UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

Departamento de Enxeñaría Química

FISHING FOR SOLUTIONS

Environmental and operational assessment of selected Galician fisheries and their products

Memoria presentada por:

Ian Vázquez Rowe

Para optar ao grao de Doutor pola

Universidade de Santiago de Compostela

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Informan:

Que a memoria titulada “Fishing for solutions. Environmental and operational assessment of selected Galician fisheries and their products” que, para optar ao Grao de Doutor en Enxeñaría Química e Ambiental, presenta D. Ian Vázquez Rowe, realizouse baixo a nosa inmediata direción no Departamento de Enxeñaría Química da Universidade de Santiago de Compostela.

E para que así conste, firman o presente informe en Santiago de Compostela, o 11 de abril de 2012.

Fdo. G. Feijoo Fdo. M.T. Moreira Fdo. I. Vázquez

Trabazo contoulle que cando rematou o servizo militar, antes de marchar a Santiago para estudar a carreira, pasara uns meses embarcado nun bacallaeiro que pescaba en Terranova.

-Acórdaste ou non?

Caldas fixo un xesto ambiguo mentres fendía a uña na casca dunha castaña para pelala. Aínda que recordaba con nitidez a historia non o quixo interromper. Volveu oír falar dos bacallaus grandes coma homes, das redes tensadas ata case romper ao seren izadas do mar, e das focas ruidosas que se achegaban aos barcos.

-Sabes unha cousa, Caldiñas? – díxolle, como facía cando era un pícaro para atrapar a súa atención -. As focas berrábannos desde a auga. Eu estaba convencido de que se queixaban porque lles estabamos a acabar cos peixes, mais os meus compañeiros burlábanse de min. E sabes outra cousa, Caldiñas? Eu tiña razón. Xa non queda bacallau en Terranova. Esgotouse.

Domingo Vilar, *A praia dos afogados* (2009)

Abstract

Fishing is the only hunting activity which is still maintained on an industrial level to sustain worldwide food demand. Currently, worldwide fisheries are suffering a series of hazards linked to overexploitation and increasing human demand for protein, causing a wide range of environmental impacts on marine ecosystems, such as stock depletion or ecosystem disruption. Moreover, the fishing industry has grown to an extent where the environmental burdens associated with on board and on land operational activities, such as fuel consumption by vessels or wastewater generated by canning factories, are also becoming important environmental concerns. From a regional perspective, Galicia (NW Spain), the main fishing region in the European Union (EU) in terms of landed fish and economic turnover, does not escape these global threats. Additionally, Galicia supplies the rest of Spain and other EU countries with important amounts of fresh and processed seafood.

The current importance of environmental sustainability has led to the development of a varied set of environmental management tools, in order to monitor the environmental impacts of human activities. Given the use of a life-cycle perspective to evaluate the environmental performance of products, processes and services nowadays, Life cycle assessment (LCA), a standardized technique for assessing the environmental aspects and potential impacts associated with a product by compiling an inventory of relevant inputs and outputs of the product system, evaluating the potential environmental impacts associated with those inputs and outputs and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study, is presented as the main environmental management tool that will be used in this dissertation. LCA has been widely developed in the agri-food sector. However, seafood analysis from an LCA approach has been limited to date to a few case studies, most of which correspond to analyses in Scandinavian fisheries.

Hence, this doctoral thesis focuses on the application of LCA in seafood systems related to the Galician fishing fleet. In the first place, the wide set of fishing fleets and species that have been assessed makes it possible to give a broad range of results which are open for discussion regarding

their environmental profile, as well as the supply chains that may arise after the landing of these seafood products. Secondly, a specific protocol is proposed for the implementation of LCA in combination with a management tool named Data envelopment analysis (DEA), which permits the analysis of multiple data points in order to include operational benchmarking and eco-efficiency verification together with the assessment of the environmental performance of fishing vessels. Furthermore, the sole use of DEA is proposed to assess the importance of skipper skills in terms of vessel efficiency. A third step of the dissertation deals with the quantification of discards in the Galician fishing sector, which is possible thanks to the broad representativeness of the inventory data collected, as well as proposing a specific impact category for discards to be included as a fishery-specific impact in fishery/seafood LCA studies. Finally, a similar approach to that performed for discards is used to calculate the carbon footprint (CF) of the Galician fishing sector. Moreover, this doctoral thesis proposes a specific CF calculator for fishing systems, which is discussed in Chapter 13 and is available in the annexed CD.

The application of LCA to several fishing fleets in Galicia permitted the assessment of three different types of fishing gears: trawling, purse seining and long lining. In fact, the fleets inventoried include littoral, offshore and open sea fleets. The relevance of this study is increased due to the fact that to date only the open sea tuna purse seining fleet has been assessed from an LCA point of view in Spain. Detailed inventories are presented for each of the fleets assessed. Moreover, discussion focuses on the environmental comparison of the different gears, especially when more than one fleet (and gear) are targeting the same species, on the main hot spots that were identified in each of the systems analysed, on proposing a series of improvement actions to reduce the environmental burdens linked to fishing and on the inclusion of fishery-specific indicators in seafood LCA studies. When data were available certain emblematic and highly-consumed species in Galicia and Spain, such as octopus or hake, were analyzed up to human consumption, evaluating the different on land subsystems.

In the current dissertation LCA appeared a suitable methodology due to its application to evaluate the environmental performance of fishing systems and their derived supply chains. Furthermore, the inclusion of certain fishery-specific indicators helped to provide a more integrated perspective to the assessment.

DEA is a management methodology that permits the comparison of the efficiency of multiple units with similar collective characteristics. Its use combined with LCA has been considered suitable in fishing fleets, as a new methodological approach to link environmental and socioeconomic assessments of fisheries, in order to increase the assessment ability of both tools. The use of LCA+DEA avoids problems with standard deviations which usually arise when LCA practitioners work with average inventories. Moreover, the new approach facilitates the interpretation of the results for practitioners who deal with multiple individual LCAs for the same fishery. Furthermore, the joint application of LCA and DEA carry synergistic effects related to the link between operational efficiency and environmental impacts.

Finally, the global inventory of all the fishing fleets made it possible to carry out two estimations on a Galician scale. The first one concerned discards amount in fishing activities. Results showed that roughly 60,250 t of marine organisms were discarded by the Galician fleet in 2008, representing 16.9% of the total capture. Moreover, an important percentage of discards was linked mainly to trawling vessels and, to a lesser extent, to certain long lining fisheries. In fact, this estimation may improve the assessment of stocks and help to quantify the damage that discards may have on wild ecosystems. The second insight is linked to CF calculation of the Galician fishing sector. For this particular case study, extensive and intensive aquaculture inventory data, available from previous studies conducted in Galicia, were used in order to reach a final value for the entire fishing activity in this region. Results showed that Galician fishing activity would entail 3% of total GHG emissions at a regional scale and 0.2% of emissions on a national scale in 2008, stressing the relevance of Galician fishing activity in terms of GHG emissions.

Finally, CF calculator software is provided adapted to the specific characteristics of fishing systems, allowing stakeholders in the fishing business to easily calculate the GHG emissions linked to the extraction of different fishing species.

Keywords: Carbon Footprint (CF), Data Envelopment Analysis (DEA), discards, fisheries, fishing, fuel, LCA+DEA, Life Cycle Assessment (LCA), seafood, vessels.

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SECTION I

INTRODUCTION TO THE STUDY

Chapter 1

Introduction to fishing systems

Summary

Fishing is the only hunting activity which is still maintained at an industrial level to sustain worldwide food demand. Currently, worldwide fisheries are suffering a series of hazards linked to overexploitation and increasing human demand for protein. This is having a wide range of environmental consequences in marine ecosystems, such as stock depletion or ecosystem disruption. Moreover, the fishing industry has grown to an extent where the environmental burdens associated with on board and on land operational activities, such as fuel consumption by vessels or wastewater generated by canning factories, are also becoming important environmental concerns. From a regional perspective, Galicia, the main fishing region in the European Union (EU) in terms of landed fish and economic turnover, does not escape these global threats. Additionally, Galicia supplies the rest of Spain and other EU countries with important amounts of fresh and processed seafood. This introductory chapter, besides analysing current fishing systems, also examines the main implications of the fishing sector in Galicia, analysing the main fishing fleets and techniques (gears). Industrial processes developed in this region based on the landed catch are detailed, as well as the main commercial and consumption trends.

Index

1.1. History of fishing

1.1.1. Development of fishing throughout humanity

Archaeologists have determined that fishing dates back to at least the later Paleolithic period, about 40.000 years ago. At that time, most human communities were nomadic, due to the need to hunt mammals. However, the first permanent communities in this period are linked with an increased consumption of both freshwater and marine fish. Research in a series of settlements along the Danube Valley, such as Lepenski Vir, evidences that fish was the primary resource of these first fluvial communities (Gartside and Kirkegaard, 2007).

Fishing slowly became more and more important in communities worldwide with the spread of Neolithic culture and its technology in 8000BC. At this point in history, humans had already developed a series of technological improvements that enabled them to increase their fishing captures. The basic forms of the fishing methods we know today appeared in this period. Tools such as harpoons, line tackles or gorge hooks were the most common instruments (Morales-Muñiz, 2007; Olson et al., 2008).

The Egyptian civilization also found fishing an important means of feeding the population. Most of what we currently know about their methods of capturing fish along the river Nile was studied through illustrations found in drawings on papyrus or on the walls of ancient tombs. According to these findings, Egyptians used to fish in small reed boats with woven nets, harpoons, weir baskets or hook and line methods. The main fish in the Ancient Egyptian diet were catfish, Nile perch (*Lates niloticus*) and eels (Brewer and Friedman, 1989).

In ancient Greece, only the lower class consumed fish on a regular basis. Therefore, very few representations conserved of fishing activities have come down to us. However, a Greek author named Oppian of Corycus wrote *Halieutika,* a book in which he describes many methods employed for sea fishing (Oppian, 1928). One of the methods he describes, in which a buoyant net is used by drawing a circle while the fishermen strike the surface of the sea violently in order to capture the fish, resembles a form of purse seining. On the other hand, another Greek author named Polybius describes fishermen hunting for swordfish in the Mediterranean with harpoons (Polybius, 1962).

However, around 600BC, the demographic growth in the Aegean regions created the foundation of Greek colonies on the Black Sea coast. These towns developed a strong fishing sector on a commercial scale, exporting salted fish on a large scale to Greece in order to finance oil and wine imports. In 50BC these colonies started developing large fixed nets that were used to capture migrating fish such as tuna. These nets were shifted by up to 60 or 70 men. During the Roman Empire there is evidence of an increasingly commercial fishing sector, using rod and line and netting methods to capture a varied series of species, such as conger, sea urchin, lobster, octopus or cuttlefish (Bekker-Nielsen, 2007). At this same point in history, other societies such as the Pandyas in India, begin fishing pearls in the Indian Ocean.

There is not much information about how fishing developed in the years after the fall of the Roman Empire. However, there is evidence that towards 1000AD, Basque and Viking fleets started expanding fisheries to the North Atlantic and to the Arctic. Some researchers also claim that this expansion was due to an increase in marine fishing in this period following a decrease in the size of freshwater fish.

Basque whalers began intense fishing campaigns in the North Atlantic, and their methods were soon adopted by Dutch and English fleets. These three fleets managed to virtually exterminate bowhead whales (*Balaena mysticetus*) by the end of the Middle Ages. However, the discovery of new stocks in the Northwest Atlantic by Spanish explorers in the late 15th century lowered the pressure on whale capturing. At this point, fleets of vessels from all the major Western European nations, such as England, Portugal, France, Holland and Spain started sailing to Newfoundland (Barkham, 1984; Barthelmess, 2009).

During the following centuries, until the mid 19th century, the Northwest Atlantic provided European nations with an important source of food, mainly cod and halibut. Many wars were fought throughout the Modern Era, first between European nations and then against the newly - settled Canadian colonizers (Baker, 2003), over the fishing banks of Newfoundland and Labrador (Figure 1.1). At the same time, during these centuries little technological progress was made regarding fishing methods, techniques and vessel construction. It was not until the mid 19th century that the fishing industry began to make rapid changes in its technology and structure.

Figure 1.1. Trawlers at the port of Lunenburg (Nova Scotia, Canada). The fishing stocks off the Canadian coast have been fished for centuries.

1.1.2. The fishing industry since the Industrial Revolution.

The influence of the Industrial revolution on commercial fishing can be clearly seen after the 1840s with the rapid growth of railways, first in Britain and subsequently in other countries such as France, the Netherlands and Spain. The birth of the railway network increased the amount of fresh fish that could be transported to inland markets. This situation increased demand, as fish such as European hake (*Merluccius merluccius*), which had been an important seafood commodity for centuries in coastal areas of the Iberian Peninsula, became more popular inland (e.g. Madrid) due to increased availability (Clover, 2006). This, in turn, led to an increase the number of trawlers in North Sea ports, and later in other areas of the Northeast Atlantic which ultimately created an overfishing issue.

In order to supply the Western European nations with all the seafood they were now demanding, trawlers, which had only been used in a very archaic form until the late 18th century, became popular vessels given the high amounts of catch that could be landed using this type of gear. Moreover, at the time, commissions considered that bottom trawling was not a threat to marine ecosystems, since it was believed that it created a similar effect to that of tilling in agricultural systems. Throughout the 19th century the use of the steam engine, and towards the end of the century, the use of diesel to power vessels, led to an exponential increase in fleet tonnages and numbers in the North Atlantic, allowing industrial fishing vessels to increase their catches to supply the incipient seafood industry (Engelhard, 2008).

By 1890, world landings had risen to 7 million tonnes on an annual basis, 70% of which was caught in the Atlantic Ocean by European countries. Other industrial fishing networks that had arisen in those years included the Japanese and North-American coastal fisheries, including gulf menhaden (*Brevoortia patronus*), which will be analysed in Chapter 9 of this dissertation (Figure 1.2).

Figure 1.2. Fishermen on a gulf menhaden purse seining vessel (Mississippi, US).
Source: NOAA Photo Library (2009).

In the next couple of decades, before the outbreak of World War I, a high number of vessels had already shifted to diesel powered engines, increasing world landings to 9.5 million tonnes by 1913. However, due to the two World Wars, and the strong recession in the 1930s, it was not until 1945 that annual landings started to soar. For instance, estimated worldwide landings in 1947 were roughly 18 million tonnes. By 1960, this value had doubled to 40 million tonnes, and in 1967 total landings were above 60 million tonnes (Meseck, 1968; Chapman, 1970). The reasons behind this enormous growth, which was sustained until the mid 1980s (Watson and Pauly, 2001), are linked to a variety of factors, which include: i) the introduction of widespread use of freezing at sea; ii) the lack of major conflicts between developed countries; iii) the increase in fishing capacity in major countries, especially the Soviet Union and China; or iv) the extensive use of fuel to power industrial fishing vessels worldwide (Chapman, 1970).

Finally, while fishing landings have remained stable since the 1980s, with a slight tendency to decrease in recent years, attributed to overexploited fisheries and the excessive capacity of world fleets (Grainger and García, 1996; Pauly et al., 1998; Fréon et al., 2008; Villasante and Sumaila, 2010), aquaculture has arisen as an important source of seafood provision. In fact, in 1950 less than 1 million tonnes of fish or other marine species were produced through aquaculture. After several decades of high increases, with an average annual increment of 8.3% between 1970 and 2008, constituting the fastest growing food sector, the 2008 aquaculture production was 52.5 million tonnes, representing 36.9% of the total fish used for human consumption, and 45.7% of seafood (FAO, 2010).

1.2. Current state-of-the-art of worldwide fisheries

According to the latest reports, capture fisheries supplied the world with roughly 90 million tonnes of fish in 2009, about 3% less than in the year 2004 (FAO, 2010)[1]. In fact, captures during the last decade have been fairly stable, with most fluctuations being attributable to the El Niño effect in the Southern Pacific (FAO, 2010). Additionally, 32% of fisheries were identified as being overexploited

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[1] Note that this value includes the fishing landings for China, which are considered to be over-reported by FAO. Worldwide landings excluding China in the year 2009 were 75.1 million tonnes, 3.6% lower than in 2004 (FAO, 2010).

(28%), depleted (3%) or recovering from depletion (1%) in 2008, which represented the highest proportion of this segment ever recorded (FAO, 2010) (Figure 1.3). This situation has led to scientific consensus highlighting the overexploitation of most worldwide fisheries as one of the main threats to marine ecosystems, creating an important decline in marine abundance, diversity and stocks (Myers and Worm, 2005; Pauly et al., 1998, 2002; Worm et al., 2009). In fact, part of the scientific community alerts that public opinion has not received sufficient information on depleting fisheries to understand the magnitude of the problem. The reasons linked to this situation are mainly due to over-reporting of catches by China (FAO, 2010), the fact that FAO combines the fishing catches with aquaculture production, the increasing consumption of seafood from developing countries in the Western society and the lack of compromise by the governments of fishing nations (Pauly, 2008).

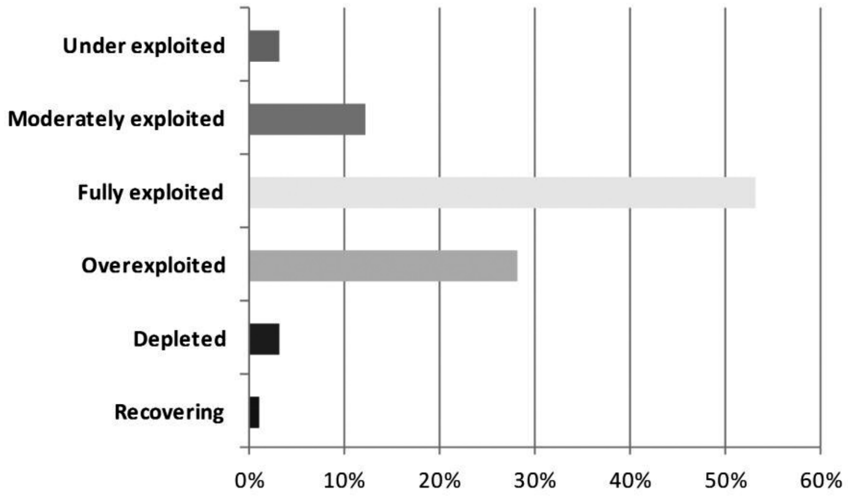

Figure 1.3. Status of world fisheries in 2008.
Source: FAO (2010).

However, it is important to note that the environmental problems linked to fish extraction are not only reduced to the enormous quantities of biomass that are being removed from the oceans for human consumption and other uses. Therefore, overfishing is just one of several environmental concerns relating to fishing nowadays that are listed and explained below:

- Overfishing. Overfishing can be defined as the consequence of uncontrolled fishing activities that can reduce the fishing stocks. Hence, the term maximum sustainable yield (MSY), which is defined as the largest theoretical catch that can be taken from a certain species' stock over an indefinite period of time (Schaefer, 1956), has arisen as an important concept to take into consideration when managing fisheries. Overfishing became of public concern in the early nineties when the cod fishery in Atlantic Canada collapsed, with serious implications from an ecological, economic and socio-cultural perspective (Roughgarden and Smith, 1996; Walters and Maguire, 1996). This situation led fishing managers worldwide to improve their assessment techniques and revise the stock size estimations of most fisheries in order to avoid future collapses. Furthermore, current trends are abandoning individual assessments of species, in order to adopt a more integrated approach, in which the entire ecosystem is analysed. This perspective allows managers to evaluate shifts in species composition in order to detect equilibrium energy flows and assess whether a fishery has the ability to recover to more sustainable stock size requirements within natural variations in fish stocks (Pontecorvo, 2008).
- Illegal, unreported and unregulated (IUU) fishing. IUU are defined as those fishing activities conducted without the permission of a specific State, that have been misreported or not reported to the authorities or that were performed in areas where there are no applicable conservation or management measures (FAO, 2001). According to Bray (2000), IUU fishing is widespread throughout worldwide fisheries, making attempts to improve fisheries management complicated. In fact, fisheries with increased levels of IUU have greater risks of collapsing due to the difficulty authorities have in quantifying the magnitude of the problem. Moreover, some reports suggest that IUU seems to be an increasing practice in order to eschew stricter fishing rules in most fisheries (Bray, 2000). Agnew et al. (2009) estimated a worldwide average of 18% of IUU between 2000 and 2003.

- Discards. Any organic material of animal origin which is thrown away or dumped at sea for whatever reason by a fishing vessel in considered a discard (Alverson et al., 1994). Efforts have been made in recent decades to reduce the amount of discards that are been returned to the sea for a wide range of reasons, including biological, economic and management motives. A recent FAO publication has set discard levels at approximately 8% of global catches, adding up to roughly 7 million tonnes of discards (Kelleher, 2005). From a biological perspective, one of the main concerns regarding discards is the high mortality of this fraction of the catch (Catchpole et al., 2006), as well as the effect that this dead biomass has on bird populations (Votier et al., 2004). Even though discards vary enormously depending on the fishing vessels and fishing technique, their importance is strongly conditioned by a set of management policies, environmental conditions, fishermen and skipper decisions and on the specific market demand at a particular time (Catchpole et al., 2011)
- Fuel use intensity (FUI). The FUI of a fishery is the total amount of fuel needed to provide a given amount of a fishing product. More specifically, it is usually measured in litres of fuel consumed by fishing vessels per tonne of landed catch (Tyedmers, 2004). Even though the main concern linked to fisheries until very recently was dealing with overexploitation through correct fisheries management, in order to guarantee sustainable fishing patterns, other environmental impacts related to the associated industrial activities in the fishing sector have proved to be of relevance when analysing fishing systems (Hospido and Tyedmers, 2005). Within these activities, the issue that has attracted most attention is the use of fuel by a high proportion of worldwide fishing fleets ever since the end of World War II (Tyedmers, 2005). In fact, Tyedmers (2005) estimated that in the year 2000 1.2% of the global consumption of oil was linked to fuel burning by a wide range of fishing vessels, suggesting that the fishing sector as a whole could be responsible for a substantial proportion of worldwide CO_2 emissions.
- Other environmental concerns. Additionally, there are a set of certain practices in fishing operations that can destroy the habitat or produce ecological disruptions.

Habitat effects are linked mainly to the use of non-selective fishing techniques, the use of illegal techniques, such as the use of dynamite (blast fishing) or cyanide and to ghost fishing (Fox et al., 2003; Woodman et al., 2004; IEEP, 2005; Wells, 2009). Moreover, fishing, as mentioned above, has important ecological consequences, creating disruptions in the food webs.

While worldwide fisheries struggle to maintain their productivity, due to the overexploitation of fishing stocks (Pauly et al., 2002, 2003; Ayer et al., 2009), the growth in seafood demand is being satisfied, at least partially, thanks to aquaculture production, despite the fact that certain aquaculture techniques may also have a significant ecological impact on wild fisheries (Naylor et al., 2000; FAO, 2010; Klinger et al., 2011). Moreover, as aquaculture intensifies and diversifies, the biological impacts and risks to humans, ecosystems and the farmed fish related to this sector have also increased over time (FAO, 2010). Nevertheless, it is important to highlight at this point that while fisheries in many areas are depleting and biodiversity is suffering, seafood systems are growing with respect to their complexity, due to the increasingly fuzzy boundary between aquaculture and fisheries, with farming techniques being applied to fisheries and vice versa (Klinger et al., 2011).

On a European Union (EU) scale, the broad set of problems that have affected fisheries has led policymakers to focus on introducing a new Common Fisheries Policy (CFP) by the year 2013, in order to increase efficiency when it comes to ensuring that fishing pressure is not higher than stocks can sustain (European Union, 2006). According to the consultations carried out by the European Commission, there is a wide consensus that the ecological sustainability of fisheries must be one of the main targets of this new framework, in order to guarantee a viable fishing sector, together with economic and social objectives (European Commission, 2010).

In this context, MSY is highlighted as one of the main targets to be implemented by the new CFP. Accordingly, increased efforts must be made to guarantee a detailed stock assessment of the entire ecosystem, since most fishing areas not only present mixed fisheries, but also a high number of juveniles or non-marketable species that end up discarded (Catchpole et al., 2005; Kelleher, 2005).

Finally, as highlighted by Hospido and Tyedmers (2005), it is important to note that focusing exclusively on biological concerns in fishing systems can give a highly distorted vision of the effects fishing operations have on the environment. In other words, the industry linked to fishing is also an important source of environmental burdens, due to energy consumption (Tyedmers, 2005), use of resources and materials (Watanabe and Okubo, 1989; Hayman et al., 2000) and other material flows.

1.3. The Galician fishing sector

1.3.1. Brief history of fishing in Galicia

The first evidence of fishing activities in Galicia goes back as far as the Bronze Age, approximately four thousand years ago. Archaeological excavations in coastal areas have shown the existence of rudimentary shellfish gathering techniques along the coast at that time. However, it is not until the development of the *Castro culture* that shellfish and coastal fish appear on a regular basis in the diet of the littoral *oppida*[2]. Fishing activities in these pre-roman centuries are thought to have developed mainly with simple tools, such as hooks and small nets. However, around the 3rd century BC the presence of some pelagic fish, such as Atlantic horse mackerel (*Trachurus trachurus*) or Atlantic mackerel (*Scomber scombrus*) in archaeological sites suggests the existence of the first basic fishing vessels (Vázquez-Varela, 1998).

