and Lovell (1995), the estimation of the MI with Variable Returns to Scale (VRS) ignores changes in scale and biases the MI.

The four efficiency measures of each DMU (in the expression (1)) were determined assuming an input-oriented DDF model with CRS. The major difference between a DDF model (specified according to the formulation proposed by Chambers *et al.* (1996)) instead of a standard DEA model by Charnes *et al.* (1978) lies in the possibility of simultaneous estimation of inefficiencies associated to subsets of inputs and outputs.

The following linear programming problem is thus solved for each DMU in each time period, using a directional vector $\mathrm{g} = \left(\mathrm{g}_{\mathrm{x}^{\mathrm{v}}}, \mathrm{g}_{\mathrm{x}^{\mathrm{f}}}, \mathrm{g}_{\mathrm{y}}\right)$ equal to $\mathrm{g} = (1\ ,0,0)$ corresponding to variable inputs, fixed inputs and output, respectively (where the x and y refer to input and output, and the v and f mean variable and fixed, respectively). The variable inputs are set to 1, because they are the ones that can be changed. The remaining components of the directional vector are set equal to zero, meaning that fixed inputs should remain unchanged, as they reflect vessel's technical characteristics outside decision makers' control, and outputs should not increase as the fishery is regulated by catch quotas.

$$
\begin{aligned}
&\min \alpha \\
&\text{s.t.} \\
&\sum_{j=1}^{J} \lambda_j x_{jn}^{v} \leq x_{j'n}^{v} - \alpha g_{x_n^v} \qquad n = 1, \dots, N \\
&\sum_{j=1}^{J} \lambda_j x_{jp}^{f} \geq x_{j'p}^{f} + \alpha g_{x_p^f} \qquad p = 1, \dots, P \\
&\sum_{j=1}^{J} \lambda_j y_{jm} \geq y_{j'm} + \alpha g_{y_m} \qquad m = 1, \dots, M \\
&\lambda_j \geq 0, j = 1, \dots, J
\end{aligned} \tag{2}
$$

Where λ_j is the intensity (activity) variable, one for each observation; x^v is a vector of variable inputs (fuel consumption and fishing days); x^f is the vector of fixed inputs (overall length, tonnage, engine power and biomass stock indicator); y is the vector of the output (the sum of the landings, measured in weight, of all species captured); J is the number of observations (number of vessel's weeks activity), N is the number of variable inputs (fuel consumption and fishing days), P is the number of fixed inputs (overall length, tonnage, engine power and biomass stock indicator); and M is the number of outputs (sum of all landings); α is the inefficiency value, and equals zero if the variable inputs cannot be decreased or is greater than zero if the variable inputs can be decreased.

Thus, the efficiency measure used to estimate the MI ($E^t(x^t, y^t)$ and $E^{t-1}(x^{t-1}, y^{t-1})$ in equation (1)) is equal to the efficiency estimate obtained as (1- α).

The assessment of the differences in inefficiency levels before and after the introduction of the MWFQ was performed using a DDF model with the additional restriction $\sum_{j=1}^{J} \lambda_j = 1$ on formulation (2) allowing for VRS. As the assessment only intended to evaluate changes in efficiency levels (free from the technical restrictions of using CRS in the MI estimation) the use of VRS seemed more appropriate, as the results would be more conservative, without requiring gains in efficiency owing to changes in scale size.

Previous research in bivalve fishery with dredge showed that an increase in the resources does not always cause a proportional increase in the landings (Oliveira *et al.*, 2010).

In the performance comparison between periods with different management, the DMU corresponding to vessel operations with similar management were grouped together. For instance, to compare the vessels' activity in period 1 and in period 2 for the Northwest area (see Table 4-1), the average of the weeks 1 from the period 1 of vessel 1 were compared with the average of weeks 1 from period 2 of the same vessel, and so on. This approach, consisting of the aggregation of homologous weeks within the same period, enabling the assessment of the impact of changes in management on vessel's activity, was followed both for the calculation of the MI and DDF.

The model (2) was run, with all DMU of the two periods together, leading to the construction of a pooled frontier. Then, the distance to the pooled frontier before and after the management change was compared. The aim was to ascertain whether the DMU of the period with MWFQ were closer to the frontier, and quantify the gains (through the deviations from the frontier for each input) that could be attributed to the new operational conditions of the fleet.

Additionally, to evaluate the robustness of the estimates obtained, all MI indices and alpha values were bootstrapped. The bootstrapping procedure proposed by Simar and Wilson (1999) relies on a data-simulation method that replicates the original case N times, each time recalculating the parameters of interest. The result is a set of N estimates of the parameters, making it possible to estimate their distributional properties. The estimation of confidence intervals (CI) for the MI provides the possibility to test hypotheses regarding the true value of productivity change. If the MI (or its components) is found to be significantly different from one, i.e. the estimated CI does not contain the value one, this means that the productivity of the DMU analysed indeed regressed (MI<1) or improved (MI>1). The models previously described were implemented with the bootstrapping option using the software MaxDEA® Pro (Cheng and Qian, 2011).

Finally, Spearman correlation analysis was conducted to investigate associations between MI, TC, EC and the input variables analysed (fuel consumption, fishing days and biomass stock indicator). This analysis was performed using the SPSS® statistics software.

4.4 Results and discussion

4.4.1 The effects of management changes on vessel productivity

The assessment of the effects of management changes on vessel productivity was investigated through the analysis of the MI and its components (EC and TC) between 1999 and 2011 and separately per fishing area.

Table 4-3 shows the evolution of MI and its two components for the studied period and for the Northwest area, whilst Table 4-4 shows the Spearman's correlation coefficients between MI, TC, EC, fuel consumption, fishing days and biomass stock indicator.

In the Northwest fleet, the Spearman's rho (Table 4-4) showed that the MI was positively correlated with the TC (0.972) and the biomass (0.641). Neither TC nor EC were correlated with biomass, fuel consumption or fishing days. It was also observed that fuel consumption was positively correlated with fishing days (0.655).

Table 4-3. Malmquist Indices in the Northwest area.

Period	MI	EC	TC
1999_2000	0.864 **	1.038 **	0.832 **
2000_2001	1.584 **	0.921 **	1.720 **
2001_2002	0.845 **	0.990 *	0.853 **
2002_2003	1.338 **	1.031 **	1.297 **
2003_2004	0.741 **	1.002	0.739 **
2004_2005	1.245 **	1.001	1.243 **
2005_2006	0.974 **	1.012 **	0.962 **
2006_2007	1.375 **	1.015 **	1.354 **
2007_2008	1.154	1.036 **	1.113
2008_2009	1.940 **	0.977 **	1.985 **
2009_2010	0.918 **	0.836 **	1.098 **
2010_2011	1.052	0.981	1.073

MI = Malmquist Index, EC = efficiency change, TC = technological change (geometric means). * and ** denote that MI differs significantly from 1 at the 95% and 99% confidence levels, respectively.

For the purposes of the MI analysis, three periods were identified in this area. During the first one (between 1999 and 2001) the MI increased from 0.864 to 1.584, which is related to the improvement (biomass indicator) of the target species stock (Figure 4-2a).

Table 4-4. Northwest fleet.

Correlation Coefficient (Spearman's rho)	NW_EC	NW_TC	biomass	fuel consumption	fishing days
NW_MI	-0.161	0.972**	0.641*	-0.476	-0.413
NW_EC		-0.280	0.532	0.098	-0.081
NW_TC			0.529	-0.462	-0.445
biomass				-0.158	-0.207
fuel_consumption					0.655*

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

In the second period (2001 to 2007), with the introduction of the MWFQ during the winter (and an MDFQ during the rest of the year), a reduction in fishing days and fuel consumption would be expected, leading to an increase in vessel productivity. However, this was not observed consistently (Table 4-3). During this period, the MI varied directly with the status of the biomass, registering three productivity losses caused by decreases in the TC index (Table 4-3), with the lowest MI score being reached in 2004 (0.741).

This inference relies on the strong correlation between MI and TC. The maximum value of MI was registered in 2007, when a high biomass level of the target species was observed, which led to fewer fishing days and lower fuel consumption (Figure 4-2a). The last period was the one in which the MI showed the best result and remained mostly above 1, implying productivity gains instead of losses (fluctuating between 0.918 and 1.940). This period was characterized by the extension of the MWFQ throughout the year.

The productivity loss in 2010 was mainly caused by the significant decrease of EC (16.4%), the largest change in the whole time window for this component (Table 4-3). The correlation found between fishing days and fuel consumption (Table 4-4) suggests a positive impact of the MWFQ on productivity. For the same quota, MWFQ allows fishermen to fill it in fewer days, spending less fuel, leading to the increase of productivity. The absence of any correlation between TC and EC with biomass, fuel consumption or fishing days, could be a result of the monospecific nature of the fishery in the Northwest area, which may also explain why MI is only correlated with the biomass indicator.

Indeed, since there are no fishing alternatives in this area, under the same management regime MI follows the trend observed for the biomass indicator, i.e. if biomass increases

MI also increases, or vice versa, if biomass decreases MI also decreases. This indicates that MI is extremely dependent on the health of the stock.

Table 4-5 presents, for the Southwest area, the evolution of the MI during the period analysed. Table 4-6 shows the correlations between the MI (and its components) and the variables studied.

Table 4-5. Malmquist Indices in the Southwest area.

Period	MI	EC	TC
1999_2000	0.893 **	1.002	0.891 **
2000_2001	0.948 **	0.998	0.950 **
2001_2002	1.284 **	1.013 **	1.268 **
2002_2003	1.015 **	0.976 **	1.040 **
2003_2004	1.085 **	1.001	1.084 **
2004_2005	1.029	1.005 **	1.024
2005_2006	1.014 **	0.990 **	1.024 **
2006_2007	1.018	1.007 **	1.011
2007_2008	0.937 **	1.006 *	0.931 **
2008_2009	1.059 **	0.988 **	1.072 **
2009_2010	1.121 **	1.024 **	1.095 **
2010_2011	1.053 **	1.034 **	1.018 **

In the Southwest area the Spearman's rho (Table 4-6) revealed significant correlations of the MI with the TC (0.900), as well as with the biomass (0.790) and fishing days (-0.666). The EC was shown as negatively correlated with fishing days (-0.669). The TC index was also revealed as correlated with biomass (0.697). Finally, the biomass was shown as negatively correlated with fishing days (-0.606), indicating that when the target species are abundant the fishermen go to sea fewer times.

Three periods with substantial changes in management were identified (Table 4-1). The first one (between 1999 and 2000) was more difficult to analyse due to its reduced duration. Notwithstanding, in this period, the MI score obtained (0.893) indicates a significant loss in productivity, which reflects the decrease of TC (Table 4-5). The poor status of the biomass stock, along with an increase in fishing days, explains the low TC value (and consequently the MI) observed (Figure 4-2b).

Although during the first year of the second period (2000–2009) an increase was observed in productivity, the MI remained below 1 (MI = 0.948). This result shows that the introduction of a new dredge (more efficient than the old one), and the slight increase in abundance of the target species, coupled with fewer fishing days, was not enough to offset the negative impact caused by the reduction in MDFQ per vessel (Table 4-5). Even so, the new gear, along with a higher value of biomass stocks, contributed to the highest MI registered in 2001–2002 (1.284). During this period, the lowest value of the EC (0.976) was coincident with the highest number of fishing days (2002–2003), as a result of a biomass stocks decline (also followed by a decrease in TC). These chain reactions reveal once again the correlations among the TC and the biomass status as well as the EC and the fishing days (Table 4-6).

In the third period, the MI improved significantly, registering values of MI and its components above 1. It is important to underline that it was during this period that the highest EC scores of the whole time-window were registered (Table 4-5), indicating that the vessels with poorer performance were able to move closer to the best-practices of the fleet. Although the stocks' status declined in 2010, the productivity increased due to the introduction of the MWFQ. The multispecificity that characterizes the Southwest dredge fleet leads to higher fishery complexity (compared with the Northwest area), reflected in the number of correlations observed (Table 4-6).

This fleet targets four species, which means that when the abundance of a species is low, the vessels can direct their fishing effort to the other three species. This explains why the MI (along with the best-practice vessels of the fleet reflected in the TC) is positively correlated with biomass and negatively correlated with fishing days, evidencing that when the biomass of the target stocks are high, the number of fishing days decreases, leading to an increase in MI.

Table 4-6. Southwest fleet.

Correlation Coefficient (Spearman's rho)

	SW_EC	SW_TC	biomass	fuel consumption	fishing days
SW_MI	0.385	0.900**	0.790**	0.203	-0.666*
SW_EC		0.077	0.559	0.210	-0.669*
SW_TC			0.697*	0.200	-0.514
biomass				0.091	-0.606*
fuel_consumption					-0.354

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

The absence of correlation between the fuel consumption and the fishing days in this fleet (Table 4-6), indicates that at low levels of biomass stocks, the vessels have to spend more time at sea (regardless of the number of fishing days) in order to fulfill the orders received.

When the biomass stocks are low, the fleet, including coastal vessels, typically directs the fishing effort to a single target species. In contrast, when the levels are high, the fuel consumption indicates that the fishing effort is directed to several species simultaneously. With a broader time-window, a negative correlation would be expected between these two variables (fuel consumption and fishing days) caused by the MWFQ's introduction in this area. The total absence of correlation between the MI and the EC in both areas can be explained by the lower magnitude of variation in EC values compared with TC values. This could be interpreted as a lack of significant fluctuations in the fleet's efficiency.