The arrival of the Roman civilization to Galicia entailed certain changes in the economic and social structures of the region. This derived in important developments in fishing activities. In the first place, a greater variety of molluscs and fish species have been identified in the diet of the local population, suggesting that new fishing techniques and vessels were used in this period. Secondly, higher captures were made in order to create the first complex seafood supply chains in the Iberian Peninsula, benefitting from the new transportation networks. Finally, the first processing industries of marine products (salt factories) were created at this time. (Vázquez-Varela, 1998).

During the Middle Ages, fish extraction and consumption continued to be an important sector in this region. In fact, given the attributed abundance in this period, fluvial fishing became an

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[2] Oppida. Celtic settlements with Roman influence that were scattered throughout the Galician geography.

important activity in many rivers. Some of the species captured in rivers which are cited in literature are salmon, trout and eel (Ferreira-Priegue, 1998). An interesting fact relating to fluvial fishing is the prohibition of capturing small individuals of salmon in Galician rivers in 1252, which may indicate an early measure to avoid the depletion of this species (López-Ferreiro, 1895).

Shellfish, with the exception of oysters, were seen as products for the lower class, so the commercialization to the developing urban towns was limited to a wide range of fish species arriving from littoral fishing fleets along the Galician coast. In the 13th century a series of technological improvements created a rise in fishing exploitation which initiated the strong economic development of fishing in Galicia. Interestingly, at this point in history studies suggest that important ecological changes due to the rise in water temperature in coastal areas created a migration of whales and cod, reducing the abundance of these species in Galicia, while small pelagic fish, mainly sardine, experienced high proliferation of stocks in this area.

By the 15th century fishing associations, known as *confrarías*, many of which are still operating nowadays, started to appear in coastal ports with incipient commercial fleets in order to improve the management of marine resources. These first solid and permanent management policies in Galician fishing systems arose due to a wide range of motives, including the fact that cyclic fluctuations of sardine abundance along the Galician coast were undermining a sector that at the time was strongly dependent on captures of this clupeid. However, at this point in history conger (*Conger conger*), hake (*Merluccius merluccius*) and octopus (*Octopus vulgaris*) were already being landed in large amounts in many Galician ports. A significant portion of these catches was dried and exported to other Spanish regions.

The 17th, 18th and early 19th centuries are characterized by strong political unrest on a domestic and European level which hindered the development of the fishing sector. Nevertheless, by 1883 Galician fishing activities represented 34.7% of total catches in Spain, 48.4% of the fishing vessels and 44% of the labour force in the fishing sector (Carreras-Candi, 1980; Santos-Castroviejo, 1998). In the late 19th century salting factories started to lose ground to the canning industry which was fast becoming the main activity within fish processing. The canning industry also benefitted from the establishment of the first railway lines in Galicia and the fact that the fisheries off the coast of Brittany, the main suppliers of canned seafood at the time, had suffered important stock reductions (Díaz de Rábago, 1885). From a fishing fleet perspective, the main techniques that are seen in Galician ports nowadays were already predominant: purse seining, long lining, artisanal vessels and rudimentary forms of trawling techniques (Fernández-Casanova, 1998).

1.3.2. Fishing in Galicia in the 20th century

During the entire 20th century Galicia represented the main fishing region in Spain. In the first decades of the century, the fishing sector continued a steady increase in captures and economic turnover, despite certain drawbacks, linked to the numerous conflicts that affected Spain and Europe in the first half of the century. At the end of the Spanish Civil War, fishing was regarded as a profitable and efficient way of guaranteeing a food supply for the impoverished Spanish population (Labarta, 1978). Additionally, the long period of time in which fishing activities had been kept very low in the 30s and 40s gave rise to recovered stocks in most fisheries, especially those in the North Atlantic (Graham, 1943; Clover, 2006). This situation led to an enormous proliferation of fishing vessels in Spain during Franco's dictatorship (1939-1975), which was also linked to important technological advances and the consolidation of a wide range of offshore fishing fleets in Newfoundland, Argentina or the Northern Stock.

The last quarter of the 20th century, however, witnessed a strong restructuration of the Galician fishing fleet due to the increasing overexploitation of many fisheries, the inadequate structure of the fishing sector, and the repercussion on the fleet of the first fuel crisis (Fernández-Casanova, 1998; Gómez-Giráldez, 1987; Labarta, 1978). This crisis, in which a series of biological and political factors coincided, was increased due to the efforts of Spain to enter the EU, which required deployment of many vessels as well as a further restructuring of the fishing fleet (González-Laxe, 1988; Fernández-Casanova, 1998).

1.3.3. Current fishing systems in Galicia

Galicia is currently the most important fishing region in Spain and one of the most fishing-dependent regions on an EU scale (Doldán-García et al., 2011). In 2008, as can be seen in Table 1.1, approximately 5,000 fishing vessels were registered in its fishing ports (Figures 1.4). Most of these vessels (*circa* 85%) are artisanal, owner-operated vessels which target a wide range of fishing species throughout the Galician *rías* (Xunta de Galicia, 2008). In fact, roughly 50% of Spanish artisanal vessels are registered in Galician ports, demonstrating the subsistence characteristics of much of the Galician fishing sector (MARM, 2011). However, there are also a wide range of industrial fishing fleets operating from Galicia (Table 1.1), which operate along the Galician continental shelf, international waters or in the exclusive economic zone (EEZ) of countries with fishing treaties with the EU.

Table 1.1. Vessel distribution in the Galician fishing fleet, divided by fishing zones (year 2008).
Source: Xunta de Galicia (2008).

Fishing zone	Description	Number of vessels	Landings (% of total)
Deep-sea fishing	Trawlers (varied fisheries)	46	2.68
	Trawlers Mauritania fishery	27	0.65
	Purse seiners (Tuna fisheries)	63	45.65
Offshore fishing	Long liners (Swordfish fisheries)	87	1.14
	NEAFC Long liners	58	6.36
	NEAFC Trawlers	66	5.74
	Trawlers Portuguese fishery	4	
Coastal fishing	Trawlers	98	16.78
	Purse seiners	166	14.60
	Other coastal vessels	124	0.70
	Artisanal vessels	4,203	5.70
Total Galician fishing fleet		4,942	100.00

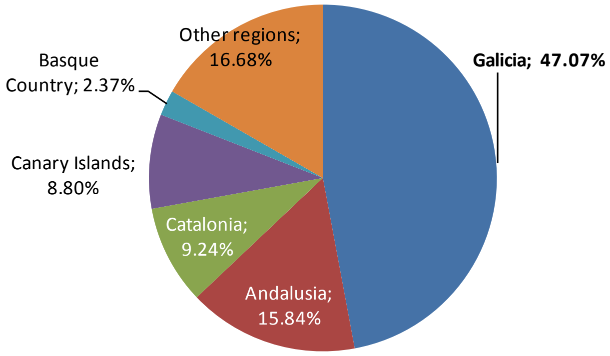

Figure 1.4. Relative number of fishing vessels per region in Spain (2010).
Source: MARM (2011).

The Galician fishing sector is divided into nine production zones (Figure 1.5). Characteristics between these fishing zones vary substantially (Table 1.2). Therefore, Zones I, III, VII and IX were, in the year 2008, the main fishing zones in terms of economic turnover and landed captures (Xunta de Galicia, 2008). Table 1.3 details the main fishing ports in each zone.

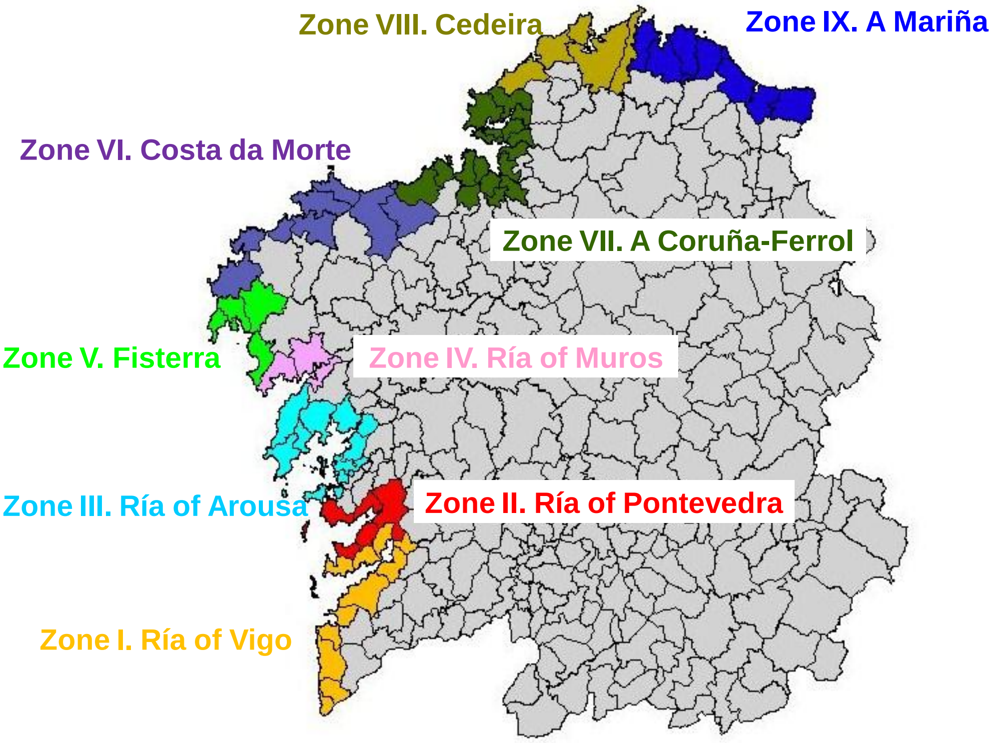

Figure 1.5. Administrative divisions of the Galician fishing sector.
Source: Xunta de Galicia (2008).

Table 1.2. Galician fishing fleet characteristics, divided by port zones (year 2007).

Production zones	**Catch (t/year)**	**Economic value (€/year)**	**Number of vessels**	**Tonnage (GT)**
Zone I-Ría de Vigo	37,702	122,347,755	830	162,402
Zone II-Ría de Pontevedra	6,292	15,531,075	425	34,896
Zone III-Ría de Arousa	39,105	90,630,424	1,839	85,219
Zone IV-Ría de Muros e Noia	15,304	23,054,452	605	15,304
Zone V- Fisterra	893	3,948,138	154	5,996
Zone VI-Costa da Morte	4,462	9,308,132	331	19,839
Zone VII-Golfo Ártabro	29,012	86,167,430	345	41,141
Zone VIII-Cedeira	2,437	9,267,231	137	11,701
Zone IX-A Mariña	38,364	91,068,385	245	73,323

Table 1.3. Main fishing ports in Galicia.

Production zones	**Main fishing ports**
Zone I-Ría de Vigo	A Guarda, Baiona, Panxón, Vigo, Arcade, Cangas
Zone II-Ría de Pontevedra	Aldán-Hío, Bueu, Campelo, Marín, Portonovo
Zone III-Ría de Arousa	O Grove, Cambados, A Illa, Rianxo, Cabo de Cruz, A Pobra, Palmeira, Ribeira, Aguiño
Zone IV-Ría de Muros e Noia	Porto do Son, Portosín, Noia, Muros
Zone V- Fisterra	Lira, O Pindo, Corcubión, Fisterra
Zone VI-Costa da Morte	Muxía, Camariñas, Camelle, Laxe, Corme, Malpica, Caión
Zone VII-Golfo Ártabro (A Coruña-Ferrol)	A Coruña, Sada, Barallobre, Pontedeume, Ferrol
Zone VIII-Cedeira	Cedeira, Cariño, Espasante
Zone IX-A Mariña	O Vicedo, Celeiro, Viveiro, San Cibrao, Burela, Ribadeo

The main species in terms of economic turnover correspond to high or medium value species that are fished mainly in the Northern Stock, such as hake, megrim or anglerfish. Additionally, cephalopods such as octopus or sepia, which are linked to artisanal coastal fleets or to the Mauritanian fishery, also show significant economic revenues. Other species, such as Atlantic horse mackerel, sardines or whiting also generate large revenues, due to the high amounts that are landed on an annual basis. Table A.1 in Appendix I details the main fishing species landed in Galicia in 2008, as well as the economic turnover they generated at auction sale.

Main fishing techniques in the Galician fishing fleet

Throughout history a wide set of fishing techniques have been developed. Galicia, together with the rest of Spain, has historically been renowned for the varied types of fishing techniques used in its fisheries and fishing fleets (Rodríguez-Santamaría, 1923). More specifically, the first fishing techniques to be developed in Galicia, like in many other coastal areas worldwide were linked to the use of hooks and rudimentary nets. Thereafter, with the development of the sardine industry in the final centuries of the Middle Ages, purse seining techniques, as well as other fishing techniques, such as *xeitos*, proliferated. The commercialization of bottom dwelling species, such as hake or conger, in the following centuries, encouraged the development of new fishing techniques aimed at targeting the seabed, such as *traíñas* or the first trawlers.

Currently, there are still dozens of different fishing techniques used in Galicia by the artisanal fleet. In fact, most of these vessels have licenses that allow them to use several of these techniques throughout the year, with the aim of targeting a wide range of species that will vary depending on the time of the year, fishing quotas, fishing bans or natural environmental variations in coastal habitats (Freire and García-Allut, 2000). However, fishing fleets that developed into industrial fisheries, landing thousands of tonnes in the main Galician ports, have specialized in very specific fishing techniques:

- Purse seining. Seiners are fishing vessels that use fishing nets that hang in the water thanks to lead weights placed on the bottom edge and flotation devices (usually made of cork) placed on the top. A very common type of seine net is the purse seine, which consists of a closed bottom part of the net that traps the fishing schools once surrounded (Figure 1.6). Purse seiners in most parts of the world are used to target small pelagic fish, such as sardines, herring or anchoveta, or larger tunids, like bonito or skipjack. The use of this gear increased enormously in the 1950s thanks to a series of technological innovations, such as the development of the power block, the use of synthetic materials for netting, or the introduction of school detection methods on board and in the sea, such as fish aggregating devices-FADs (Schmith, 1959; Valdemarsen, 2001).

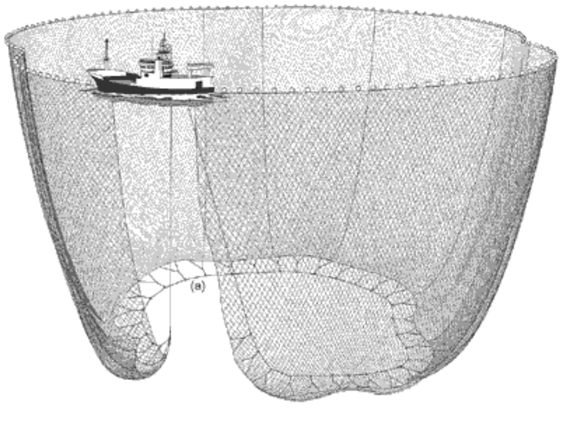

Figure 1.6. Purse seining vessel surrounding a school of fish.
Source: http://www.eurocbc.org/page371.html.

- Long lining. Vessels using long lining techniques can be used for surface or bottom fishing. In many cases the long line is left to drift in open sea until the fishermen consider that enough fish have been caught by means of the baited hooks that hang from it. These hooks are attached at intervals by means of a series of branch lines that are called *snoods*. Bottom long liners use leaded lines to make it sink to the seabed, while pelagic long liners, which usually target species such as swordfish, have floating devices to guarantee the buoyancy of the line (Bjordal and Løkkeborg, 1996).
- Trawling. Trawling is a fishing method that developed in Galicia in the late 19th century. This method consists of a net that is towed by the fishing vessel to collect marine organisms (Figure 1.7). The net is attached to the deck of the vessel by long resistant ropes (Fyson, 1980). The mouth of the trawl is usually maintained open during the towing process thanks to a pair of otter boards (Figure 1.8). There are a wide range of trawl nets of different designs made of a variety of materials. However, they can be divided into three different categories depending on the section of the water column that they target: surface, midwater and bottom (Valdemarsen, 2001). In the Galician fishing fleet trawl nets are mainly used as demersal gears to capture bottom-dwelling species.

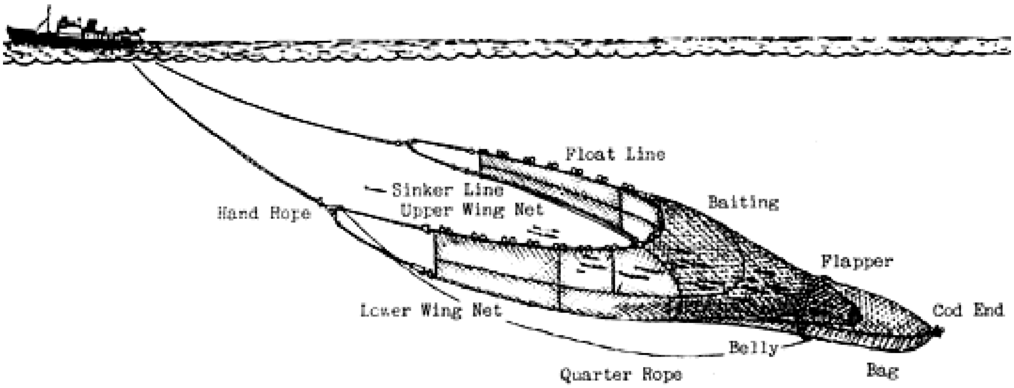

Figure 1.7. Fishing vessel towing a trawl net. The trawl net includes a schematic breakdown.
Source: Amita Company (1999).

Figure 1.8. Otter boards on trawling vessels at the port of Celeiro (Galicia).
Source: Norman Rowe.

- Trolling. Trolling is a Galician fishing technique that is limited to the bonito season (June to early October approximately). Its use is also limited to a reduced number of vessels in some ports along the Cantabrian coast, such as Burela or Celeiro. This method is based on a series of baited fishing lines that drift behind the boat while the vessel is in movement. Some pelagic fish, such as albacore, are attracted by the bait and follow the vessel in schools (Fonteyne, 2001).

Main fisheries in the Galician fishing sector

Early fishing activities in Galicia were performed in the intra-mareal area on beaches and the rest of the coast line. Slowly, the increasing demand for seafood and the improvement and development of fishing techniques permitted a gradual expansion of fishing areas, first to coastal fisheries, within the Galician *rias* or within the continental platform, and finally to other fishing zones in the Atlantic

Ocean. Currently, Galician fishing fleets travel to several fisheries outside the Spanish EEZ (Table 1.1). A brief description regarding the different fishery areas is given below:

- Coastal artisanal fisheries. The artisanal fishing fleet in Galicia is still an important source of employment and economic revenue for small and medium ports along the Galician coast. Moreover, in 2008 they represented 85% of Galician fishing vessels and 5.7% of the landings (Table 1.1). The products obtained from these vessels are usually sold fresh for local or regional consumption (Molares and Freire, 2003; Villasante, 2009).
- Coastal industrial fisheries. Trawling, purse seining and trolling fishing fleets have developed into important economic sectors in the Galician fishing sector. These fleets operate within the Spanish EEZ in Galician waters, following similar temporal patterns to the artisanal fleets, but with industrialized operational activities. Their products are more diversified, with parts of the catch going to bait, frozen seafood, fresh consumption or canning, depending on the time of the year and on the species.
- Northern Stock fisheries. The main species captured by the trawling and long lining fleets is hake. However, other medium and high value species, such as megrim (*Lepidorhombus spp.*), anglerfish (*Lophius spp.*) or Atlantic pomfret (*Brama brama*) are landed by vessels, mainly in the ports of Celeiro, Burela and Vigo. Most products are marketed fresh or frozen.
- Overseas fisheries. Overseas fisheries with Galician fishing fleets include the NAFO area, off the coast of Newfoundland, hake fisheries in South America and Namibia, tuna fisheries in the South-Atlantic, Indian and Pacific oceans, and fisheries in the EEZ of some African nations, thanks to agreements subscribed with these countries by the EU. Most of these fishing fleets do not land their products directly in Galician ports. Usually, the products are landed in convenience ports and then they are freighted by air or cargo ship to the ports of A Coruña, Vigo or Marín. With the exception of octopus and other cephalopods arriving from the Mauritanian EEZ, which in some cases are transported by aeroplane to Spain or other European countries for fresh consumption, most of the products from these fisheries are used in the canning industry (e.g. tuna) or are marketed frozen (e.g. hake) or as elaborate multi-ingredient products (e.g. fish sticks or *surimi*).

1.3.4. The processing industry linked to fishing

A total of 66 industries in Galicia performed activities linked to on land seafood processing, including freezing and canning industries, in 2009. These represent 44.9% of the total amount of industries in this sector in Spain, as well as 77.7% of the labour force. In fact, fish processing in Galicia accounts for approximately 2% of the GDP and 6.5% of the industrial labour force (ANFACO, 2010). Approximately one third of the seafood processed in this region is exported, accounting for 355 million euros. Therefore, this subsector represents a highly diversified sector, with important commercial links with neighbouring countries, mainly Italy, France and Portugal, and countries such as the US or Mexico (ANFACO, 2010).

Nevertheless, it is important to highlight the high annual consumption per capita of processed seafood products in Spain, roughly 4 kg, according to the Spanish government, which explains why Spain, despite its strong seafood processing sector, has to import a wide range of products from abroad, as can be observed in Table 1.4.

Table 1.4. Spanish imports of seafood per type of product in 2009.
Source: ANFACO (2010).

Seafood products	Volume (t/year)	Economic value (€/year)	Average price (€/kg)
Fresh fish	222,554	766,925	3.45
Frozen fish	340,270	563,369	1.66
Fish filets	188,563	502,739	2.67
Dried, salted or smoked fish	46,393	196,484	4.24
Crustaceans	192,859	898,523	4.66
Molluscs	330,853	743,549	2.25
Canned and other processed products	163,201	515,369	3.16
Total fish products	1,484,693	4,186,958	2.82

1.4. Fish consumption and distribution in Galicia and Spain

Fish consumption in Spain has historically been high with respect to other European nations, only second to other countries with a strong fishing tradition, such as Norway, Iceland or Portugal, as can be seen in Table 1.5. Furthermore, consumption in Spain increased greatly throughout the 19th and 20th centuries (Table 1.6), reaching an average per capita consumption of 40 kg in 2007. This justifies the fact that Spain cannot supply domestic demand exclusively with the seafood landing performed by its national fleet, explaining why it is the third largest world importer of seafood and why aquaculture development in Spain in recent decades has been high (Martín-Cerdeño, 2010).

Table 1.5. Seafood consumption per capita in the EU (2007).
Source: FAOSTAT (2011).

Country	Consumption per capita (kg/year)	Country	Consumption per capita (kg/year)
Portugal	54.82	Netherlands	19.02
Spain	40.03	Estonia	16.39
Lithuania	37.55	Germany	14.80
France	34.79	Austria	13.36
Finland	31.71	Latvia	12.59
Malta	30.18	Czech Republic	10.41
Sweden	28.50	Poland	9.54
Luxembourg	27.78	Slovenia	9.38
Denmark	24.53	Slovakia	8.03
Belgium	24.48	Romania	5.26
Italy	24.40	Bulgaria	4.20
Cyprus	22.59	Hungary	N/Av
Ireland	21.35	EU (average)	22.03
Greece	21.09	Iceland	87.40
United Kingdom	20.35	Norway	51.43

N/Av= not available.

Table 1.6. Seafood consumption per capita in Spain (1858-2007 period).
Source: Piquero-Zarauz and López-Losa (2005).

Period	Consumption per capita (kg/year)	Per capita consumption growth (%)
1858-1867	5.97	--
1883-1892	6.24	+4.52%
1908-1917	7.48	+19.87%
1918-1927	15.00	+100.53%
1928-1934	13.90	-7.33%
1939-1948	17.72	+27.48%
1949-1959	20.10	+13.43%
1960-1975	28.96	+44.08%
1976-1985	31.43	+8.53%
1986-2001	34.64	+10.20%
2007	40.03	+15.56%

In 2009, a total of 1,580 million kilograms of seafood were consumed in Spain (Table 1.7). This sum represented an economic output of approximately 11,000 million euros. Most of the seafood consumed in Spain (80%) corresponded to households, while 16% of the consumption corresponded to restaurants and bars. Finally, 4% was consumed in other locations, such as gastronomic venues, school canteens, governmental premises, etc (Martín-Cerdeño, 2010). In fact, according to the Regulation and Organization Fund for the Fish and Marine Cultures Market (FROM), an organization dependent of the Ministry for Environment, Rural and Marine Affairs (MARM), fish is consumed on average 1.88 times per week in school canteens (FROM, 2010). Furthermore, these statistics reflect that out-of-home consumption of seafood has increased in the last few years due mainly to the increased presence of women in the labour force and to *migration from rural to urban areast*, shifting food consumption patterns. Therefore, Spanish households tend to spend less time cooking during working days, reducing the amount of seafood in the shopping cart (MARM, 2000). At the same time, the higher income in Spanish households, and the increase of gastronomic tourism in Spain, with foreigners eager to taste traditional dishes, has helped to maintain the consumption of high price value fish and shellfish species in the Spanish market (Millán, 2002).