Once we identified the input factors responsible for the productivity changes observed, the analysis was focused on the effect of the main management changes on vessel productivity, which required a new data grouping according to the periods presented in Table 4-1. In the Northwest, the transition from period one to period two was characterized by a slight productivity improvement (9.1%), revealing that the introducing of MWFQ in the winter months had the expected positive effect on vessel productivity.

The extension of the MWFQ throughout the whole year significantly improved the MI by 16.3%. This was essentially due to the TC (which also showed an increase of 17.7%). In other words, the vessels considered to employ "good practices" expanded the frontier by 17.7% with their best-practices. The remaining vessels (not belonging to the frontier) moved further away from it, resulting again in a loss of efficiency (EC) of 1.2% (Table 4-7). This loss of efficiency was also registered in the transition from the first to the second period (reduction in EC by 0.9%).

Regarding the Southwest fleet, the productivity decreased 22.1% in the transition from the first to the second period, related to the abrupt reduction of the daily fishing quota (800 kg per vessel) registered in the beginning of the second period. The introduction of the weekly quota for the fishery in the third period resulted in a significant increase (10.3%) of MI and its components (9.7% for TC and 0.5% for EC). Despite the biomass variation observed during that period, vessel productivity level improved due to the reduction in fishing days

(Table 4-7), suggesting that the MWFQ also had a positive impact on the fleet's productivity in this area.

Table 4-7. Malmquist Indices per period.

	Period	MI	EC	TC
Northwest area	1_2	1.091 **	0.991 **	1.101 **
	2_3	1.163 **	0.988 **	1.177 **
Southwest area	1_2	0.779 **	0.977 **	0.797 **
	2_3	1.103 **	1.005 **	1.097 **

4.4.2 The impact of the weekly quota on vessel productivity

To evaluate the impact of the MWFQ on vessel productivity, the performance of the vessels before and after the implementation of this measure in each area were compared. The results are presented in Tables 3-8 and 3-9 together with the geometric mean of the deviations by area and input.

Table 4-8. Results of original and bootstrapped alpha estimates and deviations from efficient levels per fleet (Northwest).

Northwest area										
	before MWFQ					after MWFQ				
				deviations					deviations	
vessel	original alpha	bias-corrected alpha	± SD	fuel consumption	fishing days	original alpha	bias-corrected alpha	± SD	fuel consumption	fishing days
1	1.979	1.981	0.070	49.3%	59.0%	1.433	1.432	0.072	20.2%	43.0%
2	1.954	1.955	0.073	55.7%	59.1%	1.457	1.456	0.071	48.4%	49.1%
3	1.955	1.957	0.072	54.8%	58.7%	1.542	1.544	0.073	47.7%	49.7%
4	2.079	2.080	0.071	53.5%	58.5%	2.074	2.069	0.072	28.8%	62.5%
5	1.733	1.735	0.072	49.0%	51.7%	1.361	1.360	0.072	45.0%	45.6%
6	1.935	1.936	0.071	52.0%	59.0%	1.663	1.664	0.072	42.2%	49.2%
7	1.875	1.875	0.072	45.2%	59.3%	1.534	1.536	0.070	50.2%	51.1%
8	1.961	1.962	0.071	49.6%	56.3%	1.502	1.503	0.071	47.4%	50.3%
9	1.891	1.891	0.071	62.0%	56.2%	1.421	1.422	0.071	59.3%	50.8%
10	1.798	1.796	0.072	46.9%	55.0%	1.538	1.540	0.072	52.0%	49.4%
11	1.975	1.976	0.072	57.1%	58.9%	1.592	1.591	0.072	54.5%	49.0%
geometric mean	1.919	1.920		52.1%	57.4%	1.547	1.547		43.4%	49.8%

SD - Standard deviation

Low values of deviations mean that the DMU is close to the frontier, and therefore if the values of the deviations diminish from one management period to the other, it means that the vessel performance improved. These results are supported by both original alpha scores and bias-corrected alpha scores. The difference between the two estimates is, in both areas and periods, less than 0.2%, on average, which is a very small difference (Tables 3-8 and 3-9).

Table 4-9. Results of original and bootstrapped alpha estimates and deviations from efficient levels per fleet (Southwest).

Southwest area										
	before MWFQ					after MWFQ				
		bias-		deviations			bias-		deviations	
	original	corrected		fuel	fishing	original	corrected		fuel	fishing
vessel	alpha	alpha	± SD	consumption	days	alpha	alpha	± SD	consumption	days
1	2.286	2.285	0.063	44.5%	59.1%	1.883	1.880	0.063	36.7%	48.4%
2	2.435	2.434	0.063	68.5%	61.1%	1.720	1.717	0.063	49.5%	31.8%
3	2.634	2.635	0.064	47.7%	64.9%	1.642	1.642	0.063	26.3%	39.5%
4	2.133	2.134	0.063	56.6%	59.0%	1.906	1.905	0.064	51.5%	54.0%
5	2.332	2.333	0.063	51.6%	58.3%	1.975	1.974	0.064	54.2%	48.4%
6	2.125	2.125	0.063	64.7%	54.0%	1.788	1.789	0.063	62.2%	44.3%
7	2.472	2.472	0.063	49.8%	63.7%	1.972	1.971	0.062	45.0%	60.1%
8	2.173	2.171	0.062	37.4%	57.6%	1.609	1.608	0.063	36.1%	45.1%
9	2.992	2.990	0.063	68.0%	68.5%	2.091	2.093	0.062	63.3%	60.5%
10	1.869	1.871	0.063	68.7%	42.1%	1.811	1.812	0.064	67.5%	41.0%
11	2.497	2.498	0.063	55.0%	60.1%	2.148	2.146	0.065	38.2%	42.9%
12	2.293	2.293	0.063	54.8%	57.5%	1.999	1.999	0.064	50.6%	52.8%
13	1.744	1.746	0.063	53.0%	48.9%	1.432	1.432	0.062	50.1%	46.3%
14	2.180	2.175	0.064	57.1%	52.1%	1.000	1.003	0.063	57.9%	50.0%
15	2.119	2.117	0.061	38.2%	49.2%	1.450	1.446	0.064	34.3%	38.9%
16	1.816	1.818	0.063	44.0%	41.8%	1.000	1.000	0.063	27.4%	30.0%
17	1.978	1.977	0.063	42.8%	51.5%	1.338	1.335	0.063	19.5%	23.6%
18	1.717	1.718	0.062	55.0%	58.0%	1.617	1.614	0.063	31.1%	32.2%
19	2.333	2.338	0.064	41.0%	59.6%	1.674	1.676	0.062	27.5%	40.0%
20	2.752	2.750	0.064	67.8%	66.9%	1.841	1.840	0.063	50.0%	50.9%
21	2.409	2.407	0.063	58.4%	60.2%	1.866	1.865	0.063	54.0%	34.4%
22	2.406	2.403	0.063	50.7%	61.2%	1.593	1.591	0.061	23.7%	32.4%
23	2.546	2.545	0.063	56.5%	59.4%	1.654	1.655	0.063	39.5%	27.6%
24	2.269	2.268	0.063	56.8%	54.7%	1.719	1.718	0.062	43.2%	42.9%
25	2.334	2.332	0.062	59.8%	59.7%	1.370	1.367	0.063	47.3%	30.7%
geometric mean	2.223	2.223		51.1%	56.2%	1.655	1.654		41.4%	40.8%

SD - Standard Deviation

Although the confidence intervals (CI) are not included in these tables, it was verified that the bias-corrected alpha estimate was within relatively narrow CI for all the vessels, i.e. the lower and upper bounds of the intervals were relatively close (on average in both areas and periods, the amplitude of the CI is less than 0.05).

Since some of the inputs used in the present study are related to the technical characteristics of the vessels, and no restructuring or vessel modernization was contemplated, the analysis focused on the inefficiencies of the variable inputs (fuel consumption and fishing days). The analysis of the difference between the mean deviation of the observed and the target values, "before" and "after" the MWFQ introduction, showed that the fuel consumption in the Northwest (Table 4-8), and the number of fishing days in the Southwest (Table 4-9) were the inputs that displayed the highest reduction (corresponding to an efficiency gain).

The introduction of the MWFQ led to a reduction in the number of fishing days both in the Northwest (7.6%) and in the Southwest (15.4%) (Tables 3-8 and 3-9). Fuel consumption decreased in the Northwest (8.7%) and in the Southwest (9.8%) (Tables 3-8 and 3-9). The higher reduction in daily fuel consumption registered in the Southwest fleet (compared with the Northwest fleet), could be related to the multispecificity of the fishery. In this area for each trip a vessel spends more time steaming between bivalve beds to achieve the fishing quotas for all the commercial species exploited. Being a fishery that operates essentially on orders received on land, after the introduction of the MWFQ the fishermen can choose to catch in one day the whole volume of orders, decreasing the fuel consumption in this way.

As was mentioned before, an important bivalve dredge fishery also exists on the South coast of Portugal. Nevertheless, in this area, the fishery instead of being managed by weekly fishing quotas per vessel is managed by daily fishing quotas established per vessel and species. The question that arises is this: if weekly quotas were to be implemented in the South bivalve dredge fishery, what would be the impact in the production costs of the fleet? In the light of the results gathered in the present study, the implementation of the MWFQ in this area may be considered a positive measure since it could increase productivity of the dredge fleet operating in that area.

In the South, the dredge fleet is segmented into a local and a coastal fleet. The local fleet presents a behaviour similar to the Northwest fleet, since it directs the fishing effort towards a single species. In contrast, the coastal fleet exhibits a behavior similar to the fleet operating in the Southwest, which directs its fishing effort towards two or more species simultaneously.

Thus, based on the results obtained in this study for the Northwest and Southwest dredge fleets, a hypothetical implementation of the MWFQ for the entire fleet in the South area, would have led in 2011 to an overall reduction of 10.8% in the number of fishing days (390 days). This overall reduction comprises the 7.6% performance improvement observed after the MWFQ implementation in the Northwest area (Table 4-8) applied to the total number of fishing days in the local vessels registered in 2011 and similarly, the 15.4% performance improvement in the Southwest (Table 4-9) applied to the total number of the fishing days in the coastal vessels. This would be reflected in a reduction of the time spent between the homeport and the bivalve beds of about 2 h/day/vessel, corresponding to an average decrease of fuel consumption of 50 l/day for local vessels and 140 l/day for coastal vessels. Based on these assumptions, the overall reduction in fuel consumption would reach 12.8% (about 39 844 l) for the entire fleet.

4.5 Conclusions

The results showed that bootstrapped MI can be used to analyse the effects of changes in management on the productivity of the Portuguese dredge fleet (that operates in the Northwest and in the Southwest fishing areas). Furthermore, the DDF can be used to explore a hypothetical implementation of the MWFQ in the South fishing area. In the present study the time-window analysed (1999–2011) was split into different periods, during which the management of the bivalve dredge fishery operating in the Northwest and Southwest of Portugal remained unchanged.

From the results of bootstrapped MI it was concluded that the implementation of the MWFQ improved vessel productivity in both areas. This increase reflects not only the impact of the management measure itself but also the role of the best-practices in both fleets' productivity reflected in the TC component and its correlation with the MI index.

For the Northwest and Southwest dredge fleets, the inefficiencies estimated with the DDF showed a significant reduction in fuel consumption and in fishing days after the MWFQ introduction. If the MWFQ had been implemented in the South fishing area in 2011, the number of fishing days and fuel consumption would have been reduced by about 10.8% (390 days) and 12.8% (39 844 l), respectively. This would certainly have contributed to an increase in the productivity of this fleet.

The results obtained demonstrate the importance of the implementation of weekly fishing quotas in fisheries similar to the one analysed in the present study. This measure has proven to improve fleet productivity by reducing production costs, since the number of fishing days to attain the fishing quota decreases, and thus fuel consumption can also be reduced.

The introduction of MWFQ also minimizes the impact of this type of fishery on the environment. Indeed, it not only reduces indirectly the impact on the stocks of target species (cumulative fishing stress induced by the fishery decreases, diminishing indirect mortality due to both predation and low physiological condition (see Gaspar and Chícharo, 2007)) but also the impact on associated macrobenthic communities and on the habitat. Moreover, for the same biomass status the fishing days and consequently the fuel consumed to attain the quota are also reduced. All these effects contribute to diminish the ecological footprint of this type of fishery, suggesting the importance of applying this measure in other fisheries worldwide, especially in those using active gear and managed by daily quotas.

CHAPTER 5. Enhancing the performance of quota managed fisheries using seasonality information: The case of the Portuguese artisanal dredge fleet[4]

Abstract: Several fisheries across the world are managed by a quota regime. These quotas can be set yearly, monthly, weekly or daily. However, for some fish species demand seasonality may occur, which should be taken into consideration in the establishment of the quota (especially in those fisheries managed by daily or monthly quotas). This would allow fishermen to catch more fish at times of the year with higher demand in detriment of periods when demand is low. The present work investigates the existence of demand seasonality for bivalves from the artisanal dredge fleet. This fleet operates along the entire coast of the Portugal mainland. The analysis of fleets' revenue efficiency is assessed with Data Envelopment Analysis models, and the monthly seasonality effects on the revenue efficiency were tested using a Tobit regression. The results revealed that on the South coast there is a strong demand in the summer whereas on the western coast (Northwest and Southwest fishing areas) demand increases during Christmas and New Year festivities. Since this fishery is managed by weekly/daily quotas, it is proposed that these quotas should be redistributed in order to adjust them to periods of higher demand, thereby increasing the profitability of the vessels. The approach followed could be applied to similar fisheries worldwide.

Keywords: Artisanal fleets; Bivalve fishery; Demand seasonality; Management; Data Envelopment Analysis; Tobit regression

[4] Oliveira, M.M., Camanho, A.S., Gaspar, M.B., 2014. Enhancing the performance of quota managed fisheries using seasonality information: the case of the Portuguese artisanal dredge fleet. Marine Policy, 45(3):114–120.

5.1 Introduction

Seasonality is invariably present in worldwide fisheries. This presence could be detected through the abundance of different species (*e.g.* Sbrana *et al.*, 2003; Sigler and Csepp, 2007) related to their life cycles and migration (*e.g.* Henderson *et al.*, 2007; Sánchez and Demestre, 2010; *Harry et al.*, 2010), their distribution in different fishing grounds (Madurell *et al.*, 2004) and the body size of different species caught at different times of the year (*e.g.* Motta *et al.*, 2005; Arocha and Bárrios, 2009; Romero *et al.*, 2013). In addition to these factors, seasonality could also be felt in fisheries due to the variation of commercial demand throughout the year (*e.g.* Floros and Failler, 2004; Floros and Advelas, 2004).

Behavior of demand seasonality is an important factor that should be considered in fisheries policy, especially in those fisheries that are managed by maximum catch quotas regimes. Indeed, the adequacy of quotas should consider not only the adjustment of the catches to the status of the resources but also the fluctuations of demand which could represent a significant improvement to fisheries sustainability through maximizing the profits of the vessels. Unfortunately, the lack of studies addressing this issue is quite significant, the works carried out by Floros and Failer (2004) and Floros and Advelas (2004) being an exception. In the former work, the authors examined the evidence for seasonal effects and cointegration among fisheries prices of main species landed in Cornwall (South West England).

The form and magnitude of seasonal fluctuations was explored, and it was concluded that their reflection on fish prices can be beneficial to fisheries managers in their decisions regarding policy, development and management. In the latter work the seasonal behavior of fish prices in Greece is explained and it is argued that the main factors that influence the demand for species are weather conditions, public holidays and demand fluctuations during the year. Yet, to the authors' best knowledge, the present work is the first that focuses on demand seasonality applied to an artisanal fishery managed by maximum daily/weekly quotas.

Among the artisanal fisheries in mainland Portugal, the bivalve dredge fishery is one of the most important, both in terms of the number of the vessels, fishermen, and employment in fisheries-related activities, as well as in terms of weight and value of the catches (Oliveira *et al.*, 2009). From a management point of view, the Portuguese coast is divided into three main fishing areas, namely: Northwest, Southwest and South. This fishery differs in features and operability along the Portuguese coast and is managed by a seasonal closure (from 1st of May to 15th of June), minimum landing sizes, gear restrictions and a regime of maximum fishing quotas per vessel's tonnage and species.

The present paper aims to understand if bivalves demand is subject to seasonality by analyzing the monthly fluctuations of fleets' revenue efficiency (RE) in the three areas between 2006 and 2012. The mean wave height (MWH) was also analyzed by fishing area to screen any effects on the RE of the fleets. With this purpose, Data Envelopment Analysis (DEA) models were applied to measure vessels' RE, and Tobit regression was used to explore the monthly impact.

In the literature, the analysis of fisheries RE attracted increased attention recently, with a few studies considering not only the species landings but also their revenue. Lindebo *et al.* (2007) proposed an economic measure of capacity for the Danish North Sea trawlers. Oliveira *et al.* (2010) estimated RE as a complement to the technical efficiency analysis, using the annual quota per vessel as a contextual factor. The procedure adopted allowed a two-dimensional representation of vessel performance and enabled the identification of benchmark vessels in the artisanal dredge fleet operating in the Portuguese South coast. The study of Pascoe and Tingley (2006) analyzed the segments of the Scottish fishing fleet concerning their profit maximizing behavior. Alam and Murshed-e-Jahan (2008) applied DEA to study technical efficiency and the ability to minimize costs in the aquaculture of the prawn-carp in Bangladesh.

In the absence of any previous study addressing demand seasonality in artisanal fisheries, this paper provides basic knowledge that will be useful to other artisanal fisheries managed by quotas. Based on the results achieved, some considerations concerning managerial policies are provided aiming to enhance the sustainability of the Portuguese bivalve dredge fishery.

5.2 Portuguese artisanal dredge fleet

Currently the artisanal dredge fleet comprises 93 vessels (11, 25 and 57 vessels operating in the Northwest, Southwest and South coast, respectively) (Figure 5-1) with an overall length ranging from 5 to 16 m, an engine power between 20 kW and 130 kW, a gross tonnage (GT) between 1 and 24 tons and a crew composed of one to five fishermen. The vessels are classified as local or coastal according to the area in which they operate. Local vessels can only operate near the homeport or adjacent fishing ports, whereas coastal vessels can fish within the fishing area for which they are registered. In the Northwest and Southwest fishing areas only coastal vessels operate due to the distance of the bivalves' beds from the fishing ports, as well as the hydrodynamic conditions observed in these areas, namely high MWH.

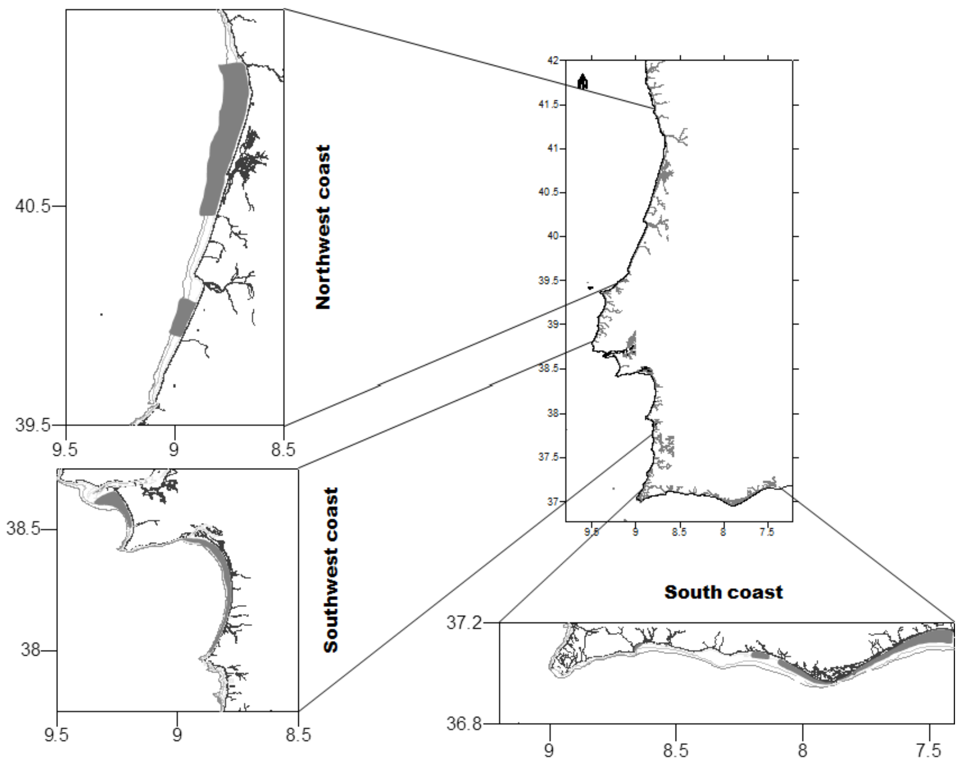

Figure 5-1. Distribution of bivalve beds (grey areas) in the three fishing areas of mainland Portugal (A - Northwest area; B – Southwest area; C – South area).

The bivalve dredge fishery in the Northwest area is monospecific targeting the surf clam (*Spisula solida*), contrasting with the other two areas where the fishery is multispecific, targeting four species. In the Southwest area the target species are the surf clam, the smooth clam (*Callista chione*), the donax clam (*Donax spp.*) and the pod razor clam (*Ensis siliqua*), whereas in the South the target species are the surf clam, striped venus (*Chamelea gallina*), donax clam and the pod razor clam.

Although the majority of the management measures are similar in all three fishing areas (*e.g.* seasonal closure, the minimum landing sizes and the gear specifications), there are differences in terms of the quota regime. In the Northwest and Southwest maximum weekly fishing quotas are currently in force, whereas in the South coast the fishery is managed by maximum daily fishing quotas. The quotas are reviewed on an annual basis considering the result of the annual monitoring surveys carried out by the Portuguese Institute for the Ocean and the Atmosphere (IPMA), and can be changed if necessary to adjust the catch to the status of the stocks (Oliveira *et al.*, 2013).

Table 5-1. Profiling of the studied Portuguese dredge fleet (average values between 2006 and 2012).

Profiling of the studied Portuguese dredge fleet (average values between 2006 and 2012)

	Northwest	Southwest	South (local)	South (coastal)
(vessels per area)	11	22	29	22
Inputs				
Vessel overall length (m)	13.3	11.3	7.1	10.6
Vessel tonnage (GT)	16.9	9.8	3.7	8.5
Vessel power (kW)	102.0	72.2	44.4	64.0
No. fishing days (per week)	2.4	2.9	3.1	3.5
Fuel consumption (kl per week)	5.0	8.0	2.8	4.2
Outputs				
Capture of surf clam (kg per week)	803.0	239.2	288.2	490.7
Capture of donax clam (kg per week)	-	202.0	175.9	208.8
Capture of razor clam (kg per week)	-	190.7	-	-
Capture of striped venus (kg per week)	-	220.0	212.0	310.3
Capture of smooth clam (kg per week)	-	597.7	-	-
Output prices				
Prices of surf clam (€ per kg)	2.7	1.5	0.8	0.8
Prices of donax clam (€ per kg)	-	2.5	2.2	2.1
Prices of razor clam (€ per kg)	-	2.5	-	-
Prices of striped venus (€ per kg)	-	0.9	1.5	1.5
Prices of smooth clam (€ per kg)	-	1.0	-	-

The different quota regimes adopted are justified by the harsher oceanographic conditions observed in the western Portuguese coast from operating on the South coast, which frequently hamper the dredge fleet to operate most of the days (Table 5-1), especially during the winter when high wave heights are observed.

5.3 Methodology

5.3.1 Dataset

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 (93 vessels) only 84 vessels were included in the analysis. The other 9 vessels (3 and 6 from the Southwest and South fleets, respectively) were excluded because in most of the years they did not use dredge gears.

Table 5-1 presents the average characteristics of the fleets that operated in the three areas, the mean fishing days per week, mean fuel consumption per week, average weekly landings (in weight) and mean weekly price per kg at first sale. The daily waves' height time series was obtained from the windguru.cz website.

5.3.2 Data analysis

Firstly the oceanographic profiling of each study area was undertaken, in order to identify possible MWH effect on the fleets' RE. Analysis of variance (ANOVA) was then used to identify possible differences in MWH, and test for the existence of monthly effects. Before ANOVA, data were tested for normality (Anderson–Darling test) and homogeneity of variance (Bartlett's method). When a significant difference was detected, pairwise comparisons were performed through the Bonferroni test.

For the purpose of the RE assessment, a DEA analysis was run separately for the vessels in each area (Northwest, Southwest and South – both local and coastal fleets in the later region). The fixed inputs specified characterized the vessel (i.e., vessel overall length, tonnage and engine power), and the variable inputs were the number of fishing days and fuel consumption per week. Since the target species are not the same across areas, we opted to use as outputs the amount landed of each target species, and evaluate the optimal level of revenue for each vessel in the objective function, taking into account the price of the catches in the auction market.

The data was aggregated by week, to avoid bias in the analysis due to atypical daily catches. The weekly data aggregation is not fully devoid of the same problem, as the same vessel may obtain results that differ significantly from week to week. However, the use of weekly data instead of a monthly aggregation of catches greatly increased the size of the sample, thus avoiding the problem of lack of discriminatory power in DEA models. In this context, 16899 weeks of activity were considered for the artisanal dredge fleet during the whole time-window.

Methodologically, DEA is a mathematical programming technique that estimates a production frontier characterizing the most technically efficient combination of outputs given a set of inputs. One of the most notable features of DEA is the capacity to generate a single index to classify the efficiency of a Decision Making Unit (DMU) that produces one or multiple outputs from a set of inputs. Starting from the data observed (inputs and outputs) DEA calculates the relative efficiency of each DMU by taking the ratio of the total weighted output to total weighted input. The weights are selected by a linear programming (LP) model, first proposed by Charnes *et al.* (1978). Each DMU analyzed is compared with all other DMU in the sample using the same set of weights, subject to the restriction that the efficiency measure of all DMU is less than or equal to one.

Since an LP model is solved for each DMU, the DMU under assessment can choose the weights that show it in the best possible light. If the set of weights chosen for a given DMU returns an efficiency score of one, that DMU is regarded as efficient; otherwise it is considered inefficient. The estimation of economic efficiency follows Farrell (1957) who described a cost minimization assessment assuming that the DMU intend to produce current outputs at minimum cost, given the input prices.

The concept of economic efficiency can be generalized to an output oriented assessment, corresponding to the measurement of revenue efficiency, whose definition is as follows: revenue efficiency measures the ability of a DMU to maximize the revenue obtained, given the resources consumed and the value of the output prices (Oliveira *et al.*, 2010).