Table 1.7. Seafood consumption in Spain in 2009 (thousands of tonnes).
Source: Martín-Cerdeño (2010).

Seafood products	Total consumption
Fresh fish	627.3
Frozen fish	278.8
Fresh shellfish	252.0
Frozen or boiled shellfish	199.7
Canned fish or molluscs	223.4
Total fish products	1,580.2

Higher income households consume more seafood than lower class households. In fact, notable differences are observed regarding the consumed species. Therefore, households with high income consume important quantities of tuna, sea bass, turbot, anglerfish, octopus, shrimps or salmon, all of which are considered high or medium price species. Medium income households show similar consumption patterns to the average Spanish pattern (Table 1.8), with high consumptions of octopus, hake and mackerel. Finally, low income families tend to consume important amounts of fresh mackerel, frozen octopus and sole, while their consumption of high value species such as sea bass, turbot or anglerfish is very low (Martín-Cerdeño, 2010).

Table 1.8. Seafood consumption per capita in Spain (year 2009).
Source: Martín-Cerdeño (2010).

Seafood products	Consumption per capita (kg/year)
Fresh fish	12.2
Frozen fish	3.1
Fresh shellfish	4.8
Frozen shellfish	2.7
Boiled shellfish	0.7
Canned fish or molluscs	4.0
Total seafood products	27.6

Seafood species	Consumption per capita (kg/year)
Hake	3.9
Tuna	2.6
Sardines	2.1
Squid and octopus	1.9
Mussels	1.3
Sole	1.1
Cod	0.7
Mackerel	0.5
Anglerfish	0.5
Other species	13.0
Total seafood products	27.6

In Galicia seafood consumption is approximately 111g/person/day, 29.1% more than the second autonomous community (Cantabria; 86 g/person/day) (Varela-Mosquera and Moreiras-Tuny, 2008). In fact, a gradual cline in seafood consumption is observed in Spain between the Atlantic and Mediterranean coasts. Therefore, it is common to refer to two different concepts, the Atlantic diet and the Mediterranean diet, even though they have not been defined as two opposing concepts. In fact, some studies argue that the differences between both diets are low and are mainly linked to certain cultural diversities and crop production availability (Barroso and Grande, 2003). While the Mediterranean diet is rich in fish, vegetal oils, meat and fruit, the Atlantic diet is considered to have a higher dose of fish and shellfish products, dairy products and vegetables, as well as a higher dose of locally consumed products, mainly due to the rural characteristics of NW Spain (Barroso and Grande, 2003).

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Chapter 2

Environmental management tools. Application to the seafood sector[1]

Summary

This chapter analyses the current importance of environmental sustainability and its development into a varied set of environmental management tools, in order to monitor the environmental impacts of human activities. Given the use of a life-cycle perspective to evaluate the environmental performance of products, processes and services nowadays, Life cycle assessment (LCA), a standardized technique for assessing the environmental aspects and potential impacts associated with a product by compiling an inventory of relevant inputs and outputs of the product system, evaluating the potential environmental impacts associated with those inputs and outputs and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study, is presented as the main environmental management tool that will be used in this dissertation. Furthermore, the application of LCA in seafood systems is discussed, pointing out its advantages, limitations and recent improvements in the methodology. Finally, section 2.5 synthesizes the objectives of this thesis and describes its structure.

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[1] Vázquez-Rowe, I., Hospido, A., Moreira M.T., Feijoo, G., 2011. "Review: Best practices in Life Cycle Assessment implementation in fisheries: improving and broadening environmental assessment for seafood production systems". *Trends in Food Science & Technology,* (under review)

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2.1. Sustainable development

Environmental sustainability is a relatively recent concept that goes back to the 1950s, when increasing concern in the scientific community regarding the quality of the environment started. In fact, in 1956 The Challenge of Man's Future (Brown, 1956) was published, alerting of the benefits, but also the risks of industrializing the underdeveloped areas of the world. By the 1960s the publication of Silent Spring (Carson, 1962) led to the widespread introduction of the environmental movement, mainly in the US, warning of the effects of the undocumented use of pesticides on the environment. In the following decade, a few more books were published with the aim of instructing the population on new specific environmental concerns, such as Population Bomb (Ehrlinch, 1968), focusing on overpopulation of our planet, or The limits of growth (Meadows et al., 1972), which analysed the disequilibrium between the Earth's and human systems.

Towards the end of the 1960s, the first environmental sustainability institutions were created in North America, due to frontier tensions regarding acid rain between Canada and the United States. As a result, the National Environment Policy Act was passed by the US Congress in 1969, giving birth a year later to the Environment Protection Agency (EPA). Also in 1970 Environment Canada was founded. In 1972 the Stockholm Conference took environmental sustainability issues a step further, since for the first time it was seen as a global concern. More specifically, in this conference developed nations manifested their fear that further economic growth could trigger negative consequences for the environment (Baylis and Smith, 2005).

Throughout the 1970s environmental awareness and interest regarding environmental sustainability grew thanks, in part to the two fuel crises and the confirmation, in 1970s and 1980s, that the ozone layer depletion process was a reality requiring an urgent solution (Barsky and Kilian, 2004; Farman et al., 1985).

In 1983, the United Nations (UN) created the World Commission on Environment and Development (WCED), with the aim of addressing growing concerns linked to the "deterioration of the human environment and natural resources", as well as the consequences that these factors would have on economic and social development (Figure 2.1). The creation of this commission was a milestone in itself, given that it was the first time that a worldwide institution had recognized environmental impacts on a global scale. By 1987, the WCED had released what was known as the

Brundtland Report, since Gro Harlem Brundtland, a Norwegian socialdemocrat, chaired the WCED. This report presented the concept of sustainable development, which they defined as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". More specifically, the report synthesised the concept of sustainability in five major ideas (WCED, 1987):

- Future needs should not be put in danger based on present demands.
- The integrity of natural systems is the basis for the future of the economy.
- The needs of many human populations, especially those that are poorest, are currently not being met, which proves that the world system is not sustainable.
- The welfare and economy of poor individuals must be improved in order to protect the environment.
- Future generations have the right to take their own decisions in order to meet their own needs. Therefore, preservation of current natural systems must be a priority.

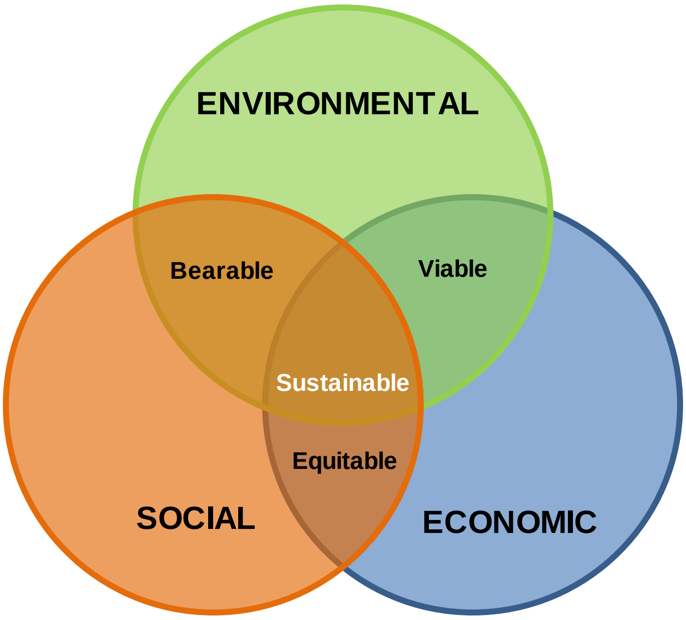

Figure 2.1. Schematic representation of the three dimensions of sustainable development.
Source: Adams (2006).

Parallel to the rise of the *Brundtland Report*, the Vienna Convention (1985) and the Montreal Protocol (1987) regulated a gradual, but thorough phase out of chlorofluorocarbons (CFCs), in order to reduce the environmental impact that human activities were exerting on the ozone layer. The main outcome of the *Brundtland Report* was visible in the United Nations Conference on Environment and Development (UNCED) in 1992, known as the Rio Earth Summit. One of the main objectives of this summit was the development of *Agenda 21,* an ambitious plan to educate the population concerning the risks of not attaining sustainable development in the near future. At the same time, widespread awareness concerning global warming and its influence on climate change started to arise thanks to scientific consensus achieved in the 1980s on this issue. In fact, since the Intergovernmental Panel on Climate Change (IPCC) was established in 1988, periodical updates on global warming, as well as its expected effects on the environment and human activities have been published in order to provide worldwide understanding of this phenomenon (IPCC, 2007). This scenario gave rise, after long negotiations, to the Kyoto Protocol, currently in force, in order to control and reduce, whenever possible, the greenhouse gas (GHG) emissions of signing nations (Houghton, 2004). Furthermore, the publication of the Stern Review in 2006, focusing on the economic costs of global warming, has increased the interest of citizens, authorities and companies in understanding the causes and consequences of global warming and obtaining pathways to reduce anthropogenic emissions (Stern, 2006).

While the mentioned environmental issues only represent a small picture of environmental impacts caused by humans on a global scale, ozone layer depletion and global warming represent two of the most widespread issues owing to their worldwide implications. Nevertheless, these two examples prove that current economic, social and operational patterns must be modified in order to achieve sustainable development. To do so, sustainability implies that human activities should only use nature's resources at rates that do not threaten their depletion, that is, at rates at which they can be replenished naturally. Following this perspective, a wide set of environmental management tools have been developed in recent years with the aim of better understanding the impacts that are caused on natural environments and, consequently, minimizing the environmental burdens associated with a given product, process or service (Feijoo et al., 2007).

2.2. Environmental management tools

Environmental management focuses on analysing human activities that are linked to impacts on the natural environment. The main advantages of using environmental management are linked to reducing environmental risks, improvement of public image and increase in business opportunities, legislative compliance or economic savings (Andersson, 1998). Hence, the use of environmental management tools has the main objective of analysing the environmental impacts of companies, organizations, institutions, etc, in order to facilitate the improvement of their environmental performance. In recent decades, there has been a strong proliferation of environmental management tools (Table 2.1). Most of these have adopted the concept of *life-cycle* in their definition, since current scientific consensus adopts a system approach to consider the entire life cycle of activities or products when analysing their environmental impacts.

Table 2.1. Selection of environmental decision tools.

Environmental management system	Acronym
Cost Benefit Analysis	CBA
Cumulative Energy Requirement Analysis	CERA
Environmental Impact Assessment	EIA
Environmental Risk Assessment	ERA
Input-Ouput Analysis	IOA
Life Cycle Assessment	LCA
Life Cycle Screening	LCS
Life Cycle Costing	LCC
Material, Energy and Toxic-analysis	MET
Material Input per Service Unit	MIPS
Design for the Environment	DfE
Environmental Auditing	EA
Environmental Performance Evaluation	EPE
Material Flow Accounting	MFA
Material Intensity Analysis	MIA

Impacts regarding all life cycle stages need to be taken into account when evaluating the production and consumption patterns of a product or process. Therefore, the use of life cycle assessment (LCA) appears as an appropriate environmental management tool to implement in a wide variety of products, as well as a widely accepted tool in the scientific community.

2.2.1. Life cycle assessment

LCA is an internationally standardized technique useful for assessing the environmental aspects and potential impacts associated with a product by compiling an inventory of relevant inputs and outputs of the product system, evaluating the potential environmental impacts associated with those inputs and outputs and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study (ISO 2006a, 2006b). LCA analyzes the entire life cycle of the product or service under study, including all stages through raw material extraction and processing, transportation, manufacture, retailing, wholesaling and other distribution stages, use or consumption, re-use, recycling and final disposal. When a particular study covers all these stages of assessment, the study is said to have a cradle to grave perspective. However, most studies do not cover such a wide span of phases, using cradle to gate or gate, gate to cradle or gate to gate approaches. A variety of applications exist in which LCA can be a useful methodology. These can be summarized in four major points:

- The identification of a series of opportunities to improve the environmental profile of products or services in a given stage or stages of their life cycle.
- The selection of important indicators for identifying the environmental performance.
- Give out information to decision-makers in a wide range of institutions, including governments, businesses, non-government organizations or research units, with the aim of influencing, if necessary on strategic planning, priority setting or process design.
- Marketing purposes, such as introducing eco-labelling for a specific product or in order to provide environmental product declarations.

A total of 4 stages can be distinguished in LCA methodology: (i) identifying the context of the study, its benefits and its limitations; (ii) collecting inventory data for significant energy and material inputs; (iii) evaluating the potential environmental impacts linked to the included inputs/outputs and, finally; (iv) interpreting the results obtained. All these stages will be explained in detail at the end of this section.

Goal and scope definition

The goal and scope of an LCA has to be clearly stated at the beginning of the study and must show consistency with the intended application. Given the iterative nature of LCA, the scope may suffer alterations during the study in order to improve the quality of the analysis or due to other issues, such as unpredicted limitations and constraints. More specifically, when defining the goal of an LCA, a series of broad objectives need to be explained. These include the intended application of the study, the main reasons that have given rise to the analysis and the potential audience that may be interested in obtaining information relating to the specific assessment under study. Concerning the scope of an LCA study, a broad selection of points must be listed and explained with as much detail as is considered appropriate (Table 2.2).

Table 2.2. Important terms and their definitions in LCA.
Source: ISO 14044 (2006).

Item	Definition
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, which models the life cycle of a product.
Functions of the product system	Performance characteristics of the selected system.
Functional unit (FU)	Quantified performance of a product system for use as a reference unit.
System boundaries	Set of criteria specifying which unit processes are part of a product system
Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems
LCIA methodology and types of impacts	The selection of impact categories, category indicators and characterization models included within the LCA study and their implementation.
Interpretation	Final phase of the LCA procedure, where results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.
Assumptions	Facts or states taken for granted in LCA thinking.
Data quality requirements	Characteristics of data that relate to their ability to satisfy stated requirements.

LCI= life cycle inventory; LCIA= life cycle impact assessment.

Out of the broad list observed in Table 2.2, two specific items, functional unit (FU) and system boundaries deserve further attention. On the one hand, the scope of the selected study must specify the performance characteristics (functions) of the system under study. In this context, the FU has to provide a reference to which the input and output data can be normalized (in a mathematical sense). Therefore, the FU should be clearly defined and easy to measure and reproduce. Moreover, it should be consistent with the goal and scope defined for the study.

On the other hand, the system boundary details which unit processes are included or left out of the LCA analysis. The criteria applied when establishing the system boundary have to be identified and explained. Additionally, the level of detail with which the included unit processes will be studied needs to be discussed. Decisions to omit life cycle stages, processes, inputs or outputs, are accepted as long as they are clearly identifiable in the text and their exclusion is linked to a valid and supportable rationale.

Finally, one other feature that must be treated with care is the data quality requirements. These must be specified to enable the goal and scope of the LCA to be met. Data quality requirements should address the items listed in Table 2.3.

Table 2.3. Data quality requirements in LCA.
Source: ISO 14044 (2006).

Item	Definition
Time-related coverage	Age of data and the minimum length of time over which data should be collected.
Geographical coverage	Geographical area from which data for unit processes should be collected to satisfy the goal of the study.
Technology coverage	Specific technology or technology mix.
Precision	Measure of the variability of the data values for each data expressed.
Completeness	Percentage of flow that is measured or estimated.
Representativeness	Qualitative assessment of the degree to which the data set reflects the true population of interest.
Consistency	Qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis.
Reproducibility	Qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study.
Sources of data	Origin of the data obtained for the inventory.
Uncertainty	Data, models and assumptions.

Inventory analysis

The definition of the goal and scope of a study, as seen above, provides practitioners with an initial plan for conducting the life cycle inventory phase of the analysis. Whenever the plan for the life cycle inventory (LCI) analysis is executed, a set of operational steps should be conducted:

- Data collection. Qualitative and quantitative data must be included in the inventory. This applies to each unit process that is included within the system boundaries. Collected data, regardless of the method implemented to obtain this information (measurement, calculation or estimation) are then used to quantify the inputs and outputs of a unit process. Data collected from public sources must be correctly referenced in the analysis.
- Data calculation. Calculation procedures must be explicitly documented and should be consistent throughout the study. Any assumptions that have been made have to be explained in detail.
- Allocation. Inputs and outputs obtained through data collection have to be allocated to different products according to clearly stated procedures. These procedures must be well documented and discussed whenever the allocation procedure is explained. The sum of the allocated inputs and outputs of a unit process must be equal to the inputs and outputs of the unit process before allocation. If several alternative allocation procedures can be applied to the same production system, an extended recommendation is to conduct a sensitivity analysis to exemplify how decision making in allocation can affect the final results. Further discussion on allocation is presented in section 2.4.3.

Impact assessment

According to ISO 14044 (2006), the life cycle impact assessment phase (LCIA) is the stage of LCA that aims at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

This phase needs to be structured and planned carefully in order to achieve the selected goal and scope of a particular LCA study. Moreover, given the fact that the possible omissions or sources of uncertainty are unavoidable in this type of studies, the LCIA phase must be correctly coordinated with other phases of the methodology:

- The data quality of the LCI need to be robust in order for it to be sufficient to perform an LCIA which is in accordance with the defined goal and scope.
- System boundary and intended data omissions must be analysed thoroughly in order to guarantee the availability of LCI results to compute the selected indicators in the LCIA.
- Issues such as FU or allocation may enhance or decrease the environmental relevance of the achieved LCIA results.

LCIA involves the collection of certain indicator results for the different impact categories implemented in a particular study, representing the LCIA profile for the product system. In this sense, LCIA is composed of a set of mandatory and optional elements, as detailed in Table 2.4.

Table 2.4. Mandatory and optional requirements in life cycle impact assessment.
Source. ISO 14044 (2006).

Mandatory elements	
Item	**Definition**
Selection of impact categories	Must be justified and consistent with the goal and scope of the LCA, and should reflect a comprehensive set of environmental issues related to the product system being studied.
Classification	Assignment of LCI results to the selected impact categories.
Characterization	Conversion of LCI results to common units and the aggregation of the converted results within the same impact category,
Optional elements	
Item	**Definition**
Normalization	Calculating the magnitude of category indicator results relative to reference information.
Grouping	Sorting and possibly ranking of the impact categories.
Weighting	Converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices. Data prior to weighting should remain available.
Data quality analysis	Better understanding the reliability of the collection of indicator results, the LCIA profile.

Interpretation

Life cycle interpretation consists of, but is not limited, to the identification of significant issues based on the findings in the LCI and LCIA phases, an analysis that takes into account the completeness, sensitivity and consistency of the results obtained and any conclusions, limitations or recommendations that can be extracted from the final values observed.

2.3. Life cycle assessment for seafood products

As mentioned in Chapter 1, the current international scenario, in which worldwide seafood demand is maintained based on increasing the potential hazards on populations and ecosystems (especially those that are marine), has led to the development of environmental assessment methodologies as important mechanisms to evaluate and supervise the environmental performance of fishing activities.

More specifically, previous LCA publications relating to fishing systems and to their derived industry and supply chains have proved that LCA provides a standardized and relevant methodology for the environmental analysis of these fishing systems (Pelletier et al., 2007). Despite its original development to assess industrial production systems, its use in food production systems, including seafood production systems, has increased notably in recent years (Andersson, 2000), thanks to a set of methodological adaptations that have been included for the study of seafood extraction or production.

However, it is also important to highlight that the efficacy of LCA in covering the wide range of environmental impacts that are potentially linked to fishing presents certain limitations, since many direct impacts on fishing stocks cannot be assessed without further development of the methodology (Hospido and Tyedmers, 2005; Pelletier et al., 2007).

2.3.1. LCA studies of worldwide fisheries

A wide range of published LCA studies have analysed the environmental characterization of fisheries and their associated industrial processes. In the first stage of seafood LCA, in which fisheries LCA studies started to arise, the number of fisheries and species analysed was considerably low, focusing mainly on trawling and purse seining fleets that captured high and medium economic value fishing species, such as cod, flatfish or tuna (Eyjolfsdottir et al., 2003; Ziegler et al., 2003; Thrane, 2004; Hospido and Tyedmers, 2005). Recent studies, however, have widened the scope of the assessed species and amplified the range of fishing vessel types and fisheries included in LCA evaluation.

Regarding fishing fleets, environmental characterization studies for long liners (Svanes et al., 2011a), artisanal fleets (Ziegler et al., 2011) and creels (Ziegler and Valentinsson, 2008) have been some of the novel fleets assessed, while new trawling and purse seining assessments have also been performed (Ramos et al., 2010).

The main species that have been assessed in these studies corresponded to small pelagic fish, such as mackerel and herring (Thrane, 2004); crustaceans, such as Norway lobster or pink shrimp (Ziegler and Valentinsson, 2008; Ziegler et al., 2011) or gadoids, such as hake, Pollock or cod (Sund, 2009; Ramos et al., 2010, 2011; Svanes et al. 2011a).

2.3.2. Environmental assessment of seafood processing

Despite the varied amounts of products that are processed for human consumption, the amount of LCA studies linked with this particular phase of the life cycle of seafood products is still low. Additionally, it is sometimes difficult to detect the complete processing chain, due to the fact that many seafood products are partially processed on board fishing vessels (Fet et al., 2010). Therefore, the environmental impacts linked to certain processing activities, usually in industrial fleets (i.e. freezer trawlers), are reported as part of the fishery phase. Moreover, it is also important to consider the different degrees of complexity in seafood processing. For instance, fish preparation for fresh consumption undergoes basic preparation activities, such as cleaning and gutting, while canned seafood products or manufactured seafood products such as *fish fingers*, pass through complex processing phases.

Thrane (2004) analysed three frozen seafood products (cod, mussels and shrimps), pickled herring and canned mackerel, following MECO analysis, a simplified LCA assessment focusing on material exchange. Additionally, other frozen seafood products, such as frozen cod from the Canadian, Icelandic and Swedish fisheries, have been analysed from a life cycle perspective, (Fulton, 2010; Ziegler et al., 2003). Canned seafood products that have undergone LCA analysis include tuna (Hospido et al., 2006) and mussels (Iribarren et al., 2010), both of which assessed all post-landing stages of the seafood up to consumption in households. Finally, Fikseaunet (2007) analysed the production of fish sticks in China, Norway and the UK for consumption in Norway, constituting the first assessment of the production chain of a complex multi-ingredient manufactured product.

2.3.3. LCA of fish-containing meals and diets

Seafood constitutes a group of products that have not been fully introduced in publications relating to diets and meals, due to the fact that seafood is not a key ingredient in the diet of many countries and also to the limited amount of publications relating to these food products with respect to beverages or meat. Nevertheless, in recent years a series of articles have included fish products in the assessment of diets and meals.

Muñoz et al. (2010) included in their analysis of the Spanish diet a wide range of fish and other seafood products that were available in literature at the time, such as tuna, salmon and mussels (Hospido and Tyedmers, 2005; Hospido et al., 2006; Ayer and Tyedmers, 2009; Iribarren et al., 2010). Nilsson and Sonesson (2010) also analysed the influence of food consumption on GHG emissions in Sweden, by comparing current consumption patterns to those recommended by the Swedish National Food Administration, based on the daily food intake. According to this organization, the Swedish population consumes 14% more fish than strictly necessary. Reductions in consumption patterns to target values would results in a 0.17 million tonne annual reduction in GHG emissions. Results from this study support previous research performed by Carlsson-Kanyama et al. (2003), which identified high improvement potential for energy efficiency in the Swedish diet. This particular study included the analysis of several fish and crustacean products. Finally, Wolf et al. (2011) took into account a series of canned, fresh and frozen fish products when analysing the GHG emissions in changing European diets.

Concerning specific meals, Zufía and Arana (2008) assessed the environmental impacts linked to a prepared dish of pasteurized tuna with tomato, with the aim of providing potential environmental impact reductions through process modifications and eco-design.

2.3.4. Eco-labelling

Eco-labels are labelling systems for a wide range of products, including food and consumer products. Both systems were started by NGOs, but nowadays the European Union has legislation for the rules of eco-labelling and also has its own eco-labels, one for food and one for consumer products. Their objective is to provide information to consumers and stakeholders regarding sustainability whenever acquiring products. However, it is important to take into account that eco-labels are usually not substitutable, since they quantify different environmental dimensions. For instance, some of them measure energy consumption through index scores or units of measurement, while others may perform more integrated sustainability analysis. Finally, another interesting feature that varies between eco-labels is the standards that they require. Some of these labels will actually report a measured value or unit to provide the consumer with additional, more specific information. Others only assert compliance with certain requirements that have been demanded for sustainable certification (Thrane et al., 2009). Within the seafood sector, numerous eco-labels have arisen for sustainable certification in recent years, as can be observed in Table 2.5.

Table 2.5. Selected eco-labels for fishing products and their objectives.