In order to obtain a measure of revenue efficiency, the maximum revenue that can be obtained by the DMU under assessment (DMU j_0), given the current level of resources consumption and the output prices, is estimated solving the model (1) (Färe *et al.*, 1985):

$$max\left\{\sum_{r=1}^{s} p_{rj_0}\, y_r^0 \;\middle|\right.$$

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

$$\sum_{j=1}^{n} x_{ij}\,\lambda_j \leq x_{ij_0}, \;\; i = 1, \dots, m \tag{1}$$

$$\lambda_j \;\geq 0, j = 1, \dots, n$$

$$\left. y_r^0 \;\geq 0, i = 1, \dots, m \right\}$$

This model considers *n* DMU, defined by *j* (*j*=1,…,*n*), which use the inputs x_{ij} ($x_{1j}, \dots, x_{mj}$), to obtain the outputs y_{rj} ($y_{1j}, \dots, y_{sj}$). In the formulation above, p_{rj0} is the price of output r for the DMU j_0 under assessment. Here, we specified the output prices for each vessel as the average price for each species in the vessel's port of landing. y_r^0 is a variable that, at optimal solution, gives the output *r* to be produced by DMU j_0 to maximize revenue, subject to the technological restrictions imposed by the existing production possibility. The RE of each DMU j_0 is given by as the ratio of current revenue observed at DMU j_0 to the maximum revenue estimated by the optimal solution to model (1):

$$Revenue\ efficiency_{j_0} = \frac{\sum_{r=1}^{s} p_{rj_0}\, y_{rj_0}}{\sum_{r=1}^{s} p_{rj_0}\, y_r^{0*}} \tag{2}$$

Considering previous studies applied to the artisanal dredge fleet (Oliveira *et al.*, 2010) the next step of the analysis attempted to explore whether scale inefficiency had a significant impact on artisanal dredge fishing activity. Following Banker (1993) who first proposed the use of hypothesis tests for determining the type of returns to scale of the DMU' activity, the existence of Variable Returns to Scale (VRS) in vessels' activity was formally tested using the nonparametric Kruskal–Wallis test. The null hypothesis was rejected ($p = 0.0000$) for all fleets which suggests that the vessels operated under VRS during the time-window studied.

Thus, the results reported in this paper correspond to efficiency scores obtained using a VRS model. This required adding the restriction $\Sigma^{n}_{j=1}\,\lambda_j=1$ to model (1). In order to test the monthly effect on the levels of RE achieved, a Tobit regression was specified given the limited range of the RE scores (i.e. 0 to 1). The model was formulated according to Tobin (1958) using the RE score as the dependent variable, and the month as regressor:

$$y_{jw} = \beta z_{jw} + u_{jw} \tag{3}$$

In expression (3) subscript j represents the j^{th} vessel (j=1,…,n) and subscript w represents the time period (week) (w=1,…,t). z_{jw} represents the regressor corresponding to the month, β denotes the regression coefficients and $u_{jw} \sim N(0,\sigma^2\varepsilon)$ is the error term. Note that y_{jw} corresponds to the RE score of the vessel j in week w, estimated using expression (2). August was selected as basis for comparisons because most foreigner and domestic holiday makers choose this month for spending their holidays in Portugal (INE, 2008). It is worth noting that May does not appear in the Tobit regression results because there is no fishing activity in this period due to the seasonal closure.

Finally, the Spearman correlation analysis was conducted to investigate associations between RE scores and fishing days with the MWH. Concerning the software, the DEA model was implemented with MaxDEA® Pro (Cheng and Qian, 2011). The Tobit regression was performed with STATA® and the remaining statistical analyses were undertaken using SPSS®.

5.4 Results

5.4.1 Mean wave height

The variation of the MWH along the year, in the three areas, is shown in Figure 5-2. The results of the ANOVA confirmed the existence of statistically significant differences in MWH among the months in the three areas studied. The p value of pairwise comparisons between months using the Bonferroni test are reported in Table 5-2.

During the period studied, in the Northwest area the MWH varied between 0.6m and 11.3m (2.7±1.3m). Table 5-2 revealed the presence of a lower MWH period between May and September (2.1±0.7m; maximum wave height=5.1m) and a higher MWH between November and February (3.5±1.6m; maximum wave height=11.3m). These periods are linked by two transition periods (March-April and October).

In the Southwest area the MWH ranged between 0.5 m and 8.9 m (2.2±1.1 m). Table 5-2 allows identifying two main periods, namely: summer months (June to October – 1.7±0.7 m), when the waves' height do not exceed 7.4 m, and winter months (November to March – 2.8±1.3 m), during which the maximum MWH in this area is observed. These periods are linked by only one transition period (April to May). In this part of the coast, the wave profile is more homogenous than in the Northwest coast, which is reflected by the lower standard deviations observed throughout the year (Figure 5-2).

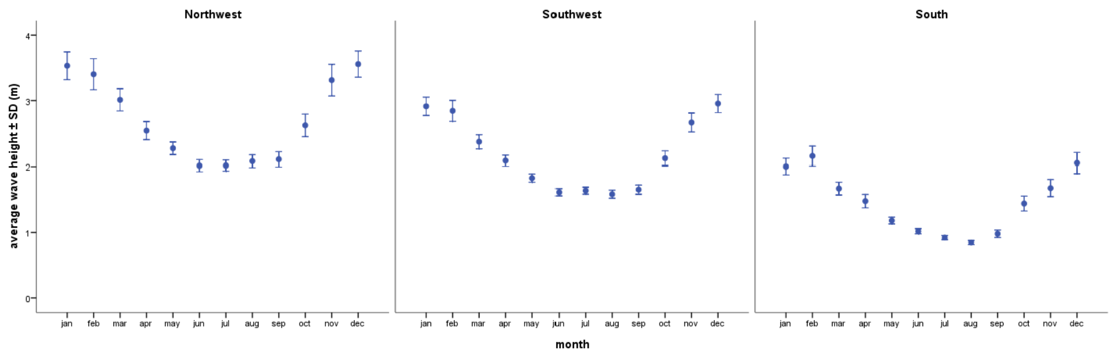

Figure 5-2. Mean wave height's variation in the three fishing areas of mainland Portugal between 2006 and 2012. Standard deviations are represented by bars.

Of the three fishing areas, the South coast is the one that shows more stable oceanographic conditions, with a MWH varying between 0.3 m and 6.2 m (1.4±0.9 m).

The analysis of the Bonferroni test results (Table 5-2) indicates the existence of two main periods linked by two transition months (April and October). There are five months of lower MWH from May to September (1.0±0.5 m), with wave height not exceeding 4.3 m, and five months of higher MWH from November to March (1.9±1.0 m), when the maximum MWH of this area was observed.

Table 5-2. Multiple comparisons between months (ANOVA).

Multiple comparisons between months (ANOVA)

Northwest

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	1.000	.970	.634	**.021**	**.002**	**.001**	**.001**	**.021**	.569	1.000	1.000
Feb		.998	.859	.082	**.011**	**.008**	**.005**	.078	.814	1.000	1.000
Mar			1.000	.644	.222	.206	.143	.598	.999	.851	1.000
Apr				.994	.854	.869	.802	.987	1.000	.343	.974
May					1.000	1.000	1.000	1.000	.997	**.002**	.253
Jun						1.000	1.000	1.000	.893	**.000**	.051
Jul							1.000	1.000	.907	**.000**	**.044**
Aug								1.000	.851	**.000**	**.027**
Sep									.993	**.003**	.232
Oct										.283	.959
Nov											.998

Southwest

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	1.000	.999	**.007**	.948	**.000**	**.000**	**.000**	**.000**	**.000**	.990	1.000
Feb		.971	.118	.992	**.000**	**.000**	**.000**	**.000**	**.009**	1.000	1.000
Mar			**.000**	.716	**.000**	**.000**	**.000**	**.000**	**.000**	.606	.998
Apr				1.000	.901	**.000**	.464	**.002**	1.000	.527	**.012**
May					.971	.173	.861	.286	1.000	1.000	.963
Jun						.574	1.000	.817	.995	**.004**	**.000**
Jul							.888	1.000	**.003**	**.000**	**.000**
Aug								.979	.846	**.000**	**.000**
Sep									**.022**	**.000**	**.000**
Oct										.118	**.000**
Nov											.996

South

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	1.000	.997	.682	**.011**	**.002**	**.000**	**.000**	**.001**	.713	.975	1.000
Feb		.985	.507	**.004**	**.000**	**.000**	**.000**	**.000**	.541	.920	1.000
Mar			.996	.246	.065	**.005**	**.001**	.055	.997	1.000	1.000
Apr				.974	.788	.401	.207	.761	1.000	1.000	.829
May					1.000	.997	.972	1.000	.967	.487	**.030**
Jun						1.000	1.000	1.000	.761	.174	**.005**
Jul							1.000	1.000	.368	**.022**	**.000**
Aug								1.000	.185	**.005**	**.000**
Sep									.732	.154	**.004**
Oct										1.000	.851
Nov											.995

(**in bold**) p_values are significant at the 0.05 level

5.4.2 Monthly effect on revenue efficiency

Table 5-3 presents the average weekly RE estimated for the dredge fleets (local and coastal), in the three areas, during the period studied. The low values of RE efficiency reveal the existence of significant variability in performance among the weeks studied. These scores were used for the Tobit regression analysis to test if RE changes significantly throughout the year due to the existence of monthly seasonality (Table 5-4). In the Northwest, the monthly effect explains 41.3% of the variability in vessels RE. Statistically significant differences in RE were observed between August and July (-0.032, p-value=0.011), as well as between August and three months of the winter period: November (-0.085, p-value=0.000), January (-0.043, p-value=0.003) and February (-0.037, p-value=0.014).

Table 5-3. Weekly means (±SD) of pure revenue efficiency scores.

Weekly means (± SD) of pure revenue efficiency scores

	Northwest		Southwest		South	
Fleet	**mean RE**	**SD**	**mean RE**	**SD**	**mean RE**	**SD**
local	---	---	---	---	0.279	0.053
coastal	0.397	0.129	0.269	0.017	0.320	0.084

During these months the RE estimated was significantly lower than that registered in August. Although the difference is not statistically significant, March was the only month with RE better than August (0.018, p-value=0.177). The month effect explains 25.3% of RE variability in the Southwest area. The differences in RE were only significant between August and November (-0.033, p-value=0.007), with August outperforming November, and between August and December (0.037, p-value=0.002), with December having the best performance. Further South, the month effect explains 32.4% and 40.0% of RE variance for the local and coastal fleet segments, respectively.

Table 5-4. Tobit regression results.

Tobit regression results

	Northwest (R^2 = 0.413)			Southwest (R^2 = 0.253)			South local (R^2 = 0.324)			South coastal (R^2 = 0.400)		
	Coef.	**Std. Error**	**p_value**	**Coef.**	**Std. Error**	**p_value**	**Coef.**	**Std. Error**	**p_value**	**Coef.**	**Std. Error**	**p_value**
constant	0.640	0.002	0.000	0.365	0.014	0.000	0.461	0.019	0.000	0.640	0.014	0.000
January	**-0.043**	**0.015**	**0.003**	-0.004	0.012	0.751	**-0.096**	**0.009**	**0.000**	**-0.181**	**0.012**	**0.000**
February	**-0.037**	**0.015**	**0.014**	0.017	0.013	0.174	**-0.089**	**0.010**	**0.000**	**-0.193**	**0.014**	**0.000**
March	0.018	0.013	0.177	0.012	0.012	0.301	**-0.094**	**0.009**	**0.000**	**-0.192**	**0.013**	**0.000**
April	-0.012	0.014	0.379	-0.012	0.012	0.341	**-0.055**	**0.010**	**0.000**	**-0.169**	**0.015**	**0.000**
June	-0.017	0.013	0.180	-0.021	0.013	0.089	**0.048**	**0.010**	**0.000**	-0.002	0.013	0.892
July	**-0.032**	**0.013**	**0.011**	0.017	0.012	0.152	**0.025**	**0.009**	**0.005**	0.005	0.012	0.648
September	-0.015	0.013	0.273	-0.023	0.012	0.062	**-0.059**	**0.009**	**0.000**	**-0.102**	**0.012**	**0.000**
October	-0.005	0.013	0.686	-0.018	0.012	0.129	**-0.048**	**0.009**	**0.000**	**-0.107**	**0.012**	**0.000**
November	**-0.085**	**0.015**	**0.000**	**-0.033**	**0.012**	**0.007**	**-0.041**	**0.009**	**0.000**	**-0.116**	**0.013**	**0.000**
December	0.002	0.015	0.916	**0.037**	**0.012**	**0.002**	**-0.044**	**0.010**	**0.000**	**-0.117**	**0.013**	**0.000**

Particularly in the local fleet, the best months were June and July (significantly better than August). The remaining months were statistically worse than August, with the period from January to March showing the lowest RE scores. In the coastal fleet, there was no statistically significant differences between August and both June and July. All the remaining months were statistically worse than August, particularly in the period between January and April.

The results of the correlation between the MWH and fishing days and RE are presented in Table 5-5. Both fishing days and RE scores are negatively correlated with the MWH in the Northwest and South areas (coastal fleet) meaning that the higher the wave height the lower the number of fishing days and the RE scores achieved. In the Southwest areas no relationship was found between MWH and RE, whereas for the local fleet in the South coast the fishing days are not influenced by the MWH.

Table 5-5. Pearson correlation results.

Pearson correlation results

		Northwest	**Southwest**	**South**	
		coastal	coastal	local	coastal
		mean wave height			
fishing days	Pearson correlation	**-0.396****	**-0.254****	-0.018	**-0.309****
	sig. (2-tailed)	0.000	0.000	0.171	0.000
	n	2528	4753	5739	3879
revenue efficiency	Pearson correlation	**-0.055****	-0.015	**-0.068****	**-0.119****
	sig. (2-tailed)	0.005	0.315	0.000	0.000
	n	2528	4753	5739	3879

** correlation is significant at the 0.01 level (2-tailed)

5.5 Discussion

This paper explored the monthly variation of RE between 2006 and 2012, in order to investigate the effect of demand seasonality on the performance of the Portuguese artisanal dredge fishery. In contrast to fish stocks that are mobile, bivalve species are sedentary and therefore no seasonality changes are expected to occur due to, for instance, seasonal migrations. Moreover, the daily/weekly quotas that are implemented on a yearly basis are set assuming that if the fishing vessels can go fishing every single day of the year, they can achieve the quota established without compromising the target species stocks themselves.

Therefore, changes on monthly revenue efficiency cannot be attributed to changes on stock abundance over the year. In the context of the Portuguese dredge fisheries, seasonal variations in performance are likely to be attributable to variations in demand or oceanographic conditions, which are discussed in more detail next.

Overall, our results revealed that although demand seasonality exists in the three fishing areas, its impact on fisheries performance is more evident in the South coast than in the other areas. The Northwest area is by far the most affected by wave height.

The statistical analysis revealed no significant differences on RE scores from March to October (with the exception of July). In fact, during this period (with waves' height inferior to 3 m), the fleet operated normally, fulfilling the quotas with no evidence of an increase in demand. From November to February, when the MWH was higher, a decrease in the fishing revenue was observed, that can be justified by the harsh sea conditions observed during this time of the year. Nevertheless, it was observed that RE in December was not statistically different from August, suggesting that, despite the high MWH registered, there was a demand increase during December leading to better performance. Most of the landings are exported live to Spain throughout the year, and during December the demand for bivalve increases due to Christmas and New Year festivities.

Regarding the Southwest area, there is also a high MWH period from November to March, although the analysis reported in Table 5-5 shows that RE is not significantly affected by the wave height. This shows that the stability in RE values throughout the year may be related to the fleet ownership profile. In fact, in the Portuguese artisanal dredge fishery the skipper is usually the shipowner. However, in the Southwest area, the shipowners usually own several vessels and therefore can manage the activity of their vessels according to the oceanographic conditions, market and fishing priorities. Indeed, the shipowner can decide when and which vessels can fish to accomplish the fishing priorities.

This ownership structure seems to effectively influence this fishing activity in such a way that it is possible to overcome the MWH effect on RE. The results reported in Table 5-4 identify two months with RE values worth noting: November is the month with worst performance, and December is the only month with RE significantly higher than August. Although this geographical area attracts regional tourists during the main calendar festivities and in the Summer (INE, 2008), the nonexistence of statistically significant differences in RE during most of the year is related to the fact that this fleet supplies the bivalve market needs of Lisbon and peripheral areas throughout the year and consequently bivalve demand is quite stable.

Nevertheless, and despite the high MWH observed in December, good performance of the fleet in this month indicates that the demand for bivalves increases significantly in this region only during Christmas and New Year festivities. The lower RE in November compared to August is likely to be caused by the joint effect of lower demand and high MWH during this period.

The South area registered more stable sea conditions than the other two areas (Figure 5-2). Our results suggest that MWH does not affect the fishing days of the local fleet (Table 5-5), which was unexpected since this fleet targets mainly *Donax trunculus*, a species that occurs in the surf zone, between 0 and 6 m depth. Therefore, this segment of the dredge fleet can only operate with low height waves (less than 1.5 m). The lack of correlation observed can be explained by the presence of high levels of phycotoxins in the water during late spring and summer, the time of the year when MWH is lower. During periods of high phycotoxins levels fishery is forbidden due to public health issues. Since local vessels are only allowed to operate near their homeport, this fleet cannot displace to areas free of phycotoxins as opposed to coastal vessels that can operate within the entire fishing area.

Although the MWH does not affect the fishing days, there is a significant relationship between MWH and the RE scores, suggesting that higher waves reduce the performance of vessels, which could be expected given that they operate mostly in the surf zone.

Concerning the coastal fleet segment, it was observed that both fishing days and RE scores was influenced by MWH. Despite operating far from the coast and along the entire fishing area, these vessels are also affected by the sea conditions, notwithstanding being the area with the smoothest and lowest MWH variation. The results of the Tobit regression reported in Table 5-4 suggest that in the South, the performance of the local and coastal fleets is mainly affected by demand. Indeed, the Algarve (Southern Portugal) is a well-known tourist destination, especially in the summertime, when the demand for bivalves and other seafood increases exponentially, which explains the seasonality observed.

Floros and Failler (2004) concluded that integration of price seasonality and cointegration phenomenon into the strategy of fishermen in the Cornish fishery would allow them to benefit more from their landings, by adding processing value into their catches in order to mitigate the low price months and take more advantage of the good price months. The fishermen would be able to predict the market conditions for the other main species and adjust (according to that) their fishing strategies to be less vulnerable to price fluctuations and demand driven market.

In the Portuguese dredge fishery, price fluctuations do not occur since catches are sold through a contract that is established in the beginning of each year between the fishermen and the buyer. 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. On the contrary, the daily/weekly catch orders made by the buyer can change over the year due to variations in demand (Oliveira *et al.*, 2013).

In the artisanal dredge fleet one of the strategies to reduce vulnerability to RE fluctuations related to demand seasonality, could involve redistribution of the daily/weekly quota per tonnage and species. For instance, in the Northwest and Southwest, since a demand increase was observed in December, the catch quota could be increased during this month by transferring part of the quota from November (a month highly conditioned by MWH in both areas) to December. In addition, in the Northwest area due to the harsh sea conditions observed during the winter mainly in November, January and February, a part of the catch quota could be transferred to months with lower wave height.

Regarding the South area, since demand seasonality was observed during summer (June, July and August), increase of the daily quota by transferring quota from the winter months is suggested. It is considered that such management measures would contribute to improve the fishery revenue sustainability (and somehow compensate the raise of production costs in recent years, namely the dramatic increase of fuel cost). At the same time, the quota allocation proposed for the three areas would not affect the exploited resources, since the total amount of the quota at the end of year remains unchanged.

Although the present work is devoted to the dredge fishery, the results achieved indicate that demand seasonality should be taken into consideration in any fisheries management plan (especially those fisheries managed by a quota regime). In fisheries managed by quotas, instead of splitting the limits equally throughout the year, it is suggested to allocate more quota to months with higher demand, in detriment of the months with lower demand or with harsh sea conditions, increasing the profitability if the fishery in this way.

CHAPTER 6. The phycotoxins' impact on the revenue of the Portuguese artisanal dredge fleet[5]

Abstract: The bivalve dredge fleet, considered as one of the most important artisanal fleets due to the high value of the catches, is by far the most extensively studied among the Portuguese artisanal segment. Acknowledging the growing presence of marine phycotoxins in the waters, the present study explores their impact on the revenue of the fleet that operates along the coast of mainland Portugal. The results obtained using stochastic frontier analysis models enlighten the harmful impact of algae blooms on the activity of the artisanal dredge fleets. In particular, it was observed that in the Algarve region, where the frequency and the intensity of these episodes is higher, the sustainability of the dredge fishing activity is seriously compromised by the phycotoxins.

Keywords: Artisanal fleets; Bivalve fishery; Phycotoxins; Management; Stochastic Frontier Analysis

[5] Oliveira, M.M., Camanho, A.S., Gaspar, M.B., 2014. The phycotoxins' impact on the revenue of the Portuguese artisanal dredge fleet. *Marine Policy*, doi:10.1016/j.marpol.2014.10.022 (*reviewed paper*).

6.1 Introduction

Harmful Algal Bloom (HAB) has a strong impact on commercial fisheries worldwide by causing direct fish mortalities (of wild or cultured stocks) and habitat loss leading to lower ecosystem carrying capacity. This situation force managers to establish closures, increasing the fishing costs and causing consumer demand to contract (Hoagland *et al.*, 2002).

Algae are unicellular microscopic plants that occur naturally in marine environments and that may develop blooms at certain times of the year due to changes on the environment (Ferrante *et al.*, 2012). Of particular concern are HAB that produce toxins. Toxins associated with phytoplankton are known as phycotoxins. Because of the filter-feeding behavior of bivalves as well as their physiology, bivalves are capable of accumulating toxins sometimes at levels potentially lethal to humans (Arapov, 2013).

There are a number of different seafood poisoning syndromes associated with toxic marine algae, such as paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), diarrheic shellfish poisoning (DSP) and neurotoxic shellfish poisoning (NSP). To ensure the safety consumption of bivalves, HAB monitoring programs have been implemented in Europe to determine whether the toxins in bivalves exceed levels that can trigger problems in human health conditions. Whenever a critical level is achieved, the consumption is prohibited, and the bivalve fisheries that occur in the HAB affected areas are closed.

In Portugal mainland, dredge fishery for bivalves takes place along three fishing areas, namely the Northwest, Southwest and South zones (Oliveira *et al.*, 2014). In recent years, the occurrence of HAB episodes has increased in many parts of the world, including Portugal, both in frequency, intensity and geographic spread (e.g. Hallegraeff, 1993; Smayda, 1997). This may pose serious risks to the sustainability of the bivalve dredge fishery, as the unfavorable water conditions can affect the revenue of the fishing vessels.

The purpose of the research reported in this paper is to study the impact of phycotoxins' occurrence on fisheries activity, using a stochastic frontier analysis (SFA) model that is able to explain variations in revenue due to inefficiencies in vessels' activity and occurrence of phycotoxins and harsh sea conditions. From a methodological perspective, Aigner *et al.* (1977) and Meeusen and van den Broek (1977) were the first to propose the modelling approach of SFA. In the fisheries context, SFA implies that deviations from the production frontier, representing the maximum revenue attainable from the resources available, may not be entirely under the control of the Decision Maker Unit (DMU, i.e., a vessel). These models evaluate inefficiency acknowledging that random factors outside vessels' control may affect individual performance. Different factors that can cause disruptions to production, such as fishing experience, fishermen skills, effort, management policies, or other factors, can be accounted for in the inefficiency model.

The SFA approach has been widely used in a variety of fisheries studies. The most frequent purpose of the models is the analysis of the determinants of inefficiency, causing output losses (e.g. Garcia del Hoyo *et al.*, 2004; Solís *et al.*, 2012; Shen, 2012; Onumah and Acquah, 2010; Kareem *et al.*, 2012; Jamnia *et al.*, 2013). Other authors compared parametric and nonparametric models to measure productivity and technical inefficiency (e.g. Pascoe and Mardle, 2003; Kim *et al.*, 2011; Ghee-thean *et al.*, 2012; Collier *et al.*, 2014).

In the present study, the SFA approach was used to investigate the contribution of HAB to the performance of the Portuguese artisanal dredge fleet.

6.2 Portuguese artisanal dredge fleet

6.2.1 Fleet description

The artisanal dredge fleet comprises 93 vessels (11, 25 and 57 vessels operating in the Northwest, Southwest and South fishing areas, respectively). The vessels overall length ranges from 5 to 16 m, the engine power between 20 kW and 130 kW, the gross tonnage (GT) between 1 and 24 tons and the crew varies between 1 and 5 fishermen. The vessels are classified as local or coastal, according to the area in which they operate. Local vessels can only operate near the homeport or adjacent fishing ports, whereas coastal vessels can fish within the fishing area for which they are registered. In the Northwest and Southwest fishing areas, only coastal vessels operate, due to the distance of the bivalves' beds from the fishing port and to the hydrodynamic conditions, such as high mean wave height (MWH).

Along the Portuguese coast, five species are harvested, namely the surf clam (*Spisula solida*), the donax clam (*Donax trunculus*), the smooth clam (*Callista chione*), the striped venus (*Chamelea gallina*) and the razor clam (*Ensis siliqua*). The first species is caught along the entire coast while the donax clam, the striped venus and the razor clam are caught between Lisboa and Sines (Southwest area) and between Sagres and Vila Real de Santo António (South area). The smooth clam is only exploited in the Southwest area, because of its abundance in the other two fishing areas is extremely low.

Even though the majority of the management measures are similar in the three fishing areas (*e.g.* seasonal closure, minimum landing sizes and gear specifications), the quotas regime is different among them. Maximum weekly fishing quotas are currently in place in the Northwest and Southwest, whereas in the South coast maximum daily fishing quotas are imposed. The distinct quota management systems are justified by the harsher oceanographic conditions observed in the West coast compared to the South coast. Those quotas are reviewed on an annual basis, and changed, if necessary, in order to adjust the catch to the status of the stocks (Gaspar and Chícharo, 2007; Oliveira *et al.*, 2013).

Regarding phycotoxins monitoring, the European Union (EU) established legal controls of HAB prescribing food safety legislation. Under this legislation all EU member states are committed to implement monitoring programs to ensure that the occurrence of HAB episodes in the fishing areas is detected in due time.