Label	Objectives
Beluga	To improve life quality promoting environmental conservation and ecologically sustainable development.
Dolphin Safe	To monitor tuna stakeholders throughout world oceans to guarantee that tuna is caught by methods that do not threaten dolphins and protect the marine ecosystem.
Friend of the Sea	This eco-label requires target stocks to generate a maximum of 8% discards, avoid by-catch of endangered species, have no impact on the seabed, compliance with international regulations (TAC, IUU, minimum size, etc), social accountability, a gradual reduction of the carbon footprint and guarantee that stocks are not being overexploited.
KRAV	KRAV evaluates whether fishing is carried out on stocks that are within biologically safe limits, whether the equipment is selective and whether target species contain abnormal levels of environmental toxins.
Marine Stewardship Council (MSC)	The MSC fisheries standard has 3 principles that every fishery must prove that it meets: ➢ Sustainable fish stocks. Fishing activity must be at a level which is sustainable for the fish population. Certified fisheries must guarantee that fishing can continue indefinitely and that stocks are not overexploited. ➢ Environmental impact minimization. Fishing operations should be managed to maintain the structure, productivity, function and diversity of the ecosystem. ➢ Effective management. The fishery must meet all local, national and international laws and must have a management system to respond to changing circumstances and maintain sustainability.
Seachoice	To raise consumer awareness regarding the importance of buying seafood from sustainable sources.
Seafood Safe	Intended for seafood companies, retailers or restaurants whose seafood contains safe consumption levels of mercury and PCBs.

TAC= total allowable catch; IUU= illegal, unregulated and underreported fishing.

However, the fact that the different eco-labels included in Table 2.5 are used within different analyses and criteria approaches to report the sustainability of fishing systems leads to a scenario where caution is needed when interpreting their meaning. For instance, two widely used eco-labels, which have gained international recognition, are the ones provided by the Marine Stewardship Council (MSC) and Dolphin Safe. However, these two labels only focus on the fishing stage of the evaluated products. Furthermore, they both focus on fishery-specific issues, MSC assessing the overexploitation of a given fishery and Dolphin Safe performing surveillance to verify that tuna fisheries are extracting fish without putting at risk dolphin and other marine mammal populations (Thrane et al., 2009). Therefore, while these two eco-labels succeed in informing consumers of the benefits of consuming seafood products that are being correctly managed from two specific fishery management issues, they lack an integrated overview of other environmental issues that can imply a potential hazard, not only to marine organism ecosystems, but to a wider range of environmental impacts.

In fact, LCA studies have shown the importance of other stages of the seafood supply chain, as well as highlighting that, even though stock assessment is a key issue when it comes to guaranteeing the correct exploitation of a fishery, other environmental burdens, linked to resource utilization and emissions can also be important factors in the fishing stage. Consequently, a future challenge within the fishing/seafood sector and the environmental management sector will be to develop attractive eco-labels on an international scale (or adapt existing ones) able to include a wide range of criteria that allows an integrated analysis of fishing systems.

2.4. Methodological assumptions in seafood LCA studies

2.4.1 Attributional or consequential LCA perspective.

The selection of one of these approaches in LCA is usually based on the goals of the case under study (Thrane, 2004; Fulton, 2010). The use of consequential analysis in fishery LCA studies was limited to a small number of case studies. For instance, its use in Danish fisheries was aimed at determining whether certain decision making would imply a change in the life cycle of the flatfish fishery (Thrane, 2004). However, the consequential approach in LCA shows high levels of uncertainty when predicting the future consequences of a change (Ekvall, 2002). Furthermore, fisheries systems, strongly influenced by important stock abundance fluctuations, periodic changes in fishing management policies or quota limitations in order to achieve sustainability of an increasingly overexploited product, may show increased unpredictable variations with respect to other more industrialized systems (Fréon et al., 2008; Driscoll and Tyedmers, 2010).

Additionally, considering the relatively low number of fishery LCA studies that have been performed to date, it is not surprising that most studies have based their assumptions on a more descriptive, and therefore, current state of the art, using the retrospective (attributional) approach. Finally, it is important to note that result interpretation for the two approaches may be substantially different due to the differing perspectives regarding system boundaries and co-product allocation.

2.4.2. Functional unit and system boundaries.

The selected FU in a particular case study was found to be highly dependent on the nature of the project and its aims and goals. Therefore, FU choice was directly dependent on the system boundaries considered in terms of included and excluded processes. For instance, LCA studies that limited their scope to the landing of the catch at a given port showed, in general terms, less elaborate FUs, referring to bulk landings at port in some cases (Hospido and Tyedmers, 2005), and to intermediate supply chain packaging units whenever basic fish processing activities were developed on board (Ziegler et al., 2011). In the first case, some case studies referred to the total mass of landed catch independently of the nature of the captured species, named global functional unit by Svanes et al. (2011b), which is usually based on an integrated fishing fleet approach (no co-product allocation needed), while other studies suggested an allocation approach in order to focus on a specific species (Ziegler et al., 2011). In contrast, those case studies focusing on the entire supply chain of the fish products presented highly specific FUs, referring usually to final package fish product presentations ready for consumption, in the case of processed products (Fikseaunet, 2007; Thrane, 2004; Zufía and Arana, 2008), or, as will be seen in Chapter 5, to standard consumption portions in the case of fresh consumption. Finally, other publications related to fisheries LCA, such as diet LCAs, where reporting the environmental assessment of fish was not the main aim of the study, reported a varied set of FUs depending on the nature of the project.

2.4.3. Allocation procedures

Allocation has proved to be a key feature in fisheries LCA, since it may affect all the stages of the supply chain, including the fishing phase, due to the multispecies characteristics of most fisheries (Ayer et al., 2007). Moreover, increasing debate relating to allocation has arisen recently given the strong repercussion that allocation-based decisions have on results (Pelletier and Tyedmers, 2011).

Initial allocation patterns in fisheries LCA (Table 2.6) were based on two alternatives: (i) mass allocation, applied in many fisheries where the economic value of the multiple species caught was found to be similar (Eyjolfsdottir et al., 2003), and (ii) economic allocation, which implies an economic value assigned to the different co-products based on the assumption that the economic value itself argues in favour of the existence of the particular system (Pelletier and Tyedmers, 2011; Tillman, 2000). However, recent debates on allocation procedures have slowly shifted towards a more critical vision regarding economic allocation, due to its volatility with respect to other alternatives and to the misleading results that can derive from this approach, assuming that lower value species perform in a more sustainable way within a unique biophysical system.

Table 2.6. Methodological assumptions in selected seafood LCA studies.

Authors	LCA perspective	LCA method	FU	Allocation
		Year 2003		
Eyjólfsdóttir et al.	Att.	Eco-Indicator 99	9 kg frozen cod fillet	Mass
Ziegler et al.	Att.	CML Baseline	400 g frozen cod fillets	Economic
		Year 2004		
Thrane	Consq.	EDIP	1 kg of flatfish-based products	System expansion[1]
		Year 2005		
Hospido and Tyedmers	Att.	CML	1 tonne of tuna	Mass
		Year 2006		
Hospido et al.	Att.	CML	1 tonne of raw frozen tuna	Mass
		Year 2007		
Fikseaunet	Att.	CML/EI99	200 g fish sticks	Economic
		Year 2008		
Zufía and Arana	Att.	SO_2 PO_4^{3-}	2 kg tray meal	--

[1] System expansion was used for the fishing and processing stages. Economic allocation was applied for the use stage.

Table 2.6. Methodological assumptions in selected seafood LCA studies (cont.).

Authors	LCA perspective	LCA method	FU	Allocation
Year 2009				
Winther et al.	Att.	CML	1 kg delivered to wholesaler	Mass
Year 2010				
Fulton	Att.	IPCC 2007	1 kg filet	Mass
Muñoz et al.	Att.	CML	1 Spanish annual diet	--
Ramos et al.	Att.	CML	1 tonne of gutted cod	Mass
Year 2011				
Parker	Att.	CML	Varied. Consumer-oriented	Mass and energy
Svanes et al. (a)	Att.	CML	1 kg varied products	Mass, economic, hybrid and energy
Svanes et al. (b)	Att.	CML	1 kg product	Mass and economic
Ziegler et al.[2]	Att.	CML	1 kg frozen shrimp	Economic

[2] Ziegler et al. (2009), a FAO report on pink shrimp in Senegal, was not included in the discussion since it constitutes an extended version of Ziegler et al. (2011).

In this context, recent studies in the fishing sector have shown an increased use of mass allocation and, in an attempt to use a more specific and concise form of reporting environmental impacts in terms of human needs, new biophysical allocation approaches, such as energy density (Ayer et al., 2007; Parker, 2011), have been applied to fishery systems (Svanes et al., 2011b). However, the introduction of new biophysical allocation schemes may trigger a race to determine improved perspectives, which could lead to an atomization in LCA reporting and, therefore, as pointed out by Fulton (2010), a loss in credibility of the methodology. Nonetheless, most fisheries LCA practitioners agree on the need to provide deep and well-supported discussion on allocation selection in order to guarantee the transparency and reproducibility of studies (Ayer et al., 2009).

2.4.4. Impact category selection

An increase in the number of impact categories used in fisheries LCAs has been identified in recent years (Table 2.7), due to the inclusion of toxicity categories and the ozone layer depletion potential (ODP) category, due to findings that brought to light the significance of anti-fouling paint and refrigerant emissions in fisheries. Impact category selection strongly depends on the background and aims of each study. Consequently, in recent years a greater specialization in the type of papers has given rise to two trends within fisheries LCA: an exclusive focus on GHG emissions, which is reflected in the sole use of global warming potential (GWP) or carbon footprint (CF), or a greater interest in an integrated assessment of the fishery, using a wide set of commonly used LCA impact categories, while broadening towards new fishery-specific impact categories.

Table 2.7. Impact categories and category indicators employed in selected LCA research of seafood production systems.

Authors	EC	GWP	CF	ADP	AP	EP	ODP	POFP	CED	HTP	FETP	METP	TETP
Year 2003													
Eyjólfsdóttir et al[1].	X	X	--	--	X	X	X	--	--	X	Eco-toxicity potential		
Ziegler et al.	--	X	--	--	X	X	--	--	--	--	X		--
Year 2004													
Thrane[2]	X	X	--	--	X	X	X	X	--	--	Eco-toxicity potential		
Year 2005													
Hospido and Tyedmers	--	X	--	--	X	X	X	--	--	--	--	--	--
Year 2006													
Ellingsen and Aanondsen	X	X	--	X	X	X	--	--	--	X	Eco-toxicity potential		
Hospido et al.	--	X	--	X	X	X	X	X	--	--	--	--	--
Year 2007													
Fikseaunet	--	X	--	X	X	X	X	X	--	X	X	X	--
Pelletier et al.[3]	--	X	--	X	X	X	X	X	X	X	X	X	X
Ziegler and Valentinsson	--	X	--	X	X	X	X	X	--	--	--	X	--
Year 2008													
Zufía and Arana	--	X	--	X	X	X	X	--	--	X	Aquatic toxicity		X
Year 2009													
Sund	--	X	--	--	--	--	--	--	X	--	--	--	--
Winther et al.	--	--	X	--	--	--	--	--	X	--	--	--	--
Year 2010													
Fet et al.	--	X	--	--	--	--	--	--	--	--	--	--	--
Muñoz et al.	--	X	--	--	X	X	--	--	X	--	--	--	--
Nilsson and Sonesson	--	X	--	--	--	--	--	--	--	--	--	--	--
Ramos et al.	--	X	--	X	X	X	X	X	--	X	X	X	X
Year 2011													
Parker	--	X	--	--	X	X	X	--	X	--	--	--	--
Svanes et al. (a)	--	X	--	--	X	X	X	X	X	--	--	--	--
Svanes et al. (b)	--	X	--	--	X	X	X	X	X	--	--	--	--
Ziegler et al	--	X	--	X	X	X	X	X	X	X	--	X	X

EU= energy consumption; ADP= abiotic depletion potential; AP= acidification potential; EP= eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; POFP= photochemical oxidant formation potential; CED= cumulative energy demand; HTP= human toxicity potential; FETP= freshwater aquatic eco-toxicity potential; METP= marine aquatic eco-toxicity potential; TETP= terrestrial eco-toxicity potential; CF= carbon footprint.

[1] This report used the EcoIndicator 99 method for LCIA computation.

[2] This report used the EDIP 97 method for LCIA computation..

[3] Pelletier et al. listed the commonly used impact categories in seafood LCAs.

Hence, certain patterns predicted and/or recommended by Pelletier et al. (2007) have been accomplished in recent years, but many questions proposed in that review remain unanswered. For instance, the implementation of biotic resource use (BRU) has not had a widespread application in literature (Papatryphon et al., 2004; Parker, 2011), while further inclusion of fishery-specific indicators has been limited to including seafloor impact and discards values within the discussion. Finally, a final observation by Pelletier et al. (2007) suggested the use of local impact categories in fisheries (and aquaculture) to address specific ecosystem characteristics. Therefore, studies have experienced a moderate increase of biophysical approaches, not only from an impact category perspective, but also based on other methodological assumptions, such as allocation, while broader socio-economic and regional analysis factors remain major potential areas for future development (Pelletier et al., 2007).

2.5. Objectives and structure of the dissertation

The main aim of this doctoral thesis is to evaluate the environmental performance of the extractive fishing sector in Galicia through the application of LCA and other complementary tools. A schematic representation of the structure of the dissertation can be seen in Figure 2.2.

In the first place, Section I, which includes Chapters 1 and 2, focuses on discussing the framework which justifies the need of the current study from an environmental perspective, introducing the management tools that are used in the dissertation (LCA and CF), and from a fisheries point of view, highlighting the main concerns in fishing systems nowadays, as well as their associated on land stages. Special attention is given to the specific characteristics of the Galician fishing sector and its derived industries. Additionally, Chapter 2 provides a brief review of recent seafood and fishery LCA studies, focusing on recent developments and achievements.

Secondly, Section II deals with the environmental assessment through LCA implementation of the most representative fishing products from a selection of industrial Galician fleets. Therefore, in Chapter 3 Atlantic horse mackerel (*Trachurus trachurus*), the most landed species in Galicia in terms of metric live tonnes, landed by coastal purse seiners and trawlers is evaluated and compared. Chapter 4, even though it does not evaluate directly a fishing fleet from Galicia, due to data limitations, includes a methodological development by analysing the potential interannual variability of environmental impact results in a Basque small-pelagic purse seining fleet. Chapter 5 deals with the entire production chain up to consumption in Spanish households of European hake (*Merluccius merluccius*), the species with highest income revenues of the Galician fleet, captured by long liners and trawlers in the Northern Stock, with the aim of determining the main environmental burdens throughout the supply chain. Finally, Chapter 6 assesses the supply chain up to point of export of common octopus (*Octopus vulgaris*), another iconic seafood product of the Galician fleet, fished by vessels in the Mauritanian EEZ thanks to the EU-Mauritania fishing agreement. Additionally, some biological related indexes are discussed together with conventional LCA impact categories in some of these chapters in order to give a broader scope of assessment.

Section III focuses on evaluating the fishing vessels as the unit of assessment, rather than the products derived from their operation. To do so, LCA was combined with a management tool, named data envelopment analysis (DEA) to individually assess the environmental efficiency of vessels within a given fishery. Furthermore, additional advantages of using this integrated method, such as those linked to result interpretation or the handling of standard deviations, are discussed in Chapter 7. While Chapter 7 constitutes a detailed theoretical presentation of the LCA+DEA method, including only one brief case study, Chapter 8 fully develops the joint method from a practical perspective, analysing the operational patterns and verifying the eco-efficiency of a set of 6 different Galician fishing fleets. Finally, Chapter 9 deepens in the understanding of the sources of inefficiency in fishing vessels, through the use of DEA as an independent tool, even though the results obtained can be discussed from a life cycle perspective. Chapter 9, as Chapter 4, includes inventory data from a fishing fleet, the US menhaden fishery, which has no economic or geographical tie to Galicia, but offered ideal inventory characteristics to conduct the study.

Section IV feeds on the vast inventory data achieved for Sections II and III regarding discard reporting by Galician fishing vessels. Hence, in Chapter 10 this information is used to quantify the estimated discards that are performed by the entire Galician fleet for one year of operation. The fact that discards assessment has not been considered in life cycle thinking to date, except for timid attempts to report its value per FU, constitutes the background for Chapter 11. The aim of this chapter, besides the detailed discussion of the main environmental impacts linked to discarding, is to propose a specific indicator to include discard quantification in LCA studies.

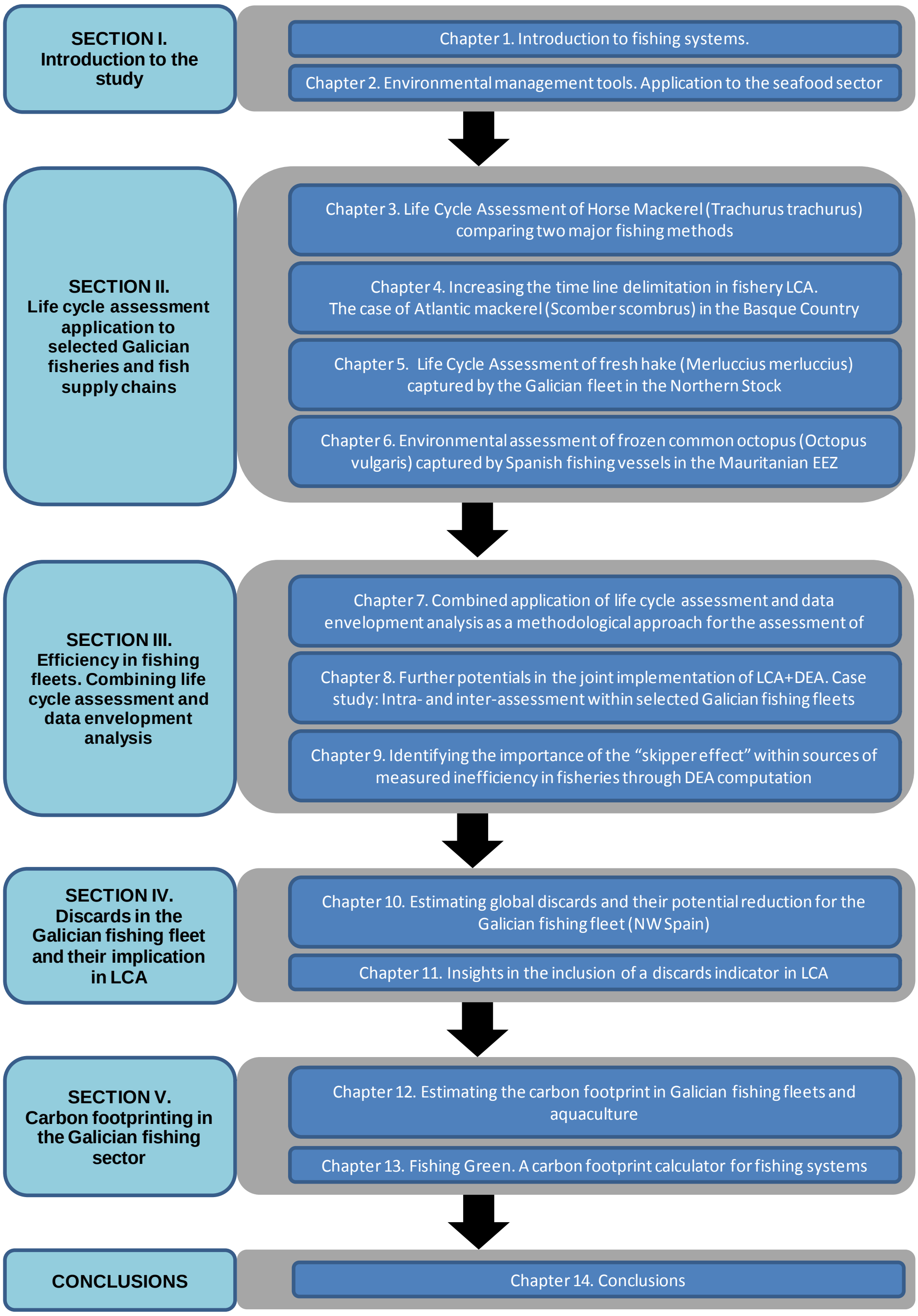

Figure 2.2. Schematic representation of the structure of the thesis.

Section V focuses on CF, a GHG-specific environmental management tool that is based on LCA methodology and assumptions, following ISO 14040 specifications. Chapter 12, in a similar way to the approach used in Chapter 10, estimates the global CF of the entire Galician seafood sector[2], in order to account for the climate change profile of fishing activities in Galicia, given the increasing interest that this specific dimension of environmental reporting is developing nowadays. Chapter 13 describes, within the scope of CF, current eco-labelling patterns. Additionally, it proposes a specific seafood CF software, which can be found in the CD attached to this document, aimed at providing stakeholders in the seafood sector with a calculation tool.

Finally, Chapter 14 presents the main conclusions obtained throughout the dissertation.

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[2] Chapter 12 includes inventory data from intensive and extensive aquaculture analyzed and discussed by Iribarren (2010). A description of the specific system boundaries for extractive fishing and intensive and extensive aquaculture is discussed in Chapter 12.

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SECTION II

LIFE CYCLE ASSESSMENT APPLICATION TO SELECTED GALICIAN FISHERIES AND FISH SUPPLY CHAINS

Chapter 3

Life Cycle Assessment of Horse Mackerel (*Trachurus trachurus*) comparing two major fishing methods[1]

Summary

Atlantic horse mackerel (*Trachurus trachurus*) is one of the main target pelagic species of the coastal purse seining and bottom trawling Galician fleets. The goal of this LCA study was to assess and compare the environmental impacts associated with the fishing operations related to Atlantic horse mackerel extraction in these coastal fisheries. This analysis included the operation of the vessels, together with major inputs related to the production of diesel, fishing nets or anti-fouling paints. Data regarding vessel operation were obtained from the questionnaires filled out by a total of 54 skippers. Results showed that environmental burdens regarding horse mackerel landing were associated mainly with activities related to diesel production, transport and consumption by the fishing vessels. Furthermore, cooling agent leakage from the cooling chambers was identified as a major impact regarding ozone layer depletion and global warming potentials. When comparing both fishing activities, horse mackerel captured by purse seiners presented reduced environmental burdens for all impact categories with respect to horse mackerel landings by bottom trawlers. The environmental reduction ranged from 49% to 89%, depending on the impact category analysed. Discard rates for coastal trawlers were also identified as a major environmental impact in this fishery. Revision of fishing quotas and fishing strategies for the horse mackerel fishery and reduction of energy consumption, through the introduction of new alternative fuels or technological actions, are necessary in order to reduce the environmental impacts of a highly fuel-dependent activity.

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[1] Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2010). “Life cycle assessment of horse mackerel fisheries in Galicia (NW Spain): Comparative analysis of two major fishing methods”. *Fisheries Research,* 106: 517-527

Index

3.1. Introduction

3.1.1. The Galician continental shelf horse mackerel fishery

Atlantic horse mackerel is a pelagic species of mackerel belonging to the Carangidae family. It is abundant in North-eastern Atlantic fisheries from Iceland to Senegal, including also the Mediterranean and Black Sea (Whitehead et al., 1986), congregating in large shoals in rocky coastal waters, feeding of smaller fish, crustaceans and squid. It is fished all year round, but the best quality individuals that are sold fresh in markets are captured during the late spring and summer periods. Not surprisingly, two thirds of the horse mackerel landings in Galicia take place in that period, while lowest landings are identified during the winter months, when part of the landings are used for fishmeal production or for canning (Xunta de Galicia, 2010). The importance of this species at a national level is certified by a recent study carried out by the Spanish Ministry of Health, in which 42% of Spanish households declared buying horse mackerel on a regular basis (FROM, 2005).

The Galician stock for horse mackerel (ICES Divisions VIIIc and IXa) is characterized by a relative stability in catches and age composition throughout the year (Villamor et al., 1997; Abaunza et al., 2003), due mainly to the coincident location of the feeding and spawning grounds (Abaunza et al., 1995; HOMSIR, 2003). Identified patterns in this stock show that this area is not made up by a closed population, but receives an important input of fish from other areas (Murta et al., 2008), which may justify the good health of the Galician horse mackerel stock. The landings of this species in the year 2007 in Galician ports summed up to a total of 22,027 tonnes (Figure 3.1), representing 49.9% of the total horse mackerel quota allowed for Spain in that year by the European Commission, 12.8% of the total landings in this region's ports and 10.8% of worldwide horse mackerel landings (FAO, 2008; Xunta de Galicia, 2010). The coastal purse seining and trawling fleets account for over 95% of the horse mackerel captures in Galicia.