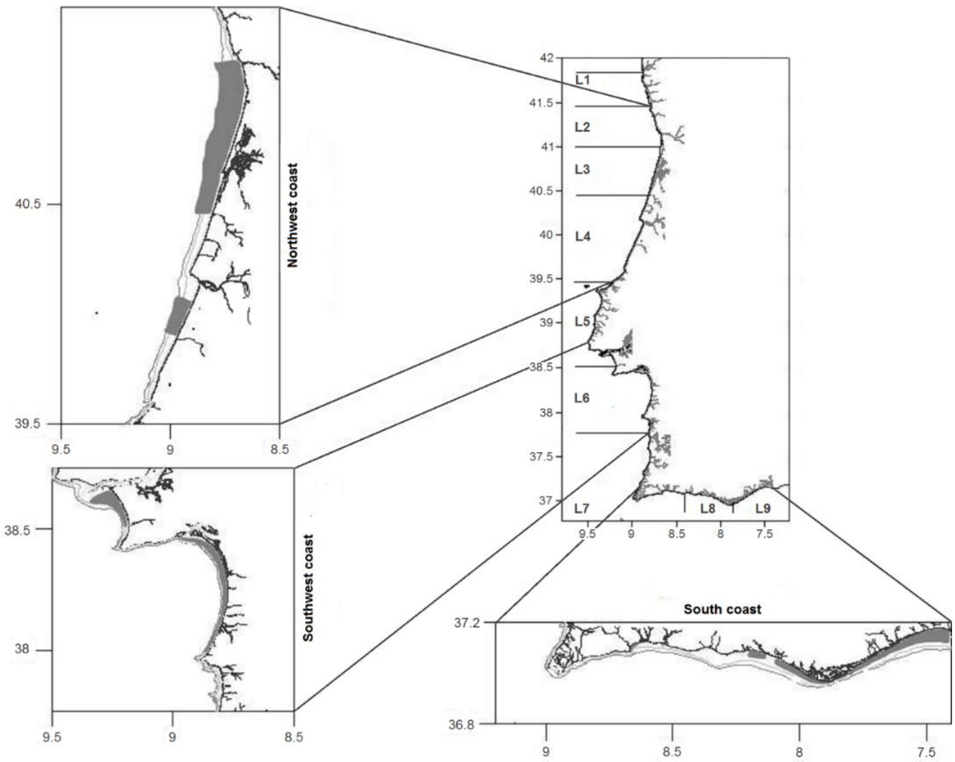

Figure 6-1. Distribution of bivalve beds (grey areas) and the bivalve production zones (L1 to L9) in the three main fishing areas of mainland Portugal

In Portugal, the Portuguese Institute for the Ocean and the Atmosphere (IPMA) is the entity responsible for managing bivalve production zones (BPZ). The Portuguese coast is divided into nine BPZs (Figure 6-1) in which the bivalve harvesting can be interdicted to one or more species, preventing harvesting of species found to contain levels of phycotoxins above the prescribed EU limits. The Northwest fishing area comprises the L2, L3 and L4 BPZs, although L4 is not explored due to its distance from the main fishing ports. The Southwest fishing area includes L5 and L6 BPZs, whereas the South fishing area encompasses the L8 and L9 BPZs.

6.3 Methodology

6.3.1 Dataset

The dataset used in the present study was provided by the General Directorate of Natural Resources Safety and Maritime Services (DGRM) and IPMA, covering the period between January 2006 and December 2012. The daily waves' height time series was obtained from the windguru.cz website.

From the 93 dredge vessels currently licensed, only 84 vessels were included in the analysis, as the remaining 9 vessels (3 and 6 from the Southwest and South fleets, respectively) did not use dredge gears during most of the years studied. The panel data is unbalanced meaning that some of the vessels did not operate during the entire time window due to the use of different gears or unknown reasons.

Table 6-1. Profiling of the Portuguese dredge fleet by area (average values between 2006 and 2012)

	Northwest	Southwest	South (coastal)	South (local)
(vessels per area)	11	22	22	29
Inputs				
Vessel overall length (m)	13.29	11.26	10.62	7.14
Vessel power (kW)	102.03	72.23	64.02	44.42
Output (prices)				
Prices of surf clam (€ per kg)	2.7	1.5	0.8	0.8
Prices of donax clam (€ per kg)	-	2.5	2.2	2.1
Prices of razor clam (€ per kg)	-	2.5	-	-
Prices of striped venus (€ per kg)	-	-	1.5	1.5
Prices of smooth clam (€ per kg)	-	1	-	-
Exogenous variables				
Phycotoxins	0.28	0.01	0.95	0.95
Mean Wave Height	2.06	2.00	1.50	1.50
Landings				
Capture of surf clam (kg per year)	28070.50	523.40	5101.60	685.80
Capture of donax clam (kg per year)	0.00	2584.00	3231.90	4461.60
Capture of razor clam (kg per year)	0.00	2967.60	0.00	0.00
Capture of striped venus (kg per year)	0.00	0.00	3886.60	1585.60
Capture of smooth clam (kg per year)	0.00	8398.60	0.00	0.00

The input variables used in the SFA model (1) represent the resources of the dredge fleet (vessel's overall length and engine power), whereas the output variable comprises the revenue from daily landings per vessel, obtained as the product of quantities caught by species with their price (Table 6-1).

The vessel's tonnage was not included in the model due its high correlation with vessel's overall length. During the period analyzed, all vessels operating in each area used dredges with similar width, so this variable did not need to be included in the model. Additional input variables, such as time at sea or crew size, were not included due to the lack of data. It is currently being tested the use of vessel tracking devices that will provide data on time at sea for the each vessel trip, so it is expected that the model can be enhanced in the future, when this data becomes available.

Regarding the factors that may impact vessels' inefficiency, and thus reduce revenue, model (2) was specified in order to analyze the effect of two exogenous variables: phycotoxins occurrence and daily mean wave height (MWH). The phycotoxins presence and intensity was modeled as an index that indicates, by fishing area and on a daily basis, the sum of interdicted species by BPZs. For instance, in the Northwest in a given day, the index can vary between 0 (both BPZs are open) and 2 (both BPZs are closed to surf clam); in the South the index can vary between 0 (the three BPZs are open) and 9 (the three BPZs are closed to the three target species).

6.3.2 Data analysis

Efficiency measurement compares the actual performance of a Decision Maker Unit (DMU) with an optimal performance level. The estimation of the optimal production levels, given the amount of resources consumed and environmental conditions can be done using a parametric approach.

This approach specifies the frontier as a function with a precise mathematical form (usually the Translog or the Cobb-Douglas functions). It requires the a priori specification of the functional form representing the frontier. Parametric frontiers are usually estimated using stochastic methods, which allow for random noise and measurement error in the data. Thus, deviations of the DMU from the frontier may be explained both by the existence of inefficiency in the DMU operation or by unpredictable and uncontrollable events (e.g. Forsund *et al.*, 1980; Battese, 1992; Coelli *et al.*, 1998). Furthermore, the SFA model can be enhanced by the inclusion of exogenous factors affecting DMUs performance, as proposed by Kumbhakar *et al.* (1991).

Given these features and aiming at investigating the determinants of vessels' revenue levels, focusing in particular on the effect of HAB on the activity of the Portuguese dredge fleet, a SFA model was applied to the daily activity of this fleet for a seven year period (from January 2006 to December 2012). The data collected was grouped by area and fleet segment, resulting in 16878, 37397, 32291 and 42051 observations (corresponding to Northwest, Southwest and South – coastal and local fleets – respectively).

The specification of the SFA model, using a Cobb-Douglas function, is shown in (1). The model proposed by Battese and Coelli (1995) was selected due to the need to evaluate data from different time periods, controlling for the contextual conditions.

$$\ln(y_{it}) = \beta_0 + x_{it}\beta + v_{it} - u_{it} \tag{1}$$

The vessels were indexed by i (i = 1, 2,…, N), y_{it} measures the revenue from landings of the i^{th} vessel (aggregating all species) in time period t, x_{it} represents a vector of the logarithm of the input variables (vessel's overall length and engine power), β is a vector of unknown scalar parameters to be estimated, and β_0 is an intercept.

In this model, the error term $v_{it} - u_{it}$ has two distinct components for each DMU. The v_{it} component is similar to that of a traditional regression model and accounts for statistical noise (random variation in output due to factors beyond control of the DMU, such as measurement errors in dependent variables or explanatory variables eventually omitted). Likewise, it is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$. The error term u_{it} is a non-negative random variable, accounting for the existence of inefficiency in production. u_{it} is a non-negative random variable, distributed as half-normal $u_{it} \sim |N(0, \sigma_u^2)|$. The subtraction of the non-negative random variable u_{it}, from the random error v_{it}, implies that the logarithm of the production is smaller than it would otherwise be if inefficiency did not exist Battese and Coelli (1995). The inefficiency is specified as follows:

$$u_{it} = \delta_0 + z_{it}\delta + \omega_{it} \tag{2}$$

where: δ is a vector of parameters to be estimated, z_{it} is a vector of exogenous effects (phycotoxins presence and the daily mean wave height) that determine inefficiency, δ_0 is an intercept, ω_{it} represents managerial inefficiency and it is obtained by truncation of the N(0, $\sigma_\omega{}^2$), such that u_{it} is non-negative.

The technical efficiency (TE) of DMU i in time period t is defined by expression (3):

$$TE_{it} = e^{-u_{it}} \tag{3}$$

The parameters of the stochastic frontier model (1) and the inefficiency model (2) were estimated using the FRONTIER® version 4.1 software (Coelli, 1996).

6.4 Results and discussion

Aiming to investigate the contribution of HAB on the performance of the Portuguese artisanal dredge fleet, the parameters of the stochastic frontier model (1) and the inefficiency model (2) were estimated by area (Northwest, Southwest and South) and fleet's segment (local and coastal). The maximum-likelihood estimates of the models' parameters and standard errors, as well as the variance parameters (σ^2 and γ) are presented in Table 6-2. The parameter gamma (γ) corresponds to the estimated share of the inefficiency term in the variance of the composed error term ($\sigma^2 = \sigma_v^2 + \sigma_u^2$). Thus, values of gamma ($\gamma = \frac{\sigma_u^2}{\sigma^2}$) close to one indicate that deviations from the frontier are mainly due to inefficiency rather than statistical noise.

Table 6-2. Estimates of the stochastic frontier model and inefficiency model for the Portuguese artisanal dredge fleet, by fleet segment

	Northwest			Southwest			South (coastal)			South (local)		
Variable	**Coef.**		**Std. Error**	**Coef.**		**Std. Error**	**Coef.**		**Std. Error**	**Coef.**		**Std. Error**
Stochastic frontier model												
constant	4.008	**	0.978	0.641	**	0.023	4.527	**	0.640	2.449	**	0.052
ln(vessel's length)	-0.073		0.089	-0.049	**	0.021	0.620	**	0.108	0.109		0.118
ln(vessel's power engine)	0.271	*	0.060	0.095	**	0.008	5.805	**	0.084	-0.152	*	0.063
Inefficiency model												
constant	0.909	*	0.064	1.501	**	0.065	0.537		0.582	0.571	**	0.060
Phycotoxins	0.323	**	0.072	0.304	**	0.051	0.111	**	0.003	0.352	**	0.004
Daily mean wave height	0.611	*	0.006	0.512	**	0.022	0.474	**	0.014	0.566	**	0.014
σ^2	0.912	*	0.087	0.824	**	0.025	0.840	**	0.006	0.731	**	0.005
γ	0.994	**	0.001	0.999	**	0.000	0.999	*	0.052	0.999	**	0.000

** significant at 1%, * significant at 5%.

The high value of gamma observed in our empirical study and its statistical significance (Table 6-2), validates the inclusion of the inefficiency effects on the model, and indicates that the observed deviations from the production frontier are mainly due to managerial inefficiency and exogenous factors (HAB and MWH) rather than random errors. The negative coefficients of the vessel's length given by the SFA model, both in the Northwest and Southwest areas (Table 6-2), indicate that the smaller vessels with more powerful engines are the ones that obtain the highest revenues.

Conversely, the stochastic model confirms that in the coastal fleet in the South, the larger the vessel the higher the revenues. This may be explained by the catch quotas' scheme, as in the South the quotas are assigned considering the vessel's tonnage. This does not occur in the Northwest and Southwest areas, where the quota is assigned per vessel and per species, without considering vessel tonnage. The increase in quotas limit with vessel tonnage, combined with the easier access to remote areas of larger vessels, with more powerful engines, may explain the results observed for the coastal segment.

Concerning the inefficiency model, the results showed that both phycotoxins and daily mean wave height (MWH) significantly contributed to vessels inefficiency, causing a reduction to revenue along the entire Portuguese coast. It is worth noting that the highest coefficient of the MWH variable (0.611, Table 6-2) was observed in the Northwest area, where harsh sea conditions are frequent. Concerning the effect of MWH on the performance of the dredge fleet, the results obtained in the SFA model are aligned with what was observed by Oliveira *et al*. (2014), which found a significant negative correlation between MWH and revenue efficiency.

Table 6-3 presents the efficiency score for all fleets in all years. It can be seen that the average efficiency scores are quite low (ranging from 46% in the coastal fleet in the South and 59% in the Northwest). This indicates that phycotoxins and MWH have a severe impact on the revenue of the fleets.

Table 6-3. Mean efficiency and standard deviation by area and fleet segment, for the Portuguese artisanal dredge fleet.

	Northwest		Southwest		South (coastal)		South (local)	
Year	**mean**	**(± SD)**	**mean**	**(± SD)**	**mean**	**(± SD)**	**mean**	**(± SD)**
2006	0.65	(0.18)	0.50	(0.07)	0.52	(0.17)	0.63	(0.19)
2007	0.44	(0.21)	0.50	(0.05)	0.55	(0.16)	0.65	(0.19)
2008	0.40	(0.23)	0.51	(0.05)	0.52	(0.16)	0.67	(0.19)
2009	0.69	(0.11)	0.53	(0.05)	0.47	(0.19)	0.60	(0.23)
2010	0.68	(0.14)	0.53	(0.04)	0.46	(0.19)	0.59	(0.22)
2011	0.63	(0.26)	0.52	(0.04)	0.44	(0.19)	0.53	(0.19)
2012	0.57	(0.32)	0.50	(0.07)	0.34	(0.14)	0.41	(0.18)
overall efficiency	0.59	(0.24)	0.51	(0.06)	0.46	(0.19)	0.58	(0.20)

Table 6-4. Number of fishing days closed due to HAB by year, species and bivalve production areas, for the Portuguese artisanal dredge fleet.

	Northwest			Southwest			South		
species	**L2**	**L3**	**simultaneously**	**L5**	**L6**	**simultaneously**	**L8**	**L9**	**simultaneously**
2006									
surf clam	16	29	6	22	22	22	0	0	0
donax clam	---	---	---	63	86	49	79	64	64
smooth clam	---	---	---	-	0	0	-	-	-
striped venus	---	---	---	-	-	-	0	0	0
pod razor clam	---	---	---	24	9	9	-	-	-
all species	**16**	**29**	**6**	**0**	**0**	**0**	**0**	**0**	**0**
2007									
surf clam	123	19	11	0	19	0	18	5	5
donax clam	---	---	---	115	126	97	65	22	22
smooth clam	---	---	---	-	58	58	-	-	-
striped venus	---	---	---	-	-	-	11	5	5
pod razor clam	---	---	---	66	30	25	-	-	-
all species	**123**	**19**	**11**	**0**	**19**	**0**	**11**	**5**	**5**
2008									
surf clam	99	53	53	0	55	0	0	0	0
donax clam	---	---	---	67	38	38	12	12	12
smooth clam	---	---	---	-	49	49	-	-	-
striped venus	---	---	---	-	-	-	0	0	0
pod razor clam	---	---	---	53	42	42	-	-	-
all species	**99**	**53**	**53**	**0**	**36**	**0**	**0**	**0**	**0**
2009									
surf clam	7	7	7	0	0	0	20	6	6
donax clam	---	---	---	0	0	0	25	6	6
smooth clam	---	---	---	-	0	0	-	-	-
striped venus	---	---	---	-	-	-	7	6	6
pod razor clam	---	---	---	0	0	0	-	-	-
all species	**7**	**7**	**7**	**0**	**0**	**0**	**7**	**6**	**6**
2010									
surf clam	13	0	0	0	0	0	0	0	0
donax clam	---	---	---	0	0	0	24	0	0
smooth clam	---	---	---	-	0	0	-	-	-
striped venus	---	---	---	-	-	-	0	0	0
pod razor clam	---	---	---	0	0	0	-	-	-
all species	**13**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2011									
surf clam	26	47	13	0	0	0	26	28	25
donax clam	---	---	---	36	43	22	82	66	63
smooth clam	---	---	---	-	0	0	-	-	-
striped venus	---	---	---	-	-	-	45	48	45
pod razor clam	---	---	---	0	0	0	-	-	-
all species	**26**	**47**	**13**	**0**	**0**	**0**	**26**	**28**	**25**
2012									
surf clam	68	17	17	103	6	6	96	132	90
donax clam	---	---	---	71	49	49	138	122	100
smooth clam	---	---	---	-	6	6	-	-	-
striped venus	---	---	---	-	-	-	96	132	90
pod razor clam	---	---	---	68	6	6	-	-	-
all species	**68**	**17**	**17**	**62**	**6**	**6**	**96**	**102**	**82**

Table 6-4 presents the number of days that the fishery was closed due to HAB. In this table, the symbol – indicates a fishing zone without the occurrence of the species, and --- indicates that the phycotoxins level is not reported because the species is not exploited in that area.

The relationship between low efficiency scores (Table 6-3) and the prevalence of phycotoxins (Table 6-4) is quite evidence. Regarding the Northwest area, the prevalence of phycotoxins was higher in 2007, 2008, 2011 and 2012. The number of days that at least one of the BPZ was closed was 131, 99, 60 and 68 days, respectively. The years with the largest number of days that the fishery was closed in both BPZ simultaneously were 2008 and 2012, with 53 and 17 days, respectively.

Although other commercial species (donax clam and pod razor clam) are available in the Northwest fishing area, the fleet that operates in this area only targets the surf clam, which is more susceptible to external factors such as harsher sea conditions (Oliveira *et al*., 2014), biological stock fluctuations (Oliveira *et al*., 2013) and the HAB, jeopardizing its performance. It is clear that in the years with higher phycotoxins prevalence, namely 2007, 2008 and 2012, the efficiency was lower (Table 6-3). Moreover, this fleet mainly operates in the L2 BPZ, as the distance and time spent to navigate to the L3 BPZ increases substantially the production costs of bivalve harvesting. Thus, the shipowners may prefer stopping the fishing activity whenever the value of first auction sale does not compensate the increase of production costs. Indeed, despite the fishing activity only being effectively prohibited if both BPZ are closed, the closure of the L2 can actually dictate the fleet inactivity.

The Southwest area was also penalized by the HAB occurrence, except in 2009 and 2010 when the BPZ were never closed for any species (Table 6-4). In this area, the simultaneous closure of both BPZ for all species only occurred in 2012 (6 days). Furthermore, in the same year, the fishery was closed for all species available in the L5 BPZ during 62 days. Additionally, the remaining years (2006 to 2008 and 2011) registered high levels of phycotoxins prevalence, which can explain the occurrence of the lowest efficiency scores of the period analysed. Notwithstanding, the low magnitude of variability in the efficiency scores throughout the time window studied may also be related to the fleet ownership profile. In the Portuguese artisanal dredge fishery, the skipper is usually the shipowner. However, in the Southwest area, the shipowners usually have several vessels and therefore they can manage their activity according to the oceanographic conditions, market demand

and fishing priorities. Thus, based on the orders received on land, the shipowner can decide which vessels will operate to fulfill the demand. Thus, the optimization of the activity is not done at the vessel level, but by groups of vessels. In this context, it is possible to have some vessels occasionally with lower efficiency because the fishing power exceeds the need of the shipowner. This ownership structure seems to effectively influence this fishing activity in such a way that it is possible to mask the effects of HAB on the fleet's performance.

The South area has been seriously affected by the HAB (Table 6-4) and their effect in the fleet's efficiency is also clear (Table 6-3). The coastal fleet segment operates far from the coast and along the entire fishing area, harvesting all species available. Yet in 2011 and 2012, this fleet experienced 25 days and 82 days, respectively, during which the fishing activity was closed for all species in all BPZ (Table 6-4), which had a severe impact on efficiency (Table 6-3).

Local fleet targets mainly donax clam, a species that occurs in the surf zone, between 0 and 6 m depth (Gaspar *et al.*, 2002). During 2012, the harvesting of this specific species was closed 138 days in L8, 122 days in L9, and 100 days in both BPZ simultaneously. In this year, the efficiency score of this fleet reached the lowest level of the 7-year time window (Table 6-3). The years 2006 and 2007 were also affected the closure of donax clam captures due to phycotoxins. Nevertheless, the efficiency scores observed (0.63 and 0.65) were higher than in 2011 (Table 6-3). This can be explained by the occurrence of a surf clam bloom in this area in 2006, which was registered by the annual monitoring surveys carried out by IPMA. Following that, the local fleet also directed the fishing effort to the surf clam species, which may have minimized the impact of BPZs closures in that year. The closure of a BPZ has always a great impact in local vessel's activity, since a local vessel is only allowed to operate in its homeport or in the adjacent ones. Considering that most local vessels in the South are registered in homeports within the L9 BPZ, only the ones registered in the homeport closest to the BPZ limit are allowed to also harvest in L8 BPZ, meaning more fishing opportunities.

The origin of the HAB is not fully explained in the literature. Notwithstanding, their frequency, intensity and geographic distribution has increased over the years, and several reasons have been pointing out by different authors. The variations in upwelling, unusual climatic conditions, seawater temperature and salinity, as well as concentration of dissolved nutrients are some of the reasons pointed out by several authors for the occurrence of HAB (e.g. Kudela *et al.*, 2005; Jewett *et al.*, 2008; Silva *et al.*, 2009; Palma *et al.*, 2010; Thomas *et al.*, 2010; Nair *et al.*, 2013).

The dynamics of the Portuguese coast, the continental shelf and upper slope bathymetry, and the coastline morphology differs along the three areas analyzed (Kudela *et al.*, 2005). According to Sánchez *et al.* (2007), the Cape São Vicente (the most South-Western tip of the European continent) highlights the split between an extensive area (the West coast) exposed to winds and currents from Atlantic Ocean, and a sheltered region in the lee of the cape (the South coast).

In fact, the Western morphology is favorable to HAB dispersion whereas the South coastline suggests the HAB retention. These characteristics may explain the higher occurrence (frequency and intensity) of HAB episodes in the South coast comparatively to the West coast. Nevertheless, the Northwest coast is also seriously penalized by both MHW and HAB mostly due to harvesting a single species. Thus, the diversification of capture composition in the Northwest could be an opportunity to minimize the HAB impact on the dredge fleet performance, as already happens in the Southwest area.

The South area (Algarve) is one of the most popular tourist destinations in Europe. This makes the tourism, and its related activities, the leverage of Algarve’s economy, especially in the summer. Being a region of fishermen, mostly centered in the sea, the gastronomy is often based on fresh fish and seafood (where bivalve are certainly included). Here, the frequency and intensity of HAB has also been increasing (as in the remaining areas) ending in almost three months closure during 2012 year. The South dredge fleet is strongly influenced by market demand for bivalves, which increases during the summer season, when phycotoxins predominate. Thus, HAB prevalence could highly compromise an entire fishing season for this fleet. Moreover, HAB may have a serious impact on local economies as has been observed in other areas (e.g. Hoagland *et al.*, 2002; Kudela *et al.*, 2005; Jewett *et al.*, 2008).

Due to the limited economic opportunities in fishing communities, coupled with the ageing of the professionals and their low educational level, the fishermen have serious difficulty to change to other economic activities. This increases the adversely spreading effect (direct and indirect) of the HAB in this particular fishery. If the trend of HAB episodes observed in the last years continues, namely for the south coast, it can seriously compromise the sustainability of the dredge fleet and can ultimately dictate the end of this fishery. This would cause dramatic socio-economic impacts on the coastal communities, which depend directly and indirectly on this activity.

6.5 Conclusion

The purpose of measuring the impact of HAB on the revenue of the Portuguese artisanal dredge fleet was accomplished using a SFA model. The results confirmed that both daily MWH and phycotoxins significantly affect the vessels performance along the entire coast, although with varying intensity. The frequency, intensity and geographic spread of HAB has increased over the years. The hydrodynamics of the Portuguese coast explains the dispersion of the phenomenon in the West coast and their retention in the South coastline.

The Northwest dredge fleet has been seriously affected by HAB episodes, mostly due to the fact that they direct the fishing effort to a single species. In order to minimize the HAB impact on the dredge fleet performance, the Northwest dredge fleet should diversify the catch composition, as currently occurs for the Southwest dredge fleet.

In the South area (Algarve), the frequency and intensity of HAB has increased considerably over the years. As the fleet is strongly influenced by market demand for bivalves, particularly in the summer, the increasing number of HAB episodes can seriously compromise the normal activity of this fleet. Indeed, as the phycotoxins have a significant impact on the fleets' revenue, their prevalence might dictate the end of this fishery, causing direct and indirect losses to local economies, including tourism and catering services that highly depend on it.

In order to contribute to the sustainability of the dredge fleet, we suggest implementing a flexible quota regime that may help overcoming the negative effect of HAB on the performance of the fleets. This could consist of allowing vessels to transfer unused quota, corresponding to the days the fishery was closed due to HAB episodes, to other periods of the year, provided that the total yearly quota of each species would remain unchanged. As the occurrence of phycotoxins is a particularly serious problem in the South region, this measure could be implemented first in this region.

CHAPTER 7. Conclusions and future research

7.1 Concluding remarks

The main purpose of this thesis was to contribute to the long-term sustainability of the bivalve dredge fleet that operates in mainland Portugal. From a management perspective, the majority of the measures established are similar in all three areas, but there are differences in terms of the quota regime. In the Northwest and Southwest maximum weekly fishing quotas (MWFQ) are currently in force, whereas in the South coast the fishery is managed by maximum daily fishing quotas (MDFQ).

Due to those differences, the research conducted during this thesis was structured by area, and the conclusions are presented in this chapter in the same way, with the main features of each fleet, and their strengths and weaknesses discussed in detail. Several management measures, bounded by what are considered reasonable, appropriate and doable policies are suggested, in order to accomplish the purpose of the thesis.

7.1.1 Northwest Fleet

Overall, the Northwest area has a consolidated fleet, which has maintained the same number of active vessels over the last 20 years. Although other commercial species (donax clam and pod razor clam) are available in this fishing area, only the surf clam is targeted, thus the total amount landed throughout the years reflects essentially the conservation status of the *Spisula solida* stock.