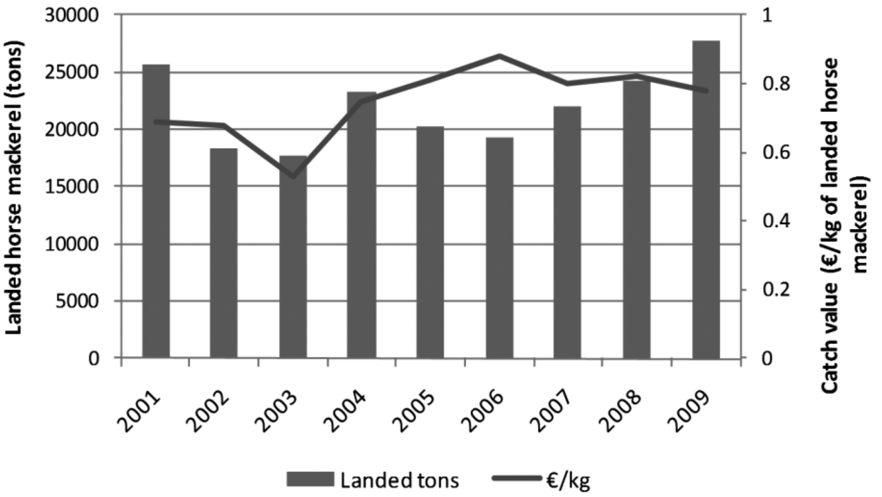

Figure 3.1. Annual Galician Atlantic horse mackerel landings, 2001–2009. Average annual price.

Source: Xunta de Galicia (2010).

3.1.2. The purse seining and trawling fleets in the Galician continental shelf

Coastal bottom trawlers in Galicia account for a total of 101 vessels distributed in 11 ports, with an average beam length of 28 m (Xunta de Galicia, 2010). They operate in areas close to the landing port, performing one or two landings per day. Most of the fleet is constituted by pair trawlers that usually operate at ranges between 1.5 and 2.1 knots/h. On an average day they operate from 9 to 13 h, performing 1 or 2 throws. Single trawlers present slightly different operation patterns, trawling at a speed that ranges from 3.2 to 4.5 knots/h and performing 3 or 4 throws per day for around 12 h.

The main species captured by coastal bottom trawlers along the Galician continental shelf are European hake and blue whiting (*Micromesistius poutassou*), two demersal species, and Atlantic mackerel and Atlantic horse mackerel, both semi-pelagic. Other species that might be caught incidentally, but are also commercialised are megrim, black bellied angler, Norway lobster and pouting. Spanish marine laws, however, do not allow landings of sardine (*Sardina pilchardus*), tuna species (mainly *Thunnus alalunga*) or anchovy (*Engraulis encrasicholus*) by bottom trawlers. Furthermore, bottom trawling was limited to depths above 100 m in 1999. In this year, pelagic trawling in ICES Divisions VIIIc and IXa was also banned (MARM, 2010).

Purse seiners developed as artisan vessels (Figure 3.2) in Galicia for centuries, mainly to catch sardines and other pelagic species, but thanks to technological improvements regarding shoal detection, these vessels have turned into an important fleet within the Galician fishing sector. In 2008, Galicia had a fleet of 165 coastal purse seiners, distributed in 29 different harbours. The average beam of this fleet is 17 m, ranging from 7 to 27m (Xunta de Galicia, 2010). Most purse seiners in Galicia set to sail before nightfall, since target pelagic species are easier to capture after sunset and at dawn. Captured fish are stored in wet-fresh conditions until they are landed for auction sale. Most vessels perform one or two landings per day, depending on fish availability and sale price among other factors.

Figure 3.2. Coastal vessels anchored at the port of Tapia de Casariego (Spain).

The pelagic target species captured by the vessels are sardine, Atlantic mackerel, Atlantic horse mackerel and anchovy. However, anchovy landings have been banned by the European Commission in this area throughout most of the past decade, due to the increased overexploitation of the fishery. Other by-catch species include bogue (*Boops boops*), common sea bream (*Pagellus bogaraveo*) and common sole (*Solea solea*).

3.1.3. The environmental impacts of fishing

The improvement of fishery management not only must be linked to efforts to reduce by-catch and discards, the disturbance created in benthic communities due to the use of trawlers and other types of gear, or the alteration of trophic dynamics (Fonseca et al., 2005), but also to analysing and mitigating the effects that global warming may produce over world fisheries. However, environmental analysis of fisheries usually focuses on biological concerns and underestimates other impacts caused by fishing activities. For instance, the energy and material use in fishing vessels can create important environmental impacts, related mainly to fuel consumption, gear usage and loss at sea, anti-fouling agents and paint or ice consumption (Hospido and Tyedmers, 2005).

In this study, Atlantic horse mackerel captured by two different types of fishing vessels (bottom trawlers and purse seiners) was analysed from an environmental perspective. The horse mackerel landed by purse seiners was compared to that landed by coastal bottom trawlers in order to describe major differences between the fleets and to identify the main hot spots.

3.2. Methods

3.2.1. Goal and scope definition

The goal of this LCA study is to assess and compare the environmental burdens associated with the fishing operations related to Atlantic horse mackerel extraction in two Galician coastal fisheries: purse seining fleet and bottom trawling fleet.

The FU considered was 1 tonne of landed round Atlantic horse mackerel in a Galician port in the year 2008. This FU is based on the assumption that the main objective of the study is to compare the environmental profile of one same product (horse mackerel) fished with two different techniques (trawling and purse seining).

The system under study comprised the different stages considered for fish extraction performed by the different vessels in the fishery (Figure 3.3), including diesel consumption, anti-fouling, oil and trawl or seine net use, ice consumption and cooling agent usage and leakage. The construction and maintenance of the vessels was also included. The product was followed starting from the production of supply materials, such as fuel, nets or ice, until landing for sale, constituting a "cradle to gate" analysis (Guinée et al., 2001). On land landing operations at port have been excluded from the system boundaries, as can be observed in Figure 3.3, as well as a series of biological issues, such as stock assessment, given that their consideration involves impact categories that are not developed in current LCA methodology. Nevertheless, a brief discussion on the discard rates of the two fleets is included in the study. Finally, emissions linked to cooling agent leakage were included in the system, since recent studies suggest that their associated environmental impact may be significant when assessing global warming and ozone layer depletion potentials in fishing fleets (SenterNovem, 2002; Klingenberg, 2005; Winther et al., 2009). Therefore, a brief discussion on cooling agent leakage in the horse mackerel fishery is also included in Section 3.4.3.

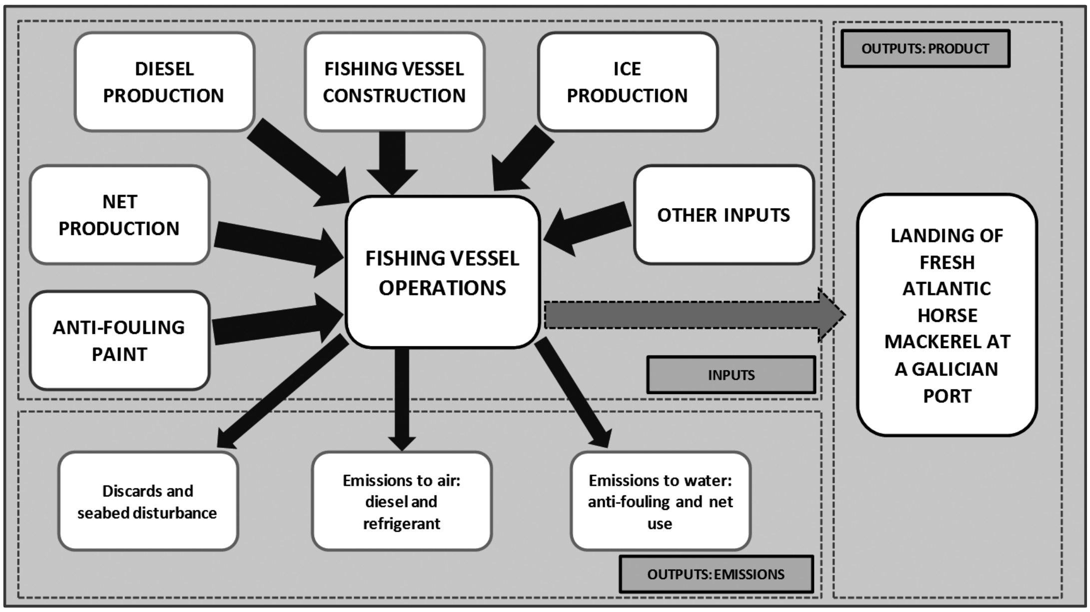

Figure 3.3. Block diagram of the studied system. Dotted line represents system boundaries.

3.2.2. Data acquistion

The sample used for this study is a group of 24 trawling vessels and 30 purse seining vessels belonging to the Galician fishing fleet. These vessels represent 24% and 18% of the Galician continental shelf trawling and purse seining fleet, respectively (Xunta de Galicia, 2010).

Primary data were obtained through a series of questionnaires filled out by skippers from three of the main coastal trawling ports in Galicia (Celeiro, Muros and Ribeira) and from seven of the most important purse seining ports: Sada, Camariñas, Portosín, Ribeira, Cambados, Portonovo and Vigo (Figure 3.4). Questionnaires comprised a wide range of operational aspects (annual consumption of diesel, discard rate, net consumption and dimensions, days at sea, crew size, etc.) as well as aspects related to capital goods (hull material, vessel dimensions, life span, etc.).

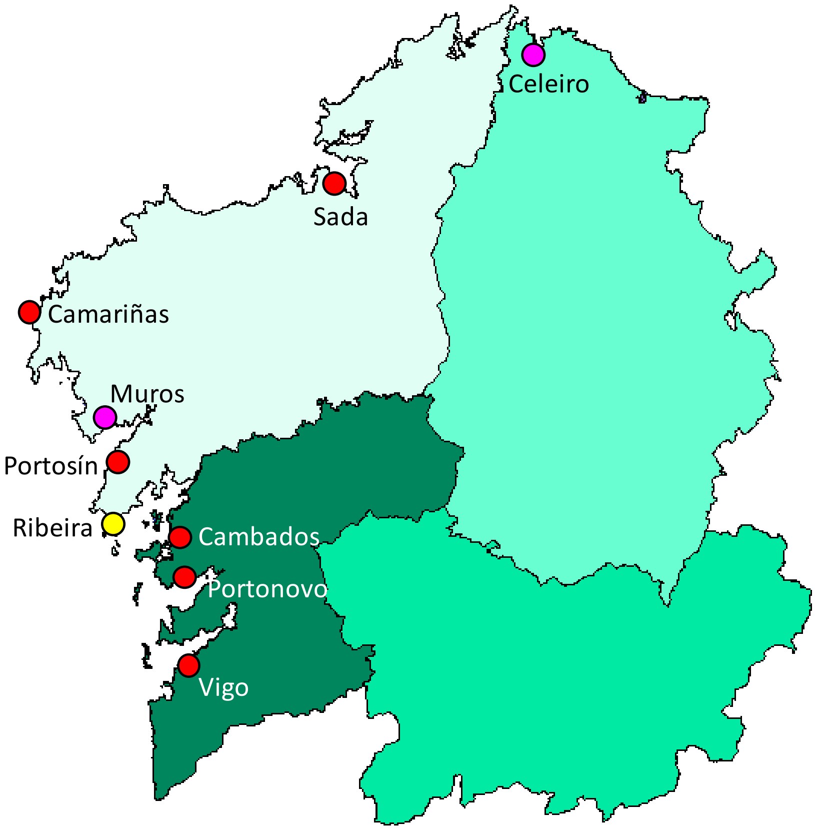

Figure 3.4. Map showing the fishing ports at which the inventoried vessels are based. Red ports refer to trawling vessels; violet ports refer to purse seining vessels; yellow ports refer to both trawling and purse seining vessels being inventoried

Anti-fouling and paint production were also considered in this study. Skippers reported sending their vessels to the docks for maintenance once per year, so these products were considered important inputs in vessel operation activities of Galician coastal fleets. Data regarding paint and anti-fouling agents' composition, as well as emissions related to their production were included in the inventory. These data were obtained from a leading world producer.

Despite fishing gear provision being excluded from prior LCA analyses (Tyedmers, 2000; Ziegler et al., 2003; Hospido and Tyedmers, 2005), in this study net production, transport and consumption was included for two main reasons. In the first place, seine and trawl nets represent an important percentage in the total weight of the vessels for these particular fleets. Secondly, questionnaires were sent to the main net sowing associations in Galician harbours, providing data on material content and gear lifespan. They reported that in recent years the production of nylon nets has shifted from local enterprises to South-East Asia (Philippines, Thailand, etc.). The average life span of trawl nets was 4 years. For seine nets, the average life span was slightly above 5 years, although the nets are usually renewed by at least 25% each year due to net losses at sea.

Despite the fact that vessel construction has been found to have a small contribution to the environmental impacts of different seafood products (Hayman et al., 2000; Hospido and Tyedmers, 2005), data availability led to the inclusion of some construction inputs, such as steel and wood used for the hull and the steel used for the engines. A Galician shipyard, specialized in the construction of coastal seiners and trawlers was contacted (Abeijón Hermanos SL Shipyard, April 2009, personal communication) and data were also provided by two large engine manufacturers. In order to account for vessel repairs and maintenance, the amount of steel or wood required for building was increased by 25% (Tyedmers, 2000). The total amount of construction material was then divided by the lifespan of each vessel (the mean for inventoried vessels was 31 years, with most boats ranging from 30 to 40 years lifespan), in order to calculate annual consumption.

None of the 54 skippers interviewed reported having an ice-making machine on board. Instead, the analysed fleets buy the ice off the port authority, like the great majority of the Galician coastal fleet. Ice production data were obtained from two different port ice-making factories (Sales Department in the ports of Sada and Malpica, May 2009, personal communication).

Finally, cooling agent data were obtained from two specialized Galician companies. The consulted technicians agreed that the great majority of fishing vessels based in Galician ports use R22, a hydrochlorofluorocarbon (HCFC) with a high ozone depletion and global warming potential. Despite this situation, they also pointed out that the industry is slowly shifting to other types of refrigerants, such as R507, R404A and, in very specific cases, NH_3, due to new policy rules that promote the use of agents that are less harming to the ozone layer. Both companies reported an average annual leakage of 150 kg per vessel for R22 in coastal trawlers, while the leakage for purse seiners was approximately 10 kg per vessel (José Manuel Juncal, Frimarte; Kinarca, S.A., June 2010, personal communication).

Background data regarding the production of diesel fuel were obtained from the ecoinvent® database. The process data for diesel production include oil field exploration, crude oil production, long distance, transportation, oil refining or regional distribution (Frischknecht et al., 2007). Additional situations where no direct data were available are linked to the production of supply materials, such as materials for vessel and gear, anti-fouling agents and electricity. Background data from the ecoinvent® database (version 2.0) were also used for these cases, since the data are representative for European conditions.

The emissions resulting from fuel combustion were calculated on the base of the EMEP-Corinair Emission Inventory Handbook of 2006 (EMEP-Corinair, 2006). The loss of paint and anti-fouling to the marine environment was set as two thirds of the total employed (Hospido and Tyedmers, 2005). It is important to point out that in this study the LCA recommendation to set the toxicity characterization factors applied to essential metals, such as zinc and copper, in oceanic waters as zero was not followed (Aboussouan et al., 2004). Instead, copper and zinc ions were included as inventory data. The rationale behind this decision is related to the fact that the studied vessels operate in highly fragile coastal ecosystems (the Galician *rias*) with high marine traffic (Alzieu, 1998; Matthiessen and Law, 2002; Hospido and Tyedmers, 2005;).

Solid waste and wastewater related to daily life on board were not taken into account in this study, due to the insignificant importance shown in other studies (Hospido and Tyedmers, 2005) and to the fact that they are not directly connected to the production activity (Ziegler et al., 2003). Finally, bilge waters were also assessed and included in the inventory.

3.2.3. Co-product allocation strategies

In both fleets more than one species is captured simultaneously during fishing operations. Allocation in past studies has been important in most mixed fisheries (Ayer et al., 2009). For this particular study, mass allocation was considered the most appropriate approach. This selection was based on the fact that three or four species are obtained from the same extractive process, so inputs and outputs from the inventory data affect all species in identical manner. Moreover, species targeted by purse seiners all have a similar economic value (Table 3.1). In the case of the bottom trawling fleet, one of the species (hake), reported approximately 50% of the economic turnover in 2008, but vessels are not allowed to land more than 20% of the total catch. The other three target species also had a similar economic value in that year. However, the increased volatility of fish prices (especially for hake and sardine in the past few years) makes economic allocation difficult to interpret. Nevertheless, economic allocation is also included and discussed in Section 3.4.2.

Table 3.1. Mass and economic allocation factors for horse mackerel fishing fleets.

Species	Landings (t)	Mass allocation	Value (€/kg)	Economic allocation
Purse seining coastal fleet				
Atlantic horse mackerel	101	23.9%	0.82	47.4%
Atlantic mackerel	116	27.7%	0.51	18.4%
European pilchard (sardine)	203	48.4%	0.65	34.2%
Bottom trawling coastal fleet				
Atlantic horse mackerel	119	17.7%	0.82	11.3%
Hake	118	17.7%	3.72	50.7%
Atlantic mackerel	142	21.2%	0.51	8.3%
Blue whiting	290	43.4%	0.89	29.7%

3.2.4. Life Cycle Inventory

The LCI, as explained in Chapter 2, involves the collection and computation of data to quantify relevant inputs and outputs of a product system, including the use of resources and emissions to air, water and soil associated to the system (ISO, 2006). Furthermore, the data sets used throughout this dissertation are adapted to the requirements suggested by the Ecotech-Sudoe project, which aims at creating a database for processes undergone in Southwest Europe (France, Portugal and Spain), at the same time as homogenizing inventories to the International Reference Life Cycle Data System (ILCD) standards (Ecotech-Sudoe, 2011). Therefore, at the back of this thesis a small brochure is provided where the inventory data for the coastal purse seining fleet used in this chapter is adapted to the ILCD format.

Coastal bottom trawlers

According to the questionnaires obtained for the trawling fleet, the 24 vessels landed a total of 16,056 tonnes of fresh fish. Blue whiting was the most captured species, followed by Atlantic mackerel and horse mackerel (Table 3.1). Hake, the species with highest economic value, only represented 17.7% of the landings.

The average allocated inventory data per FU can be seen in Table 3.2. As observed, vessel operations created an annual average fuel consumption of 496 kg per tonne of landed round horse mackerel. Ice consumption translated in an average of 323 kg per tonne, whereas specialized companies reported an average annual leakage of 0.23 kg per tonne for R22 in cooling chambers of coastal bottom trawlers. Another important operation, trawl net consumption involved that each vessel consumed 2.4 kg per tonne of horse mackerel. Net information was also used to calculate the seafloor impact potential (SIP) of this fleet.

Table 3.2. Inventory for horse mackerel landed in Galician ports by coastal bottom trawlers (Data per FU: 1 tonne of landed round horse mackerel).

INPUTS							
From the technosphere				**From the technosphere**			
Materials and fuels	**Units**	**Value**	**SD[1]**	**Materials and fuels**	**Units**	**Value**	**SD[1]**
Diesel	kg	496	±97	Boat paint	g	223	±45
Steel	kg	5.1	±1.2	Marine lubricant oil	kg	2.2	±0.9
Trawl net[2]	kg	2.4	±0.7	Ice	kg	323	±77
Anti-fouling	g	639	±86				

OUTPUTS					
To the technosphere			**To the environment**		
Products	**Units**	**Value**	**Emissions to the ocean**	**Units**	**Value**
Horse mackerel	t	1	1. Xylene	g	58.5
To the environment			2. Dicopper oxides	g	133
Emissions to the atmosphere			3. Zinc oxides	g	60.0
1. CO_2	kg	1,571	4. Nylon	kg	189
2. SO_2	kg	5.0	5. Lead	g	100
3. VOC	kg	1.2			
4. NO_x	kg	35.7			
5. CO	kg	3.7			
6. R22	g	223			

[1] SD: Standard deviation.

[2] The trawl net includes nylon, lead and cork as raw materials.

Discard data from the trawlers were provided by the skippers of each vessel. These discards comprised a wide range of undersized and non-marketable species. The main undersized species reported by the skippers were hake juveniles (*carioca*). Discard data for each vessel can be observed in Table B.1 in Appendix I.

Coastal purse seiners

Inventory data for Atlantic horse mackerel landed by coastal purse seiners were obtained from the average data provided by 30 vessels. The mean inventory data allocated per FU have been included in Table 3.3. According to these questionnaires, the inventoried vessels landed a total of 12,597 tonnes of fresh fish in the year 2008. European pilchard was the most captured species (48.4%), followed by Atlantic mackerel and horse mackerel (Table 3.1).

Table 3.3. Inventory for horse mackerel landed in Galician ports by coastal purse seiners (Data per FU: 1 tonne of landed horse mackerel).

INPUTS							
From the technosphere				**From the technosphere**			
Materials and fuels	**Units**	**Value**	**SD[1]**	**Materials and fuels**	**Units**	**Value**	**SD[1]**
Diesel	kg	176	±69	Boat paint	g	113	±31
Steel	kg	2.7	±0.6	Marine lubricant oil	g	447	±147
Wood	g	2.3	±0.4	Ice	kg	321	±117
Anti-fouling	g	365	±61	Seine net[2]	kg	10.2	±4.2

OUTPUTS					
To the technosphere			**To the environment**		
Products	**Units**	**Value**	**Emissions to the ocean**	**Units**	**Value**
Horse mackerel	t	1	1. Xylene	g	33.1
To the environment			2. Dicopper oxides	g	75.7
Emissions to the atmosphere			3. Zinc oxides	g	34.3
1. CO_2	kg	558	4. Nylon	kg	1.03
2. SO_2	kg	1.8	5. Lead	g	229
3. VOC	g	422			
4. NO_x	kg	13			
5. CO	kg	1.3			
6. R22	g	23.3			

[1] SD: Standard deviation.

[2] The seine net includes nylon, lead and cork as raw materials.

The purse seiner's vessel operations generated an annual average fuel consumption of 176 kg per tonne of landed round horse mackerel and 321 kg of ice per tonne, being two important inputs used in the fishery. Seine net consumption involved that each vessel consumed 10.1 kg per tonne of horse mackerel. Discard data for purse seiners were on average 32.6 kg per tonne by the interviewed skippers. Individual vessels' discard data can be observed in Table B.2 in Appendix I.

A final observation of the inventory data in Tables 3.2 and 3.3 is that the standard deviation for the purse seining vessels is slightly higher than the deviation within the trawling fleet. This circumstance may be attributable to two main factors: (i) the semi-artisanal characteristics of this purse seining fleet, and (ii) the low non-intensive fuel characteristics of this fleet. More analysis on this specific issue can be found in Chapter 8.

3.2.5. Selection of impact categories

The life cycle impact assessment phase was carried out using the CML baseline 2000 method (Guinée et al., 2001). Impact categories considered in the study were: abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone layer depletion potential (ODP), marine aquatic eco-toxicity potential (METP) and photochemical oxidant formation potential (POFP). SimaPro 7.3 was the software used to lead the computational implementation of the inventories (Goedkoop et al., 2010).

Moreover, a series of fishery specific indicators were included in the study. On the one side, discard reporting per FU was provided for the two assessed fishing fleets. On the other, the SIP was calculated for the trawling fleet based on the data supplied regarding net characteristics and fishing operations described by skippers, given the potential damage that this gear can have on the seabed. SIP development is based on the seafloor impact index proposed by Nilsson and Ziegler (2007). Therefore, the swept seabed area was computed by multiplying the effort by the mentioned index (area swept per hour). As suggested in their study, the calculated area was based exclusively on the area swept by trawl doors and trawl net. However, throughout this thesis it is important to take into consideration the potentiality of the results, since there is no indication to whether vessels are harvesting the same area over and over again (Nilsson and Ziegler, 2007).

3.3. Results

3.3.1. Environmental performance of Atlantic horse mackerel landed by bottom trawlers

According to the results shown in Figure 3.5, there are two main activities that produce most of the environmental impact. In the first place, vessel operations accounted for most of the impact in all categories, except ADP. Therefore, vessel operations dominated the contribution to ODP (97%), EP (89%), AP and GWP (87%), POFP (65%) and METP (48%). Nevertheless, vessel operations include a wide variety of activities, so they will be analysed in depth later on. Secondly, diesel production is also an important contributor to ADP (97%), METP (41%) and POFP (32%). Its contribution to the other categories is in all cases below 15%.

The other subsystems included in the analysis had reduced environmental impact on the different categories. Net production and transport contributes to 1% in ADP and GWP, whereas ice production contributed by 4% to METP and 2% to ADP and POFP. The manufacture of paint and anti-fouling products, as well as the vessel construction parameters barely had any effect in the different impact categories. Absolute values for the different activities can be consulted in Table B.3 of Appendix I for all the assessed impact categories.

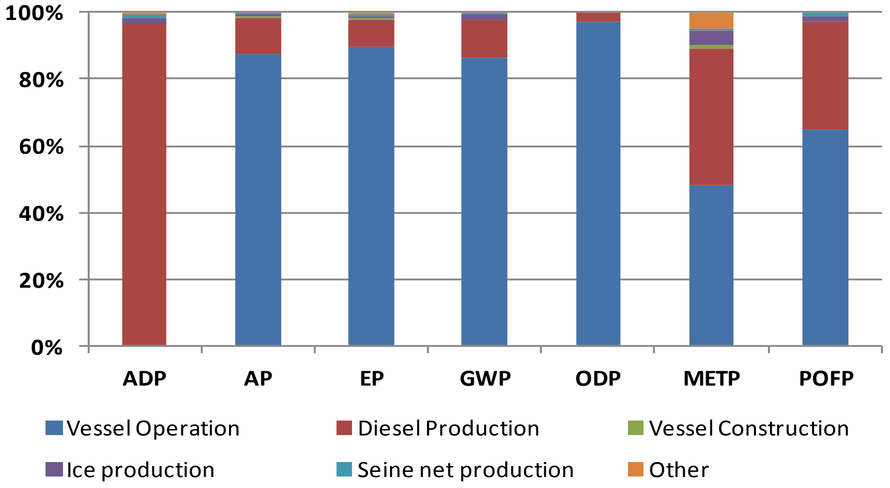

Figure 3.5. Relative contribution to environmental impacts associated with the Galician bottom trawling horse mackerel fishery.

Impact category acronyms: ADP= abiotic depletion potential; AP = acidification potential; EP = eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; METP= marine aquatic eco-toxicity potential; POFP = photochemical oxidant formation potential.

Vessel operational activities, as seen above, are the main contributors to most impact categories. However, most of the impacts generated (Figure 3.6) are due mainly to fuel consumption in all impact categories, except for METP (3%) and ODP (no contribution). For the rest of impact categories its contribution is above 99%, except for GWP, where it represents 81% of the environmental burdens.

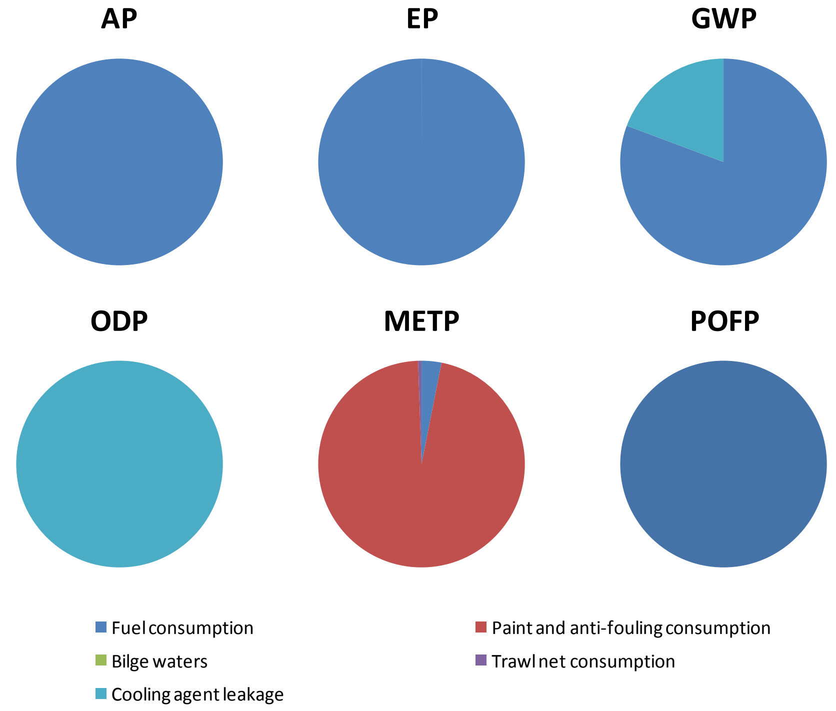

Figure 3.6. Relative contribution to selected impact categories for the activities considered in the vessel operation subsystem. Bottom trawling fleet.

Impact category acronyms: AP = acidification potential; EP = eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; METP= marine aquatic eco-toxicity potential; POFP = photochemical oxidant formation potential.

Cooling agents also have a relevant contribution to GWP (19%) and especially to ODP (100%). In METP, anti-fouling and paint consumption represent the most important impact in the operational inputs subsystem (96%). Net usage and bilge waters presented minimal impacts overall (<1%).

Regarding the fishery-specific impacts generated by this fleet, the annual average amount of discarded fish was 487.2 tonnes per vessel. This means that for every tonne of Atlantic horse mackerel landed, 727 kg of discard were returned to the ocean, representing roughly 42% of the total catch. SIP results showed a potential disruption of 0.68 km^2 per tonne of Atlantic mackerel unloaded.

3.3.2. Environmental performance of Atlantic horse mackerel landed by purse seiners

Figure 3.7 shows the relative contributions that the different fishing-related subsystems produce in each impact category. The highest contributions are linked to vessel operations in all impact categories except for ADP. Their influence is of 90% in EP, 84% in ODP, 83% in AP and 76% in GWP. The percentage is below 75% for POFP (58%) and METP (53%).

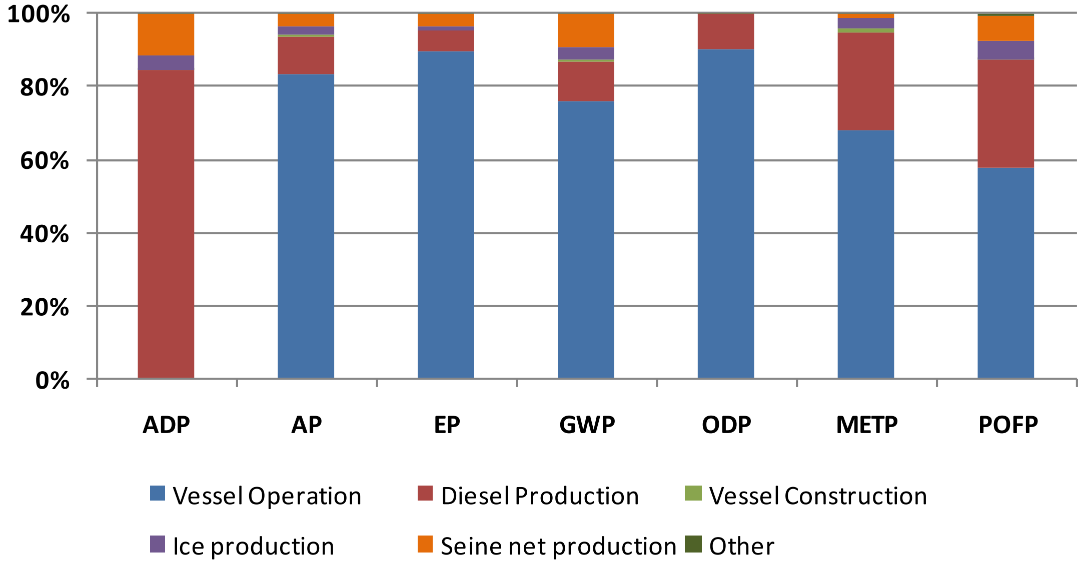

Figure 3.7. Relative contribution to environmental impacts associated with the Galician purse seining horse mackerel fishery.

Impact category acronyms: ADP= abiotic depletion potential; AP = acidification potential; EP = eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; METP=marine aquatic eco-toxicity potential; POFP = photochemical oxidant formation potential.

Diesel production is the second activity in importance in terms of environmental impact. In fact, diesel production has important contributions to ADP (84%). Its importance decreases in other impact categories, with contributions ranging from 29% (POFP) to 8% (EP). Net and ice production are the only other subsystems with relevant contributions to certain impact categories. On the one hand, net production and transportation presents contributions of 11% for ADP or 9% for GWP. On the other hand, ice production contributes in 8% for METP and 5% for ADP. Absolute values for the different activities can be seen in Table B.4 of Appendix I for all the assessed impact categories.

Vessel operations, as seen in Figure 3.8, include a series of independent activities in the daily activity of the vessels'. These activities are the main contributors to most impact categories. However, most of the impact generated is due to fuel consumption (over 90%) for all impact categories, except for METP and ODP. For ODP, cooling agent leakage represents 100% of the environmental impact. This same activity generates 7% of the contributions to GWP. In METP, paint and anti-fouling consumption are the main impact in the operational inputs subsystem (96%), while fuel and net consumption account for 2% each. Finally, the annual average amount of discarded fish was 13.68 tonnes per vessel, which represented between 2.3% and 4.9% of the total catch of each of th3 inventoried vessels. This means that for every tonne of Atlantic horse mackerel landed, 32.6 kg of discard were returned to the ocean, representing roughly 3.2% of the total catch. SIP results were assumed to be negligible per tonne of Atlantic mackerel unloaded.

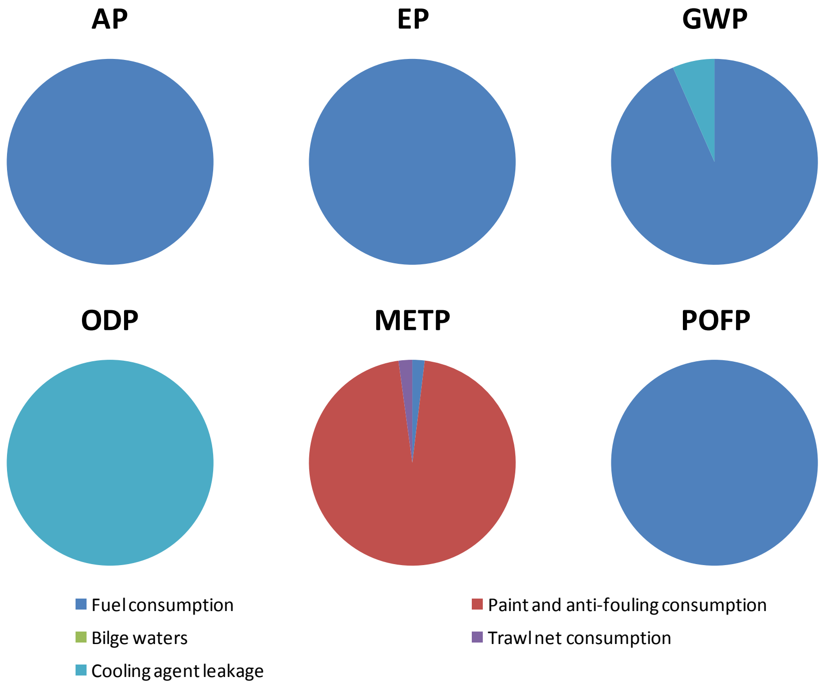

Figure 3.8. Relative contribution to selected impact categories for the activities considered in the vessel operation subsystem. Purse seining fleet.

Impact category acronyms: AP = acidification potential; EP = eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; METP= marine aquatic eco-toxicity potential; POFP = photochemical oxidant formation potential.

3.4. Discussion

3.4.1. Identification of hot spots

The environmental characterization for the horse mackerel fishery off the coast of Galicia led to the conclusion that the most important environmental impacts assessed in this study are related to the production, transportation and consumption of fuel, regardless of the fleet that is performing the landing. This finding is not new in fisheries LCA or in other fishery impact assessment studies, and echoes results previously presented in other studies (Edwardson, 1976; Watanabe and Okubo, 1989; Ziegler et al., 2003; Thrane, 2004; Hospido and Tyedmers, 2005; Tyedmers et al., 2005; Schau et al., 2009). Nonetheless, it is interesting to point out that purse seiners present a considerably lower fuel consumption pattern than the evaluated trawlers.

The obtained results show that the environmental impact for bottom trawling vessels is mainly due to operational issues, linked to the intensive use of fuel and to cooling agent leakage in these vessels. Purse seiners, however, even though the main hot spot is still the operation of the fishing vessels, also show important environmental impacts related to ice production and emissions of anti-fouling and boat paint compounds to the sea. Despite the fact that anti-fouling and boat paint manufacture showed reduced burdens for the different impact categories in both fleets (always below 1%) their contribution to marine toxicity is highly relevant due to ocean emissions of copper and zinc oxides. Ice production is also important in many impact categories due to the fact that it is produced directly in ports from the Spanish electricity mix, which is still nowadays highly dependent on fossil fuels.

Finally, seine net production and transport, vessel construction and bilge waters do not present relevant contributions. This fact leads to the conclusion that they are not key subsystems within the calculation of the environmental impacts linked to horse mackerel extraction.

3.4.2. Comparison between bottom trawlers and purse seiners for horse mackerel fisheries

Purse seiners and bottom trawlers constitute the main competitors for horse mackerel landings in Galician ports. When the two fleets are compared, as seen in Table 3.4, horse mackerel captured by purse seiners presents reduced environmental impacts in all the assessed categories. The main reason for this reduced impact is linked to lower fuel consumptions by purse seiners. Trawlers consume an average of 496 kg fuel per tonne of horse mackerel, while purse seiners consume an average of 176 kg fuel/tonne horse mackerel, 65% less. These results are in accordance with other reports that conclude that trawling in general is a highly energy-intensive fishing technique (Schau et al., 2009). Furthermore, fuel-intensive fishing operations not only present increased contributions to the assessed impact categories in this case study, but usually represent the most damaging alternative concerning the damage that may be caused to seabed habitats (Thrane, 2006). This fact was supported by the fact that over half a square kilometre of seafloor was disrupted to some extent by the trawl net. Nevertheless, it is important to note that purse seine nets can also cause occasional damage to the seabed. However, due to the difficulty to quantify this impact for seiners, its calculation was excluded from the current study.

Table 3.4. Characterization values associated with the Galician horse mackerel fishery in terms of 1 tonne of round horse mackerel in Galician ports.

Impact category	**Horse mackerel captured by purse seiners**		**Horse mackerel captured by bottom trawlers**		**% Difference seining/trawling (mass allocation)**
	Mass allocation	Economic allocation	Mass allocation	Economic allocation	
ADP (kg Sb eq)	4.99	6.28	12.27	7.82	59.3
AP (kg SO_2 eq)	10.2	12.77	27.22	17.35	62.5
EP (kg PO_4^{3-} eq)	1.95	2.46	5.19	3.31	62.4
GWP (kg CO_2 eq)	797	1003	2279	1453	65.0
ODP (kg CFC 11 eq)	8.7E-4	1.1E-3	7.9E-3	5E-3	89.0
METP (kg 1,4DCB eq)	2.26E5	2.84E5	4.40E5	2.80E5	48.6
POFP (kg C_2H_4 eq)	0.21	0.26	0.52	0.34	60.6

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrophication Potential; GWP= Global Warming Potential; ODP= Ozone Layer Depletion Potential; METP= Marine aquatic Eco-toxicity Potential and POFP= Photochemical Oxidant Formation Potential.

When results are compared with those obtained in other studies, it is important to highlight the risks of doing so, due to the different characteristics the fisheries and the fleets may have. The Norwegian coastal purse seining fleet was the fleet with closest characteristics to the seining fleet assessed in this study, given their similarity regarding landing breakdown. However, only 90 kg of fuel were consumed on average per tonne of landed mackerel (in this case, *Scomber scombrus*) by the Norwegian fleet (Schau et al., 2009), representing only 51% of the fuel intensity of horse mackerel landing by Galician seiners. Other consulted studies, such as the offshore tuna fisheries assessed by Hospido and Tyedmers (2005), show an increased fuel effort (420 kg of fuel per landed tonne of tuna) respect to that of Galician purse seiners. To our knowledge, there are no references in literature of bottom trawling vessels being used for horse mackerel extraction as a target species in other fisheries. Nevertheless, the use of bottom trawlers rather than pelagic trawlers when catching horse mackerel due to the ban of this gear in Spanish oceanic waters is obviously a major factor contributing to a high energy use in this fishery.

Results show that horse mackerel landed by coastal bottom trawlers has higher impact respect to purse seining captures, especially for ODP and GWP impact categories (89% and 65%, respectively), whereas ADP and METP present the lowest differences between the two fishing techniques (59% and 49%).

When an economic allocation was performed (data available in Table 3.4), horse mackerel landed by purse seiners showed an increase of roughly 30% for each environmental impact, linked to the fact that this species was the one with the highest economic value in 2008 and that anchovy landings (traditionally being of high economic value) were banned at the time. For bottom trawlers, environmental impacts derived from an economic allocation perspective were roughly 36% lower on average than those obtained through mass allocation. This notable difference is mainly attributable to the fact that hake landings represented on average over 50% of a trawlers' economic turnover, due to the increased value of the species (3.72 €/kg) respect to the other three species.

Regarding the discard rate of the two fishing fleets, it is important to point out the increased rate for bottom trawling vessels (42.1% of the total catch), while purse seiners reported very low discard rates (3.2%), and in all vessels the discard rate was always below 5.0%. Both average results are very close to those reported by Kelleher (2005). In this recent FAO report, a discard rate of 38% was attributed to the Spanish coastal trawling fleet, while the discard rate for purse seiners was 1.6%.

Nevertheless, the high standard deviation obtained for the reported trawling discards in the current study (±16.1%) is considerably high, showing not only a probable lack of transparency when the sector reports these data, but also the need to increase on board inspection of discards. Finally, taking into account that horse mackerel usually congregates in large shoals, it is probable that it generates less discards than other target species of this fleet, so the allocated 727 kg of discard per tonne of landed horse mackerel may be slightly overestimated.

3.4.3. Effects of shifting to low ozone layer depletion cooling agents

Data obtained concerning cooling agent leakage, as mentioned previously, were based on personal communications obtained from technicians in different specialized companies in Galicia. However, it is important to stress that no reliable data were available at a Spanish level from institutions or research centres. Therefore, the quality of data linked to these emissions still has room for improvement.

Table 3.5 shows how this estimated leakage can translate into ODP and GWP contributions of 97% and 17%, respectively for the bottom trawling fleet and 90 and 5% for purse seiners (Scenario 1). If R22 is substituted by R404A (Scenario 2), maintaining the leakage values, ODP contributions due to refrigerant leaks are close to zero, while this refrigerant would represent

11% and 33% of the total GWP characterization values for purse seiners and bottom trawlers, respectively, due to the high global warming potential of some of the main compounds in R404A. Hence, the prohibition to add newly produced R22 in cooling chambers starting in early 2010 will definitely help to reduce considerably the potential depletion of the ozone layer by fishing vessels. In contrast, the use of other compounds, such as R404A, does not seem to guarantee a reduction of burdens related to GWP.

Table 3.5. Effect of cooling agents on characterization values for selected impact categories (Data per FU).

Impact category	**Horse mackerel captured by purse seiners (mass allocation)**		**Horse mackerel captured by bottom trawlers (mass allocation)**	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
GWP (kg CO_2)	797	856	2,279	2,852
ODP (kg CFC 11)	8.7E-4	8.4E-4	7.9E-3	2.3E-4

Scenario 1= Estimated global environmental burdens considering reported R22 leakage; Scenario 2= Total environmental impact considering the same leakage if R404A substitutes R22; GWP= Global Warming Potential; ODP= Ozone Layer Depletion Potential.

3.4.4. Improvement opportunities

Taking into account the different hot spots identified in horse mackerel fishing through trawling or purse seining activities, some improvement actions can be proposed, together with the associated environmental reduction and the feasibility of the improvement.

The reduction of fuel intensity should be a major goal for both fleets when analysing vessel operations. Nevertheless, there is a highly relevant difference in fuel consumption when purse seiners and bottom trawlers are compared, with consumption levels 65% lower for purse seiners. Therefore, considering that bottom trawlers have much more varied target species, targeting a variety of demersal and semi-pelagic species, a change in the fishing strategy for horse mackerel could be proposed. In this context, the current horse mackerel quota for bottom trawlers is 4500 kg per day, while the quota for seiners is 6000 kg per day (Xunta de Galicia, 2008). A quota increase for purse seiners and a steady reduction of quotas for bottom trawlers would reduce considerably the environmental impacts associated to horse mackerel landings, including a considerable reduction of the associated discards. This reduction could be complemented with an increased quota for other targeted species, in order to maintain the economic viability of the bottom trawlers.

Another alternative for fuel intensity reduction would be to propose the reintroduction of pelagic trawls in this fishery. Pelagic trawls, according to previous studies have a reduced fuel effort when compared to bottom trawls (Thrane, 2004; Schau et al., 2009). A recent study by Driscoll and Tyedmers (2010) proved the convenience of introducing management decisions in order to influence energy demands in fisheries. In their study, Atlantic herring from the New England fishery was found to have reduced the related fuel intensity substantially through the seasonal banning of midwater trawlers in favour of purse seining and fixed gears. Nevertheless, the introduction of pelagic trawls in this particular study would only be viable provided that an integral stock assessment study in the area recommended such an initiative.

Technological improvements actions can also be included in the assessed fishing fleets. The introduction of new vessels into the fisheries with changes in hull shapes, in order to provide energy efficiency improvements of up to 20% (Schau et al., 2009) or changes in the energy carrier of the vessels could become long term solutions.

Other operational activities that could undergo potential improvements are anti-fouling loss to sea and net loss. Anti-fouling paints were identified as a main hot spot relating to marine toxicity potential in this study. However, it must be pointed out that anti-fouling paints with a high concentration of copper are already substituting TBT anti-fouling agents, which were banned by the International Maritime Organization in the year 1999 (IMO, 2008). Even so, the use of copper oxides in anti-fouling products was still identified as the main responsible for this impact. Net loss at sea was also found to entail a considerable impact in the marine toxicity category. However, most environmental burdens could be avoided with an increased prevention policy when it comes to loosing nets at sea. The effect of ghost nets on different ecosystems was not assessed in this study.

Ice production is relatively significant in certain impact categories, especially in the purse seining fleet. This is due mainly to the Spanish “electricity mix”, which is still based mainly on fossil fuel energy. On the one hand, the impact linked to ice production may be reduced through the inclusion of fresh water generators on board, taking advantage of the heat loss of the motor. On the other hand, another option is to install a renewable energy production system in the port.

Finally, at this point it is obvious that cooling agent leakage has an increased potential impact on GWP and ODP. Nevertheless, this situation is currently shifting steadily, thanks to an international phasing out scheme on the use of R22 starting in the year 2010 (European Commission, 2000). Therefore, short term challenges will be to monitor the environmental impact shifts that may occur due to the use of substitutive products and to increase safety measures for leakage prevention.

3.5. References

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Chapter 4

Increasing the timeline delimitation in fishery LCA. The case of Atlantic mackerel (*Scomber scombrus*) in the Basque Country[1,2]

Summary

The evaluation of the environmental impacts linked to fish extraction was accomplished on a temporal basis, in order to analyse the effect that stock abundance variations may have on reporting environmental burdens. Inventory data for the North-East Atlantic Mackerel (NEAM) fishing season performed by the Basque coastal purse seining fleet were collected over an eight-year period and used to carry out an LCA study. The FU was set as 1 tonne of landed round fish in a Basque port during the NEAM fishing season for each of the selected years. A series of fishery-specific impact categories and indicators were included in the assessment together with conventional impact categories. The latter showed that environmental impact is dominated by the energy use in the fishery, despite of the low fuel effort identified with respect to other purse seining fisheries. Nevertheless, strong differences in environmental impact were found between years, attributed mainly to remarkable variations in NEAM stock abundance, whereas fishing effort remained quite stable throughout the assessed years. Fishery-specific categories, such as the discard rate or seafloor impact presented reduced impacts in this fishery respect to other small pelagic fish fisheries. Finally, the Fishery in Balance Index (FiB) identified the evolution of NEAM stock abundance for this particular fishery. The outstanding variance in environmental impacts from one season to another evidences the need to expand fishery LCAs in time, in order to attain a more integrated perspective of the environmental performance of a certain fishery or species. This expansion may be an important improvement for activities that rely entirely on the extraction of organisms from wild ecosystems. For instance, future research will have to determine the importance of increasing the timeline in fishery LCAs for species, unlike NEAM, that do not show large stock abundance variations through time or are managed through thorough quota management systems.

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Index

4.1. Introduction

4.1.1 Data availability in fishery LCA studies through time

The importance of including innovative methodological improvements in LCA to broaden its scope and shift to a more comprehensive environmental analysis of fisheries is a major concern for LCA seafood practitioners (Pelletier et al., 2007). Consequently, in recent years there has been a series of publications that have proposed the inclusion of new impact categories in fishery LCA. However, to date, fishery LCA studies have been based on relatively short periods of time - in most cases one season or year – as can be seen in a wide number of publications (Ziegler et al., 2003; 2011; Ramos et al., 2010) and in the case study relating to Atlantic horse mackerel in Galicia (Chapter 3), due to the difficulty of obtaining comprehensive inventory data for a prolonged period of time (Weidema and Wesnaes, 1996; Reap et al., 2008). This situation has led to LCA publications that have not taken into account the irregular cycles that fisheries may be subject to (Pet et al., 1997), especially for those fish species, mainly small pelagic fish (e.g. NEAM), that suffer natural interdecadal abundance fluctuations (Pauly et al., 2002; Fréon et al., 2008).

Given that the case study proposed in Chapter 3 refers to a small pelagic species, attempts were undertaken in order to amplify the inventoried timeline of the assessed vessels. However, the data availability obtained was low and the quality of the few responses received did not allow any type of assessment to be conducted. Therefore, in order to evaluate potential fluctuations in the environmental assessment of different fishing seasons in a small pelagic species fishery, data from an Atlantic mackerel fishery in the Basque Country were used.

4.1.2. The Basque Country fishing fleet

The Basque country has traditionally been an important fishing region at a European level since late medieval times, when whale fishing was an important industry and the first transatlantic vessels started commercializing cod fished off the coast of Newfoundland (Macías-Pereda and Muruaga, 1992). Currently, the importance of the Basque fishing fleet has not diminished, but fleet characteristics and target species have shifted considerably due to the depletion or overexploitation of many traditional fisheries (i.e. the cod fishery in Canada), changing international fishing treaties and gradual changes in consumer patterns (Pauly et al., 2002; Worm and Myers, 2004; FAO, 2010).