From a national perspective, the Northwest fishing area is by far the most affected by wave height, in such a way that the monthly seasonality effect explained 41.3% of the variability in vessels revenue efficiency (RE). Indeed, in this fishing area, higher wave heights are associated with lower numbers of fishing days and smaller RE scores. In fact, due to the modus operandi of the fleet, it is not possible to safely operate the fishing gear (dredge) with a wave height higher than 2 m.

Concerning the landings, most of the catches are exported live to Spain throughout the year, and during December the demand for bivalve increases due to Christmas and New Year festivities. The shift from daily to weekly quota regime adopted in late 2007, justified by the harsher oceanographic conditions observed in the western Portuguese coast, improved the productivity of the fleet. Being a fishery that operates essentially on received orders, the new quota regime, also established per vessel and species, allowed fishermen to choose if they wanted to catch in one day the whole volume of orders or spread the catches over the week. In fact, this management measure led to a reduction in the number of fishing days (7.6%), and fuel consumption (8.7%), which contributed to significant efficiency improvements.

More recently, the prevalence of phycotoxins has increased, which compromised the fishing activity with special emphasis in one of the two bivalve production zone (BPZ) (the L2 BPZ). Even though the other (the L3 BPZ) is still frequently open to harvesting, the distance and time spent to navigate up to this area increases substantially the production costs of bivalve harvesting. Hence, the shipowners frequently stop the fishing activity whenever the value of first auction sale does not compensates the increase of production costs. Indeed, despite the fishing activity only being effectively prohibited when both BPZ (L2 and L3) are closed, the closure of the nearest BPZ can actually dictate the fleet inactivity. Thus, despite the advantage of this new regulation in which the fishermen are free to decide when to fill the quota, based on sea conditions, market or phycotoxins episodes, the phycotoxins episodes are still a major concern in this fishing area.

Technically speaking, this fleet was identified as being close to the optimal operation. However, its monospecific characteristic makes it more susceptible to external factors that jeopardize its performance.

From a management point of view, there are no scrapping candidates, since all vessels almost achieved the established quotas and operate in a similar pattern. Thus, our main suggestion to improve the performance of the vessels and to contribute to the increase of fishermen revenue are:

- to promote the diversification of the catch to the other bivalve species with commercial interest that occur in this area;
- to increase the catch quota of December (a month with high bivalve demand) and of other months with low MWH, by transferring a part of the quota from other periods with high MWH.

7.1.2 Southwest fleet

The Southwest fleet has a different ownership profile compared to the other regions. In the Portuguese artisanal dredge fishery the skipper is usually the ship-owner, but in the Southwest fishing 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. In fact, the ship-owner can decide when and which vessels will fish to accomplish the order lists received.

Concerning the fleet's catch composition, in the Southwest area the fishery is multispecific, targeting four species: the surf clam, the smooth clam, the donax clam, and the pod razor clam. Due to its ownership profile, this fleet does not have a consolidated pattern concerning the number of vessels operating over the years, and even the number of vessels allocated to this fishery can vary through the years.

The analysis of the technical and the allocative efficiency levels obtained for the period 2006 to 2012, showed that, in general, the composition of the catches of the Southwest fleet was good but the volume of the catches could be improved, confirming the major role played by the ownership profile in fleet's performance.

In the last 7 years (2006 to 2012), two substantial changes in management measures had impact on the productivity of this fleet. The productivity decreased with an abrupt reduction of the daily fishing quota (800 kg per vessel), whilst the introduction of the weekly quota for the fishery had the opposite effect. In fact, as observed for the Northwest fleet, the introduction of the MWFQ led to a reduction in the number of fishing days (15.4%) and fuel consumed (9.8%). The more significant reductions registered in this fleet (compared with the Northwest fleet), could be related to the multispecificity of the fishery. In this area, a vessel spends more time steaming between bivalve beds to achieve the fishing quotas for all the commercial species exploited, if the catch of the daily trip is multi-species. However, after the introduction of the MWFQ the fishermen could choose to catch in one day the whole volume of orders for a given species, decreasing the fuel consumption as well as the fishing days.

In the Southwest area, the MWH has a monthly effect, explaining 25.3% of the fleet's RE variability. The nonexistence of statistically significant differences in RE during most of the year must be related to the fact that this fleet supplies the bivalve market of Lisbon and peripheral areas throughout the whole year, and consequently bivalve demand is quite stable. Nevertheless, there is evidence of an increase in demand for bivalve in this region during Christmas and New Year festivities.

The Southwest area was also penalized by the occurrence of harmful algal blooms (HAB). However, the low variability of the efficiency scores throughout the time window studied may also be related to the fleet ownership profile. In fact, the optimization of the activity is not done at the vessel level, but by groups of vessels. This ownership structure seems to effectively influence this fishing activity in such a way that it is possible to mask the effects of HAB on the fleet's performance.

From a management point of view, besides transferring catch quotas between months, as proposed for the Northwest area, other suggestions for this fishing area are quite difficult to make. As it is not possible to change the fleet ownership structure, as this cannot be suggested to the owners, it implies that the effort to improve fleets efficiency has limited chance of being successful. This seems to be the predominant factor explaining the sub-optimal levels of performance in this region. Instead, something could be made in order to improve the performance of the "problem vessels" identified in chapter 2, but this would involve specific accompaniment of these vessels activity, rather than a general change in the managerial policies adopted in this region. In fact, four vessels were consistently identified as "problem vessels" meaning that they have the potential for achieving greater technical and allocative efficiency levels. Thus, our suggestion for this fishing area is as follows:

- to increase the total amounts of all species landed,
- to increase the catch quota of December by transferring part of the quota from November.

In a scenario of scrapping vessels in order to adjust fishing effort to the status of the exploited stocks, those classified as “problem vessels” (low allocative and technical efficiency) should be preferred.

7.1.3 South fleet

The bigger and more complex dredge fleet among the three mainland Portuguese areas operates in the South, in the Algarve. The vessels that operate in Algarve have mostly glass fibre hulls, and their engine power is below the national average of the dredge fleet, as a consequence of the hydrodynamic characteristics of the coast where they operate.

In this fishing area, the vessels are classified into two categories: local and coastal. The first group can only operate in the area of home port registry or adjacent home ports. Coastal vessels operate all along the coast of the Algarve. In terms of best-practice vessels, the local fleet must be considered as an exception, once the best-practice vessels are larger than the segment’s average. The daily quota that regulates the South fishing area, along with the operational restrictions in force for the local segment, could be a possible explanation for this result, since larger vessels have larger daily quotas and have higher capability to operate further away from the coast (reaching more fishing beds).

The hypothetical scenario drafted for the South fleet, simulating a shift in the quotas regime from daily to weekly quotas in this fishing area, presented enthusiastic results. A reduction of about 10.8% in fishing days (390 days) and 12.8% in fuel consumption (39844 l) was predicted for the year of 2011, which would have certainly resulted in improvements to the fleets’ productivity. Furthermore, the importance of this management measure goes beyond the improvement on the fleets’ productivity, as it also minimizes the impact of the bivalve dredge fishery on the environment, as the impact on the target species and on the associated macrobenthic communities is also minimized.

In bivalve fishery, due to the species sedentarily, no seasonality changes are expected to be due to variations in the stock levels of the species (for instance, seasonal migrations). The maximum fishing quotas are set on a yearly basis assuming that vessels can achieve the quota established without compromising the biological stock. Thus, changes on RE should not be attributed to changes on stock abundance over the year. Considering these assumptions, the results of the analysis reported on chapter 4 revealed that the impact of demand seasonality on fisheries performance is more evident in the South than in the other areas, with special emphasis during the summer months (June, July and August). The HAB events in this area are obviously a phenomenon of concern due to the frequency, intensity and geographic spread of harmful algae blooms that happen during the summer, when the market demand of this fishery is higher. Moreover, the hydrodynamics of the Portuguese coast explains the dispersion of the phenomenon in the West coast and its retention in the South coastline. The increasing frequency and intensity of HAB over the years, as well as the estimated impact of this phenomenon on the vessels' revenue, can seriously compromise the normal activity of this fleet. In fact, the phycotoxins prevalence may dictate the end of this fishery, and the damages can cause both direct and indirect losses to local economies.

From a management perspective, several suggestions can be made to improve the South fleet performance:

- to shift the quota regime from daily to weekly fishing quotas,
- to transfer quota from winter months to the summer months.
- To implement a flexible quota regime in the South, allowing the transfer of quota from days of closure due to phycotoxins' presence to other days along the year, in order to minimize the negative impact of phycotoxins on fleets' revenue.

Such management measures would hopefully contribute to improve the fishery revenue, reducing vulnerability to RE fluctuations related to demand seasonality. At the same time, they do not affect the exploited resources, since the total amount of the quota at the end of the year would remain unchanged. Moreover, the introduction of MWFQ would also minimize the ecological footprint of this fishery in the South fishing area.

Under a scrapping vessel plan in this area, the vessel's selection should starting from those that were consistently classified as "problem vessels" or did not reach the quotas established.

7.2 Contributions of the thesis

Pursuing the objectives initially established, this research aimed to provide innovative models and methodologies for performance assessment applicable to the management of artisanal fisheries, filling the gap on this topic that existed in the literature. Thereby, from a scientific perspective, the major contributions of this thesis can be summarized as follows:

- the development of a measure of revenue efficiency that is able to take into account the catch quota limits of the vessels in evaluations based on the DEA technique.

- the proposal of a two-dimensional graphical representation of vessel's performance, enabling the identification of benchmark vessels, both in terms of maximisation of weight of the catch for the species landed, given their inputs, as well as maximization of revenue from the fishing activity, involving the selection of an appropriate balance of captures among species, given output prices and input levels used. Such representation also facilitates the identification of the vessels of a fleet whose efficiency levels can be improved, clarifying whether the adjustments are required for the weight of the catch landed or the catch composition.

- The development of a new approach for the assessment of the impact of changes in regulatory conditions on fleets productivity. The analysis was done using a pooled frontier estimated with DEA, considering observations from two different periods (i.e., before and after the shift in quota regime from daily to weekly quotas). In the two fishing areas where this policy was implemented (Northwest and Southwest), the comparison of the deviations from the frontier for the two periods with different regulatory conditions allowed concluding that the new quota regime allowed attaining considerable gains in productivity. Based on these results, a hypothetical scenario was designed for the South fishing area that is still regulated with daily quotas and this innovative approach to the simulation of impact of changes in management policies on vessels activity allowed quantifying the benefits of the adoption of a new regulatory regime.

- the development of a methodology that enables exploring the impact of seasonality on DMUs' efficiency. Monthly seasonality effects on vessels' revenue efficiency, both due to variations in the mean wave height and market demand along the year, were explored using a Tobit regression. The dependent variable of the regression model was the efficiency score obtained from the DEA model, and the independent variables were defined as dummies corresponding to the month of operation. This approach to the analysis of seasonality is innovative in the efficiency measurement literature.

- the development of a methodology to assess the effect of harmful algal bloom on revenue of fishing fleets. The use of a SFA model specified with data from vessels daily activity is new in the fisheries literature, which is usually based on analysis at a more aggregate level (i.e., annual data of vessels activity). The use of contextual variables in the SFA model, controlling for the effect of time and sea conditions (variations in mean wave height) on efficiency is unprecedented in SSF.

All the models developed are suitable for fisheries in other contexts, with similar characteristics to the dredge fishery in Portugal, particularly those managed by quotas. In essence, this thesis contributes to illustrate how DEA and SFA, combined with other techniques, can be used with respect to a multitude of objectives of performance evaluation and improvement in the management of the fishery activity.

7.3 Directions for future research

Despite the research undertaken in this thesis, several issues regarding the activity of artisanal dredge fishery remain unclear. Thus, future research in this area will attempt to fill this gap through the collection of data on social and environmental aspects, to allow the use of the information collected to improve fisheries management and ensure long-term sustainability.

The specific objectives to be achieved in future research are as follows:

i) To develop a methodology to quantify the inefficiency caused by the ‘‘skipper effect’’. This research will use enhanced SFA models where social data will be integrated as exogenous factors, to evaluate the skipper's role on the performance of the vessel.

ii) To develop a methodology to understand how Global Climate Chances and phycotoxins episodes compromise the revenue of the fleet. The SFA approach will be applied to an environmental dataset along with technical parameters of the vessels.

iii) To evaluate the environmental impacts of the artisanal dredge fleets, and contrast potential differences arising from operations undertaken in different regions. The Life Cycle Approach (LCA) will be used to quantify the impacts and highlight opportunities for improvement.

iv) To assess vessel's eco-efficiency, combining the use of DEA and LCA techniques. This assessment will attempt to identify the vessels that are able to create more value with less impact on the ecosystem.

v) To evaluate the performance of artisanal fleets considering social, economic and environmental dimensions. This assessment will involve the use of a DEA model, specified with a directional distance function, to allow the customisation of perspectives concerning the relative importance of these three dimensions.

vi) To develop a methodology to estimate mis-reporting within catch data. The analysis will be performed using DEA models based on data collected by vessel's tracking devices, alongside other economic indicators.

vii) To develop a decision support system for fisheries governance based on Multi-Criteria Analysis (MCA) methods. The analysis will consider socio, economic and environmental variables, and their relationships with the regulatory measures.

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