The Basque fishing fleet is made up of a coastal fleet that targets small pelagic fish, a cod trawling fleet, an offshore trawling fleet that targets hake in the Northern (ICES Divisions VIIIabd and VII) and Southern stocks (ICES Divisions VIIIc) and finally a strong tuna industry made up of 24 vessels (Table 4.1). Despite of the strong reduction in the number of vessels, tonnage and overall landings in the past few years, the importance of this fleet is obvious since its current total gross tonnage (GT) is comparable to that of Denmark, Ireland or Germany (Murua et al., 2003; EUROSTAT, 2009).

Table 4.1. Number of vessels in the Basque fishing fleet (1992-2007).
Source: EUSTAT 2010.

Fishing fleet	1992	1999	2007
Coastal fleet*	399	340	226
Offshore trawling	107	63	36
Freezer-trawlers	25	5	0
Deep-sea purse seiners	29	29	24
Cod freezer-trawlers	24	8	5
Total Basque fishing fleet	584	445	291

*The analysed purse seiners are included in *Coastal fleet* vessels.

4.1.3. The Northeast Atlantic Mackerel fishery in the Gulf of Biscay

The decrease in landings, however, has not only been affected by the reduction of the fishing fleet forced by the CFP, but also by the increasing limits to the total allowable catch (TAC) for certain species such as European hake or the closure of the anchovy fishery in the Cantabrian Sea (2005-2009). Within this frame, North-East Atlantic mackerel –NEAM- (*Scomber scombrus*), a pelagic shoaling species belonging to the Scombridae family that is widely distributed in European waters (Uriarte et al., 2001; Punzón et al., 2004), presents itself as the only major target fishing species that has not only maintained, but also increased its landings in recent years. The Basque coastal fleet mainly extracts this species in ICES Division VIIIc in the late winter and early spring months (Table 4.2), coinciding with the peak of spawning activity in the East and Central Cantabrian Sea (Uriarte and Lucio, 2001). Most of the vessels involved in the NEAM season are purse seiners, but other gears that occasionally target this species are handlines, trawls and, to a lesser extent, gillnets.

Table 4.2. Calendar of catches for the Basque coastal purse seining fleet.

Species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Atlantic mackerel		░	░	░								
Anchovy					■	■						
Albacore							▓	▓	▓	▓		

NEAM is one of the main pelagic fish species commercialized in Spain. In 2009, 19,400 tonnes of this species were sold fresh across the nation, and 3,000 tonnes were sold canned (MARM, 2010; Martín-Cerdeño, 2010). Additionally, it is also used as bait in many long lining and trolling fisheries. NEAM landings in the Basque country represent approximately 15% of fresh NEAM commercialized in Spain (Mercados Municipales, 2010). However, it is important to highlight that over 90% of NEAM landed in the Basque country corresponds to the February-April period, when together with the neighbouring region of Cantabria, they represent 90% of national landings and sales (MERCASA, 2010).

The apparent robustness of the NEAM fishery in ICES Division VIIIc is reflected by the increasing spawning stock biomass (SSB) pattern in recent years (ICES, 2010) and the strong increase in landings, despite the notable reduction in the number of vessels (Figure 4.1). Nevertheless, the analysed fishing fleet is also threatened by overexploitation, mainly due to the failure to comply with the fixed TACs, and the high fishing mortality (F) of NEAM in the Northeastern Atlantic stock (Table 4.3), which is considered by ICES as a unique stock (ICES, 2007a; 2007b). In fact, recent findings suggest that current stock abundance in the southern section (ICES Divisions VIIIc and IXa) may be linked to a variety of hydrographical factors, such as plankton abundance or temperature shifts (Reid, 2001; Hannesson, 2007). Therefore, the stock increase in this area would be linked to a changing spatial distribution of the species, rather than on a net improvement of the stock.

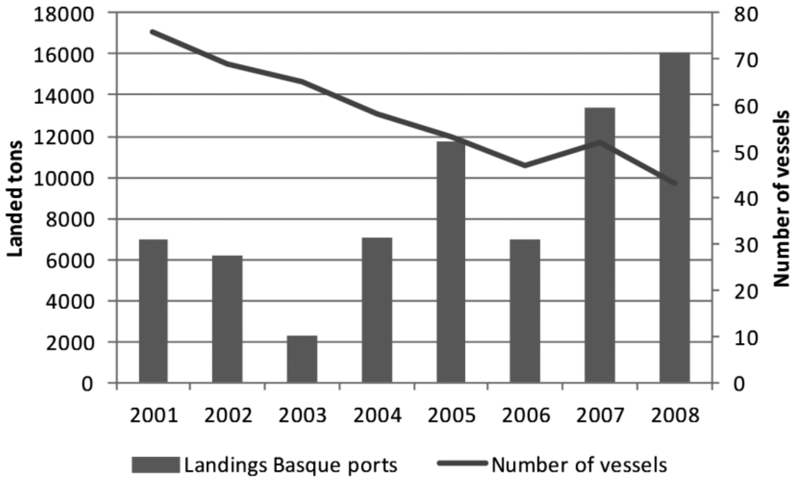

Figure 4.1. NEAM landings in the Basque Country in the 2001-2008 period.
Source: ICES; AZTI.

Table 4.3. Stock assessment summary for the NEAM stock.
Source: ICES.

Year	SSB*	F	Recruitment*	NEAM landings Divs. VIIIc, IXa*	Total allowable catch (TAC)	% over catch respect to TAC
2001	2,138,374	0.40	4,853	43,198	40,180	7.5
2002	1,749,298	0.45	7,854	49,576	41,100	20.6
2003	1,748,701	0.44	3,475	25,823	35,000	-26.2
2004	1,848,672	0.40	4,437	34,840	32,310	7.8
2005	2,290,881	0.28	6,794	49,618	24,870	99.5
2006	2,409,602	0.23	6,915	52,751	26,180	101.5
2007	2,540,759	0.24	3,818	62,834	29,610	112.2
2008	2,709,395	0.23	4,507	59,859	27,010	121.6

*Landings reported in tonnes; SSB= Spawning Stock Biomass; F= Fish mortality.

4.2. Materials and Methods

4.2.1. Goal and scope definition

The main objective of this LCA study is to analyse the NEAM season capture by Basque coastal purse seining vessels in the Gulf of Biscay (ICES Division VIIIc) during an extended period of time. The aim of this evaluation is the identification of potential environmental performance variations on a temporal basis in fleets that target species with strong annual stock abundance fluctuations. Therefore, an 8 year period (2001-2008) was set as the timeline in this particular study.

Additionally, a series of fishery-specific categories or indicators were included in the assessment to aid in the understanding of this fishery from an integrated perspective.

The FU that was selected for this particular research corresponded to 1 tonne of landed round fish in a Basque port during the NEAM fishing season for each of the selected years. This FU is based on the assumption that the main objective of the study was to compare the environmental profile of one same seasonal fishery that was assessed for an 8 year period. The rationale behind using this FU rather than adopting a product perspective (i.e., exclusively NEAM landings) is linked to the fact that it is more realistic to assess a fishery in terms of the total catch and landings, rather than on the independent landing rates of the targeted species, especially when analysing and discussing fishery-specific indicators or categories.

The selected fishing fleet was chosen based on the fact that it represented roughly 75% of annual landings of NEAM in Basque ports (Table 4.4). The system under study was made up of the different operational stages performed by the assessed coastal purse seining vessels, including diesel consumption, anti-fouling, marine lubricant oil and trawl net use and ice consumption. The construction and maintenance of the vessels, as well as cooling agent emissions were also included. However, it is important to note that this study only focuses on the Atlantic mackerel fishing season performed by the selected vessels each year. Therefore, the inventory and the environmental impacts that will be associated to the LCI will only correspond to the assigned resource use and related emissions for the seasonal period that corresponds to NEAM extraction, as will be discussed further on.

NEAM is the main target species, although a series of by-catch species, mainly European pilchard, are also landed. These species were analysed ranging from the production of the supply materials until landing operations for sale at Basque ports. Therefore, this assessment constituted a “cradle to gate” analysis (Guinée et al., 2001). The backup for this decision is the fact that on land seafood operations are not subject to the strong yearly fluctuations that are expected for fishery activities. However, it is important to note that landing operations included only take into account landing operations done on board, while on land operations at port were excluded.

Table 4.4. Selected vessel samples for the 2001-2008 period.

	2001	2002	2003	2004	2005	2006	2007	2008
Sample size	35	28	30	31	41	27	45	35
% over total fleet	46.1	40.6	46.2	53.4	77.4	57.4	86.5	81.4
Average beam (m)	29.2	28.0	27.2	30.8	31.6	33.0	32.3	32.1
Average daily capture by vessel (tonnes)	5.77	5.94	2.04	6.76	11.16	10.02	17.82	22.13
Total NEAM landings (tonnes)	3,222	2,286	164	2,990	7,255	2,897	10,171	11,394
% over total NEAM landings	63.3	68.9	36.9	77.2	96.9	87.8	99.6	97.3
% of NEAM landings over total	79.8	85.8	33.4	83.9	93.3	89.3	97.6	98.1

4.2.2. Data acquisition

The samples used for this study corresponded to a set of purse seining vessels belonging to the Basque coastal fishing fleet obtained according to availability for the different years, as observed in Table 4.4. The primary data for fishing vessel operations were obtained mainly from a specific Basque register of fish at first sale provided by the Marine Research Division at AZTI[3]. Landings, vessel characteristics (beam, GT, etc), fishing operations and fishing areas were the most relevant data obtained from the register. It is important to highlight that data from this register were obtained through a series of questionnaires filled out by AZTI observers, in direct collaboration with skippers from the most important purse seining ports in the Basque country. The response rate to these questionnaires can be seen in Table 4.4. A series of additional information, such as the number of seine nets used per vessel or the consumed ice were obtained through personal communication from Basque fishermen and skippers (J.A. Luzarraga, shipowner, personal communication, November, 2010). Cooling agent emissions were provided by AZTI's Marine Research Division (Aboitiz and Pereira, 2009; Xabier Aboitiz, 2011, personal communication). Finally, background data associated with the production of diesel, nets or anti-fouling and boat paint were obtained from the ecoinvent® database (Frischknecht et al., 2007).

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[3] AZTI is a Marine and Food Technological Centre in the Basque Country, Spain.

4.2.3. Co-product allocation strategies

The purse seining fishing fleet under study presents three distinct fishing seasons, as mentioned in Table 4.2. The first two seasons, the NEAM and the anchovy season, take place in the first half of the year, while the albacore fishing season[4] takes place throughout the second half of the year. Therefore, temporal allocation for construction and maintenance materials in the LCI was performed by assigning half of the annual inputs/outputs to the albacore season, while the other half was assigned proportionally to the other two fishing seasons depending on their annual length in days[5]. It is important to note that this procedure is influenced by the fact that the anchovy fishery has suffered strong restrictions or closure in recent years (ICES, 2009). Additionally, the same procedure was implemented to allocate cooling agent emissions to the assessed fishing seasons.

No further allocations were needed in the selected case study due to the characteristics of the chosen FU. In other words, the fact that NEAM and by-catch are analysed globally in terms of total landings makes it possible to disregard other allocation procedures, such as mass or economic allocation (Ayer et al., 2007). The rationale for disregarding mass allocation, which would be appropriate due to the similar economic value of the entire catch, is linked to the fact that it is more feasible to evaluate a fishery in terms of the total catch and landings, rather than on the independent landing rates of the targeted species, especially when analysing and discussing fishery-specific indicators or categories. Additionally, the highly specialized NEAM fishing season involves low by-catch rates. For instance, as seen in Figure 4.2, NEAM landings represent at least 80% of the total catches during the NEAM fishing season in all the assessed years, except for the year 2003, coinciding with the *Prestige* oil spill, in which NEAM landings represented only 33% of the total.

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[4] Landings in this season include albacore, bluefin and bigeye tuna individuals.

[5] This assignment was done individually for each vessel, rather than computing an average duration of each fishing season for the entire sample or fleet.

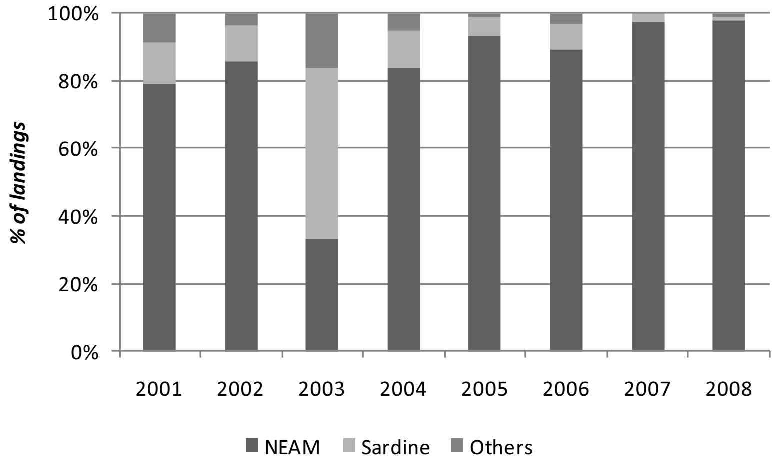


Figure 4.2. Relative landings of selected fishing species by Basque purse seiners in the assessed fishing seasons.

4.2.4. Life Cycle Inventory

The development of the LCI, as already mentioned in previous chapters, involves the collection and computation of the data in order to quantify the relevant inputs and outputs, constituting the most time consuming step compared to other LCA phases, due to the difficulty in collecting comprehensive data (ISO, 2006). Hence, this last issue is probably the main responsible for the scarce appearance of long period analysis in fisheries LCA, together with the fact that this methodology has only been implemented recently in this field. Therefore, data in this study were collected for an increased period of time, in order to achieve a reliable and representative picture of the environmental performance of the analysed system.

A simplified inventory summary regarding the main inputs and outputs of the studied system is shown in Table 4.5, while additional data can be observed in Tables C.1 and C.2 in Appendix I. Inventory data relating to NEAM landings were obtained from a range of 27 to 45 purse seiners depending on the assessed year, representing at least 40% of the total purse seining fleet (Table 4.4). Unfortunately, only 6 vessels were assessed for the entire period, due to vessel scrapping in order to meet CFP regulations and lack of data availability for certain years.

Table 4.5. Inventory for fish landed in the NEAM season in Basque ports by coastal purse seiners for selected years of the 2001-2008 period (Data per FU).

INPUTS				
From the technosphere				
Materials and fuels	**Units**	**2001**	**2004**	**2008**
Diesel	kg	31.53	34.63	14.62
Steel	kg	7.01	9.80	7.15
Anti-fouling	g	884	1,249	930.5
Boat paint	g	310	440	332.1
Marine lubricant oil	g	80.0	87.8	37.1
Ice	kg	125	125.2	122.6
Seine net[1]	kg	3.68	3.69	2.65
OUTPUTS				
To the technosphere				
Products	**Units**	**2001**	**2004**	**2008**
Total round fish	t	1	1	1
NEAM	t	0.798	0.839	0.981
Other pelagic fish	t	0.202	0.161	0.019
To the environment				
Emissions to the atmosphere				
1. CO_2	kg	100.0	109.8	46.33
2. SO_2	g	315	346	146
3. VOC	g	75.7	83.1	35.1
4. NO_x	kg	2.27	2.49	1.05
5. CO	g	233	256	108
6. R22	g	4.08	4.52	3.40
Emissions to the ocean				
1. Xylene	g	80.9	114.4	85.2
2. Dicopper oxides	g	183	259	193
3. Zinc oxides	g	82.8	117.1	87.2
4. Nylon	g	421	423	304
5. Lead	g	93.2	93.5	67.3

[1] The seine net includes nylon, lead and cork as raw materials.

Discard amounts were not available for this fleet. Nevertheless, discussion on average ranges relating to discards in these types of fisheries was included. SIP proposed by Nilsson and

Ziegler (2007) was assumed to be minimal for the gear used by this particular fleet. Nevertheless, this issue will be analysed in the discussion section.

4.2.5. Selection of impact categories

CML baseline 2000 method was selected as the computational framework for the attributional (retrospective) LCA analysis (Heijungs et al., 1992; Guinée et al., 2001). The impact categories that were included in the assessment were: ADP, AP, EP, GWP, ODP, POFP and METP. The software that was used for the computational implementation of the inventories was Simapro 7.3 (Goedkoop et al., 2010). Additionally, a series of fishery-specific categories were discussed in this research, including discard reporting, SIP as proposed by Nilsson and Ziegler (2007) and the FiB Index as proposed by Pauly et al. 1998. The FiB Index aims at identifying the *fishing down marine food webs* phenomenon, which suggests that when fish species at the top of the trophic chain are overexploited, the captures of species lower down in the trophic level increase (Pauly et al., 1998; Villasante, 2009).

4.3. Results

4.3.1. Environmental performance of Atlantic horse mackerel landed by bottom trawlers

Vessel operations were the main activities linked to fish extraction in the NEAM season that contributed to the environmental impact in all the conventional impact categories assessed, except for ODP, in which no environmental emissions were generated by this subsystem, and ADP. Nevertheless, a series of differences were found between the evaluated years. For instance, for GWP, contributions ranged from 48% in 2002, to 62% in 2004, while contributions to METP were in all years above 83% (year 2001). Diesel consumption was identified as the main contributor to environmental impact within vessel operations for all impact categories, except for METP. In this case, the main burden was linked to anti-fouling emissions to the ocean.

For the ADP impact category the main environmental burdens were linked to the diesel production subsystem. For this particular activity, impacts ranged from 54% in 2002 to 71% in 2004. The relative contribution of diesel production to the other impact categories was in all cases below 10%.

ODP relative contributions were overwhelmingly related to cooling agent emissions by the refrigeration systems on board. Their contribution to this impact category was at least 90% (years 2001 and 2004). Additionally, cooling agents (mainly R22), also presented relevant environmental impacts for GWP, ranging from 4% in 2001 to 9% in 2003.

Finally, the net production and transportation subsystem also appeared as an important contributor in the ADP and GWP categories, with values ranging from 17% in 2004 to 34% in 2002 for ADP and from 14% in 2004 to 29% in 2002 for GWP. Other relevant activities or processes regarding environmental impact were the ice production system and to a lesser extent operations relating to the construction and maintenance of the vessels (anti-fouling and steel production). More detailed data on individual contributions per activity may be consulted in Tables C.3a-C.3f in Appendix I.

When the total environmental burdens for the different seasons are compared, as observed in Figure 4.3, 2008 appears as the year with lowest associated burdens per FU for all impact categories, except for METP. The lowest impacts for the average vessel for METP were achieved in 2001. On the contrary, the season in 2003 had the highest associated impacts for all impact categories.

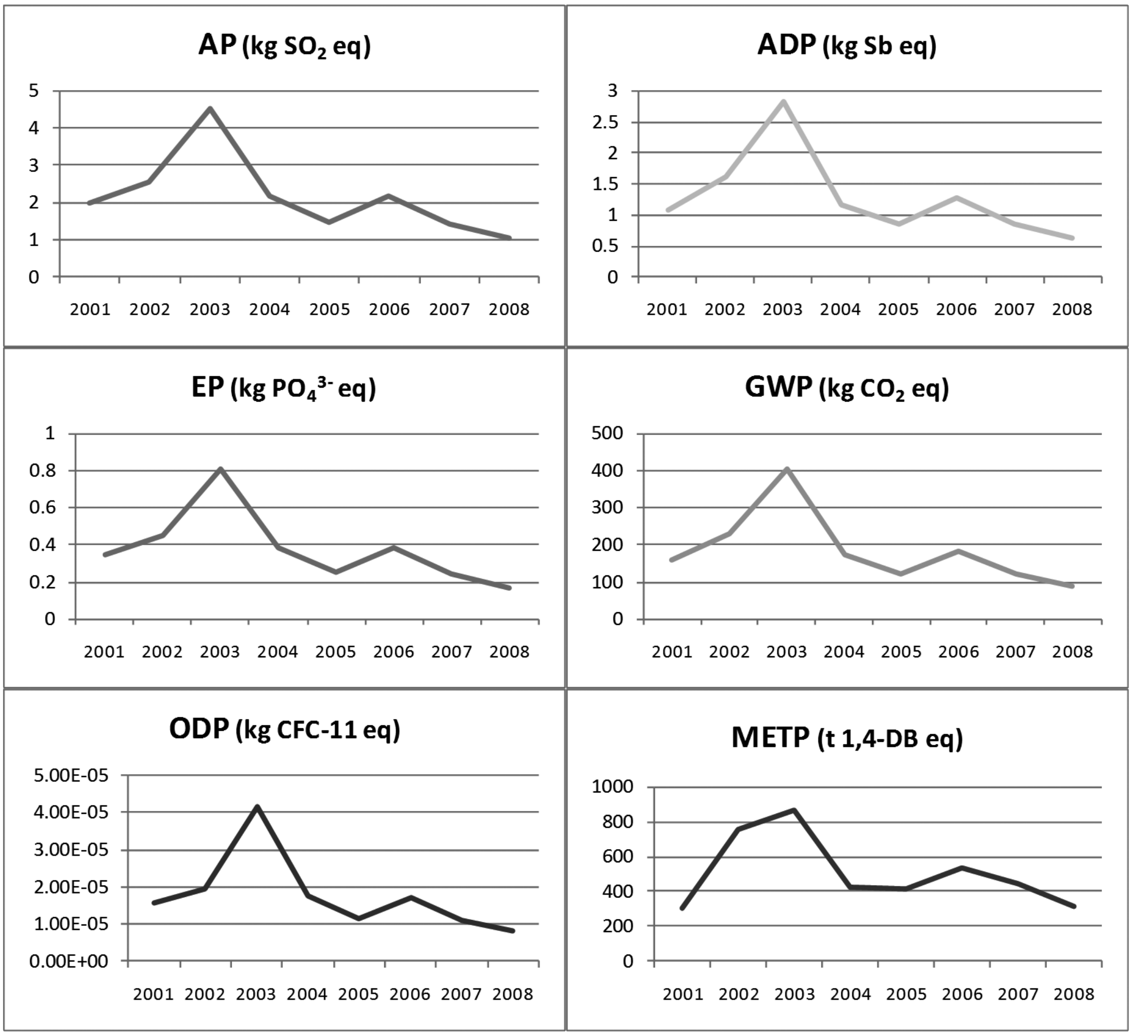


Figure 4.3. Environmental impact potentials for the average vessel per FU in the assessed period. Impact category acronyms: ADP= abiotic depletion potential; AP= acidification potential; EP= eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; METP= marine aquatic eco-toxicity potential.

If the 2001 season is taken as the reference, since it is the first assessed period in the selected time scale, a high oscillation in the environmental impacts can be observed from one season to another. On the one hand, the NEAM season in 2003 shows environmental impacts at least 130% higher respect to the reference year (AP), while in some impact categories it is 324% higher (METP). Additionally, other NEAM seasons in which the associated burdens are above those registered for 2001 are 2002, 2004 and 2006.

On the other hand, the NEAM seasons in years 2005, 2007 and 2008 showed reduced environmental impacts when compared to the reference year. The lowest impacts corresponded to year 2008, in which the associated burdens were, for example, 43% lower than in the reference year for ADP and GWP. The results for years 2005 and 2007 were very similar, with environmental impacts ranging from 19 to 27% less than in the year 2001 for ADP, AP, EP and GWP.

4.3.2. Fishery-specific environmental impacts

Discard data were not available in this fleet for any of the assessed years. Nevertheless, according to a series of personal communications in Basque ports, skippers and fishermen confirmed that the discards generated through captures in the NEAM season by the Basque purse seining fleet are close to the average 1.6% reported by Kelleher (2005) for pelagic purse seining fisheries (J. Ruiz, marine researcher, personal communication, November 3, 2010).

As observed in Figure 4.4, the FiB Index shows a strong decline in the 2001-2003 period, a relatively stable period from 2004 to 2006 and a moderate increase in the final two years of the study. The year with the strongest fall in the index was 2003, in which the decrease was above 1, while 2008 appeared as the year with highest increase in the FiB Index (0.26). These results are in accordance with the mean trophic level (MTL) observed in the different years (Figure 4.4), showing, in the first place, a strong decline in the 2001-2003 period, and secondly a quick recovery and stabilization at a trophic level of around 3.6 until 2008. This tendency would translate in a 0.225 increase in the trophic level per decade.

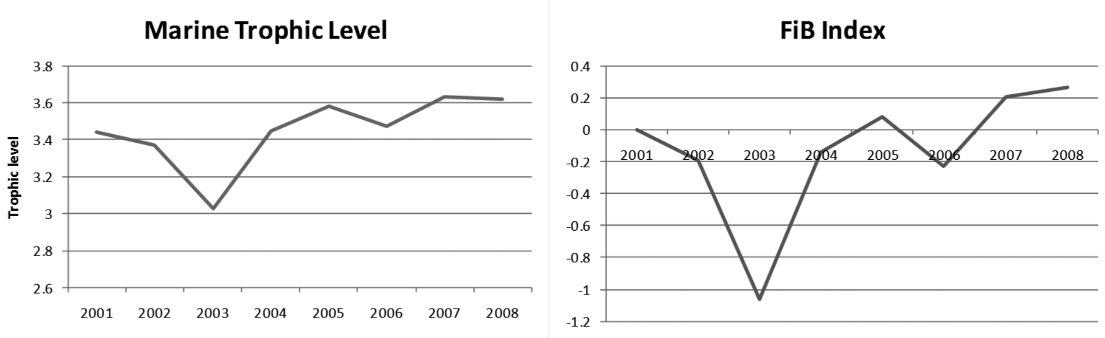


Figure 4.4. a) Calculated MTL for the Basque captures during the NEAM season (years 2001-2008). b) FiB Index for the Basque NEAM season (years 2001-2008).

4.4. Discussion

4.4.1. The importance of applying fisheries LCA for a significant extent of time

Environmental burdens related to the landing of 1 tonne of pelagic fish in Basque ports show similar trends to other landings fished by purse seiners in other fisheries (Thrane, 2004; Hospido and Tyedmers, 2005), despite the increased variance that was observed between the selected years. Furthermore, due to the reduced fuel consumption of the analysed fleet during the NEAM season, fuel related vessel operations only represented from 48% (2002) to 62% (2004) of the total environmental impact for GWP. Therefore, the importance of other vessel subsystems, such as net or ice production is greater than in other fleets that are more fuel intensive (Thrane, 2004).

Nevertheless, the fact that this study comprises a relatively long period of time shows that there can be a great difference in the environmental burdens for a given impact category from one year to another. For instance, regarding GWP, the associated environmental impact per FU in the year 2003 was of 445 kg CO_2 eq., 4.68 times more than in 2008 (95 kg CO_2 eq.). This tendency was observed for all the conventional impact categories that were included in this study, highlighting the importance of extending LCA inventories to wider periods of time, in order to obtain a broader perspective of the impacts associated to a particular fishery.

Additionally, this improvement may be extremely useful for those species that show erratic biomass and fecundity patterns (Fréon et al., 2008) or for those species that are under recovering schemes in depleted fisheries, since stock abundance variations and fishing overcapacity may generate a context that triggers fluctuations in environmental impact per FU.

The specific circumstances that surround fisheries as an industrial system make them unpredictable, since they are majorly dependent on fish abundance in a given period of time and spatial distribution. Other factors that may influence a fishery, such as management policies, are just a consequence of guaranteeing the sustainability of a limited resource (Clover, 2006). Therefore, the extension of LCA inventories in the timeline may be an important improvement for activities that rely entirely on the extraction of organisms from wild ecosystems (Hospido and Tyedmers, 2005).

Furthermore, an extended timeline in fishery LCAs not only allows identifying tendencies in a particular fishery, but may also help detect specific circumstances that create a brusque variation in LCA characterization values. For instance, the outstandingly high environmental impact results attained in the 2003 NEAM fishing season coincide with the wreck of the oil tanker *Prestige* off the Galician coast (November 19th 2002), which affected great part of the surface in the Cantabrian sea shelf. In fact, Sánchez et al. (2006) identified significant reductions in the abundance of megrim, Norway lobster (*Nephrops norvegicus*) and Pandalid shrimp (*Plesionika heterocarpus*) during the year 2003, with noteworthy recoveries during the 2004 season. Despite the fact that none of these species are pelagic, it is highly probable that NEAM suffered similar consequences linked to the oil spill, especially taking into account that during NEAM spawning, which starts usually in late February, there was an elevated presence of oil masses in the Cantabrian sea continental shelf (Sánchez et al., 2006).

Therefore, obtained results suggest the need to increase the timeframe of fisheries LCA on a regular basis. However, the handling of the results attained when timeline analysis is applied may give rise to biased or incorrect conclusions, due to the increased difficulty linked to multiple result interpretation. Hence, given that yearly results can be somewhat misleading, revealing the need to smoothen out short-term fluctuations at the same time as highlighting longer-term cycles, a five year moving average was proposed (Hamilton, 1994), as can be observed in Figure 4.5 for the GWP impact category.

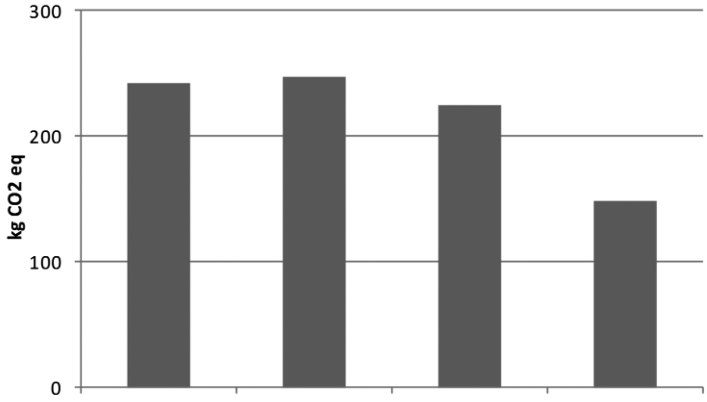


Figure 4.5. 5-year moving average for the GWP impact category.

4.4.2. Energy use

In terms of direct fuel consumption in the analysed fishery, the average consumption ranges from 14.6 kg fuel/t fish in 2008 to 41.1 kg fuel/t fish in 2002, except for the year 2003, in which the energy use rocketed to 75.9 kg fuel/t fish. Therefore, the tendency observed for the assessed years shows that fuel consumption per tonne of landed fish has decreased considerably in this period (see Tables C.1 and C.2 in Appendix I). Recent literature (Schau et al., 2009), suggested that strong declines in this ratio are usually linked to important increases in the fuel price. However, the low fuel consumption associated with this fishery makes the fleet less sensitive to the fluctuations in fuel price. In fact, the increase in the amount of landings per day and vessel (Table 4.4), as well as the overall increase in landings for the years that presented lower energy use and environmental impacts (Figure 4.1), suggest that a leading factor influencing the environmental impact in this fishery is fish availability.

Comparison of these results with other studies shows that they are on the lower range of fuel intensity for purse seiners (Tyedmers, 2001; Schau et al., 2009; Winther et al., 2009; Driscoll and Tyedmers, 2010). More specifically, when the fuel effort of NEAM season landings is compared to that of other NEAM landing fleets, the fuel intensity in the Basque fishery is considerably lower than in other important NEAM fishing regions, such as Galicia, 176 kg of fuel/t NEAM or Norway, 90 kg of fuel/t NEAM (Tyedmers, 2001; Schau et al., 2009).

The increased fuel intensity reported not only for Galician NEAM landings by purse seiners, but also for NEAM landings regarding the Galician coastal bottom trawling fleet, when compared to those in the Basque Country, evidences the high environmental impact variability between regions showing the risks of reporting LCA results at a national scale for a particular coastal species (Table 4.6). Additionally, the relevance of studying these spatial variations increases when the fisheries of the analysed country show independent patterns regarding fishing fleet characteristics and fishery management. It is important to note that results reported in Table 4.6 for the three fishing fleets are reported for 1 ton of landed NEAM following mass allocation.

Table 4.6. Comparative characterization values for selected impact categories for 1 tonne of round NEAM in three different Northern Spain fisheries (year=2008).

	Unit	F1	F2	F3
Sample size	u	35	30	24
Average beam	m	32.1	17	28
Energy use	kg fuel/t fish	14.6	176	496
Impact categories				
ADP	kg Sb eq	0.62	4.99	12.27
AP	kg SO_2 eq	1.04	10.2	27.21
EP	kg PO_4^{3-} eq	0.24	1.95	4.97
GWP	kg CO_2 eq	94.6	797	2,279
ODP	kg CFC-11 eq	1.24E-4	8.66E-4	7.86E-3
METP	t 1,4DCB eq	351	226	440
POFP	kg C_2H_4 eq	0.03	0.21	0.52
Discards	kg/FU	16.3	33.1	727
SIP	km^2	0	0	0.68

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrophication Potential; GWP= Global Warming Potential; METP= marine aquatic eco-toxicity potential; POFP= photochemical oxidant formation potential; SIP= Seafloor Impact Potential; F1= Basque purse seining fleet; F2 = Galician coastal purse seining; F3 = Galician coastal bottom trawling.

The main reasons related to this low fuel intensity are mainly related to the specialized season of NEAM catches in the gulf of Biscay, together with other key factors such as the reduced width of the continental platform in this area compared to the Galician coast. The prohibition of purse seiners to fish within the Galician *rías*, forcing the fishing fleet in that area to target NEAM stocks at an increased distance from the coastline (MARM, 2004), has also an important influence on the results.

4.4.3 Environmental impacts identified through fishery-specific impact assessment

The inclusion of fishery-specific results in LCA studies, as mentioned above, is a growing concern. However, in this particular research study the lack of specific discard data for the assessed fishery may have skewed the fishery-specific impact categories to a certain extent. Nevertheless, other publications relating to discards in pelagic fisheries in NW Spain, together with Basque skippers and fishermen comments, suggest that the discard rate for the NEAM season is very low. In fact, the reported discard rate for the Galician purse seining fleet targeting NEAM, horse mackerel and sardines, as seen in Chapter 3, was 3.2% in 2008, while Kelleher (2005) reported that seining linked discards in this area are close to the estimated 1.6% for this fishing gear worldwide.

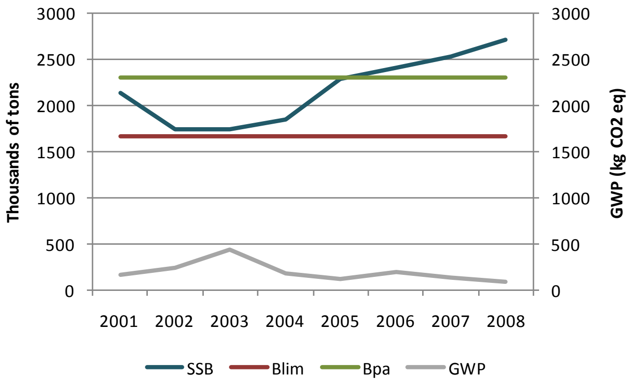
SIP was not applied to this fishery, since it was assumed that purse seining is a fishing gear that causes negligible direct damage on the seafloor according to this index, despite the fact that lost nets can potentially create ghost fishing (Brown and Macfayden, 2007; ICES, 2000). Additionally, as can be observed in Table 4.6, NEAM landings performed by trawlers imply a considerable impact on the seafloor, showing that trawling fleets can create an increased impact on benthic ecosystems (Ziegler et al., 2003).

Regarding fishery exploitation, the increasing pattern for MTL (0.225 per decade) is quite remarkable when taking into account that fisheries assessed worldwide present a decreasing MTL (Pauly et al., 1998; Villasante, 2009), especially those in which the targeted species are those with a higher trophic level (Branch et al., 2010). This increase is reflected in the FiB Index, which shows increasing positive values in the 2005-2008 period, contrasting with a sharp negative value for 2003. This tendency suggests that the increase in landings in the last few years of the assessed timeline is stronger than the net primary productivity may sustain through time or an expansion in the spatial distribution of the fishery (Pauly et al., 1998). The latter does not seem likely, since skippers from the Basque seining fleet reported not having changed their fishing zones in the assessed years.

A high number of ecosystems analysed in previous studies worldwide regarding MTL show that an increase in fish landings is usually linked to higher landings of species with a low trophic level. However, the theory of fishing down marine food webs is not completely valid for this particular case study, mainly because of the fact that at least 79% of the landings of the fishery correspond to NEAM in each season. Furthermore, taking into account that this study also focuses exclusively on the NEAM fishing season does not make it possible to see the effects that the variable landings of the species may have on other coastal fishing seasons, not only of the coastal purse seining fleet, but also of other fleets that work in the area. Nevertheless, recent studies have identified a clear tendency in the last couple of decades in which the peak of catches for NEAM in the Cantabrian sea has shifted forward (Punzón and Villamor, 2009), a situation that could also have important consequences on the ecosystem and the management of the fishery.

A certain correlation between yearly SSB variations and fluctuations in annual environmental impact for the selected categories was observed for this fishery, as can be observed in Figure 4.6. More specifically, the lowest levels of SSB, close to the biomass limit reference point

(B_{lim}) are observed in the years with highest environmental impacts (2002-2003), while the lowest impacts for all the selected categories were found in years in which SSB levels were above the biomass precautionary approach reference point (B_{pa}).



SSB= spawning stock biomass B_{lim}= biomass limit reference point

GWP= global warming potential B_{pa}= biomass precautionary approach reference

Figure 4.6. Annual spawning stock biomass (SSB) for the NEAM stock compared to annual global warming potential (GWP) environmental impacts for the assessed fishing fleet.
Source: ICES 2010.

The fact that energy use, as mentioned in the previous section, is lowest coinciding with the years with highest captures and SSB, suggests that environmental impacts in pelagic fisheries may be considerably influenced by the availability of fish in a given time period, provided that the vessels' fishing patterns do not experiment significant changes. Nevertheless, a number of factors can influence the obtained results, such as the spatial distribution of the species and fishing management policies (e. g. the fulfilment of the NEAM TAC for Spain may cause increased environmental impacts per functional unit if strict daily quotas were to be enforced). Therefore, further research in this field should be taken in order to determine to what extent stock abundance affects the assessed environmental impacts.

Finally, an additional factor that must be taken into account is the fact that the strong increase in stock abundance and landing in the Basque NEAM fishery may cause an increasing building capacity due to the expansion of the resources, which could develop into fleet and industry overcapacity whenever there is a new decline in the resources (Fréon et al., 2008; Villasante, 2010; Villasante and Sumaila, 2010).

4.5. Conclusions

This study constitutes the first fishery LCA study in which there is sufficient data in order to conduct the methodology throughout a wide period of time. To date, LCA studies, despite having a broad and praiseworthy work behind when developing the LCI, failed to display the variations in environmental impact that a particular fishery or species could have from one year to another. The results obtained in this study suggest the need to increase the timeframe of fisheries LCA on a regular basis when assessing small pelagic species, such as NEAM, since they show strong annual environmental impact variations, in order to increase their feasibility and accurateness.

Nevertheless, with the aim to avoid misleading multiple result interpretations, a five year moving average is proposed for result reporting. Further research is recommended in order to assess the importance of increasing the timeline in fisheries LCA for those species that show small annual variations in environmental impacts.

More specifically, the life cycle environmental impact of NEAM extraction in the Basque country displayed low environmental impacts per FU, with a similar range to herring landing found in literature. When compared with other fisheries targeting NEAM, such as the Galician coastal seining fleet, the Basque fleet presented environmental impacts up to 88% lower, demonstrating the high regional variability that can be identified within the same country and the risks of reporting fishery LCA results at a national scale.

Finally, the Basque purse seining fleet has shown minimal fishery-specific impacts when regarding discards or seafloor impact. Furthermore, the increasing abundance of NEAM stocks in this area of the Bay of Biscay demonstrates an acceptable state of the stock in its southern area. Nevertheless, the strong increase in landings in the studied period, which has been brought about due to extensive overfishing, may create a future overcapacity of this particular industry (fleet and processing plants) if institutions were to allow an uncontrolled expansion of the sector.

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Chapter 5

Life Cycle Assessment of fresh hake (*Merluccius merluccius)* captured by the Galician fleet in the Northern Stock[1,2]

Summary

European hake (*Merluccius merluccius*), one of the main products in the average Spanish diet, represents the highest economic income for Galician fishing fleets. In this study, LCA was used to assess the environmental impacts related to the extraction, processing and consumption of European hake captured by Galician trawlers and long liners in the Northern Stock. Furthermore, biological-related impact categories, such as by-catch and discards were also considered in the analysis. Results show considerably lower environmental impacts for European hake fresh fillets arriving from long lining vessels, due mainly to the high energy demand of the analysed trawlers. In this sense, the main part of the impact for hake arriving from both fishing fleets was attributable to marine diesel-linked activities.

Post-fishing activities, such as land transport or electricity consumption, were also highlighted as important contributors within their subsystems. Global environmental performance of the system can only be reduced through fuel consumption minimization. However, impact minimization in the fresh hake post-harvesting activities may offer attractive cost reductions for retailers, wholesalers and consumers.

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[1] Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2011). "Life Cycle Assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock". *Fisheries Research,* 110: 128-135

[2] Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2012). Corrigendum to "Life Cycle Assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock". *Fisheries Research,* doi: 10.1016/j.fishres.201201.020

Index

5.1. Introduction

5.1.1. Hake fisheries

The hake family Merlucciidae has traditionally been a very important catch within the fishing industry, as many of its species sustain a significant fishery (FAO, 2005). This genus is highly distributed geographically, being present in both hemispheres and in all oceans. However, more than two-thirds of the worldwide hake catch is captured in Atlantic waters. This situation is related to the fact that hake is a very popular dish in some Ibero-American countries, especially Spain, Argentina and Uruguay, constituting an important protein source in the dietary habits of the population. In 2001, the average Spanish citizen consumed 16.3 kg of fresh fish annually, of which 3.3 kg corresponded to hake species (Piquero and López Losa, 2001). Therefore, it is not surprising that over 40% of the hake landed in European ports comes from a Galician port (Figure 5.1).

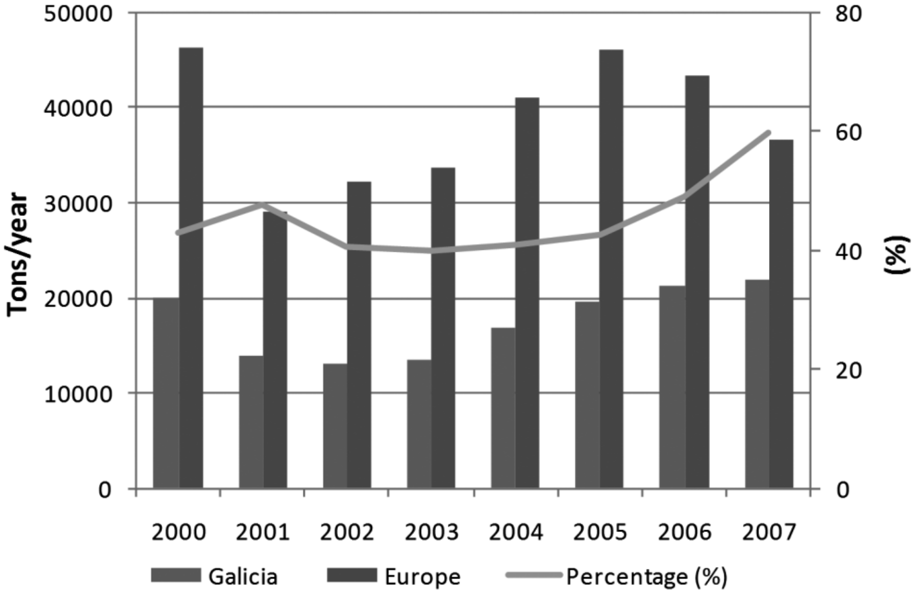

Figure 5.1. Hake landings in Galicia (Black bar) and Europe (Grey bar) in 2000–2007. Galician hake landing percentage over European total.
Source: FAO (2010) and Xunta de Galicia (2009).

European hake, *Merluccius merluccius*, is the main species of hake found in the Northeast Atlantic ranging from Norway to the Gulf of Guinea, including the Mediterranean and Black seas

(Casey and Pereiro, 1995). It is a large predatory fish found mainly in demersal areas on the continental shelf and upper continental slope. European hake is the most representative fish that the Spanish population eats fresh, arriving mainly from the so-called Northern Stock (ICES Divisions VIIIa, b, d and VII) and Southern Stock (ICES Division VIIIc and IXa).

It is estimated that hake fisheries nowadays show low possibilities for expansion, due mainly to overexploitation, despite the increased resistance to fishing pressure shown by most hake populations (Pitcher and Alheit, 1995; Piñeiro et al., 2008). This has led international organizations to adopt recovery plans for both the Northern Stock in 2004 and Southern stock in 2005. The situation in the Northern Stock has improved. In this sense, hake in this area has reached full reproductive capacity and fishing mortality levels have been reduced to relatively safe ranges (ICES, 2008). In a 2008 advice report, the International Council for the Exploitation of the Sea (ICES), expressed alarm about the unsustainable harvesting that was still being implemented in the Southern Stock due to overfishing that was reflected in a reduced reproductive capacity. However, recent research suggests that hake grow at faster rates than previously accepted. Therefore, this underestimation in hake growth may have important consequences on stock assessment and management issues (Piñeiro et al., 2007; 2008).

5.1.2. The Galician fleet in the Grand Sole

In this study, European hake captured by the Galician fleet in the Northern Stock by two different types of fishing vessels (trawlers and long liners) was analysed from an environmental point of view. The main areas where these fleets capture hake and other species in a multispecies fishery are mainly the Porcupine Bank (ICES Division VIIc), the West Great Sole (ICES Division VIIk), the Great Sole (ICES Division VIIj) and the Little Sole (ICES Division VIIh).

The 49 Galician long liners working in this fishery in 2008 landed their captures mainly in the ports of Burela and Celeiro (North Galician coast). The demersal target species captured by these vessels are European hake, Atlantic pomfret (*Brama brama*) and fork beard (*Phycis phycis*). Small amounts of common ling, rock fish and conger eel are also captured. Tides for this fleet usually range from 14 to 17 days. Nevertheless, European hake is by far the main target species of this fleet, representing roughly 60% of total captures (Porto de Celeiro, 2010). Approximately 70% of the hake caught by this fleet is then sold fresh. However, the capture obtained in the first few days of each tide reaches prices considerably lower than individuals caught in the last days of the tide (CETPEC, 2009; Xunta de Galicia, 2009).

The Galician trawling fleet working in this area is composed of a total of 63 vessels distributed in 6 ports, with an average beam above 34 m. The main species caught by these otter trawlers include megrim and anglerfish (*Lophius budegassa*). European hake represents from 10% to 20% of the total landings of this fleet (Porto de Vigo, 2009). Landings of captured fish are performed mainly at the fish market in Vigo, after 15–20 day tides, slightly longer than those of long liners. Nevertheless, some vessels may occasionally land the capture in other important Galician ports such as Celeiro, A Coruña or Marín. European hake captured by these vessels is sold mainly for fresh consumption, although some may also go towards frozen products. The highest quality hake individuals can compete with those obtained through long lining activities (Xunta de Galicia, 2009).

5.1.3. Purpose of the study

Hake constitutes one of the main products in the dietary habits of Spaniards. In fact, Mercamadrid, the biggest fish market in Europe and only second to Tsukiji in Tokyo on an international scale, sold over 86,000 tonnes of fresh fish in the year 2008 (Clover, 2006; Mercamadrid, 2010). About 14,600 tonnes corresponded to adult hake alone. Another 8000 tonnes corresponded to *pescadilla*, small hake slightly above the minimum landing size (27 cm), which weighs from 500 g to 1.5 kg (Mercamadrid, 2010). Therefore, in this study an attempt was made to collect inventory data for the entire life cycle of European hake, the most common hake species commercialized in Spain.

In this particular case study, LCA methodology is used to analyse the capture, landing, distribution and consumption of European hake fresh fillets caught in the Northern Stock by Galician vessels. Therefore, unlike in the fisheries evaluated in Chapters 3 and 4, the landed products at Galician ports are analysed throughout the supply chain. Moreover, a comparison is established between two different types of fishing vessels (trawlers and long liners) in order to determine the environmental burdens associated with an equally marketable product (hake fillets) extracted in two different ways. In fact, hot spots identification and improvement opportunities for the two systems are important discussion points in this study. Finally, discussion relating to the quantification of improvements in fish discarding is also analysed for the selected fleets.

5.2. Methods

5.2.1. Functional unit and scope definition

The selected FU for this LCA of fresh Hake fillets was based on the recommended weekly intake of fish by the Spanish Nutrition Society. This society considers that 3 or 4 weekly fillets of fish (125–150 g per raw fillet) are the most reasonable amount a human should intake in the abovementioned period (Dapcich et al., 2004). Therefore, the selected FU was set at 500 g of raw gutted fresh hake fillet reaching the household of an average consumer in the year 2008. Due to the waste generated by the product through its life cycle, 500 g of raw fresh hake fillet correspond to 645 g of landed hake (Porto de Celeiro, January 2010, personal communication; Ranken, 1969)[3].

The scope of this study focuses on all the main subsystems relating to the hake extractive industry (Figure 5.2). In this sense, the different operational stages of fish extraction, through landing in Galician ports were taken into account. A series of biological related impacts, such as ecosystem disruption or damage to the seafloor by fishing gears were excluded from the inventory for harvesting operations. Discards were excluded from the LCIA, but discard data are discussed throughout the study. Post-harvesting operations, such as the sale of fresh European hake at the fish market auction, distribution by retailers, sale at markets or supermarkets and consumption in a Spanish household were also taken into account in the study. Excluded operations included waste treatment of materials used in fishing operations. This approach from the fishery until human consumption corresponds with a “cradle to grave” analysis (Guinée et al., 2001).

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[3] Data regarding hake residues during the retailer and household stages of the process were obtained from a questionnaire regarding hake consumption, in which 100 Spanish citizens took part. Questions related to consumption habits, as well as to report how they purchased fresh gutted hake and the weight of the wastes involved in the retailing and consumption processes.

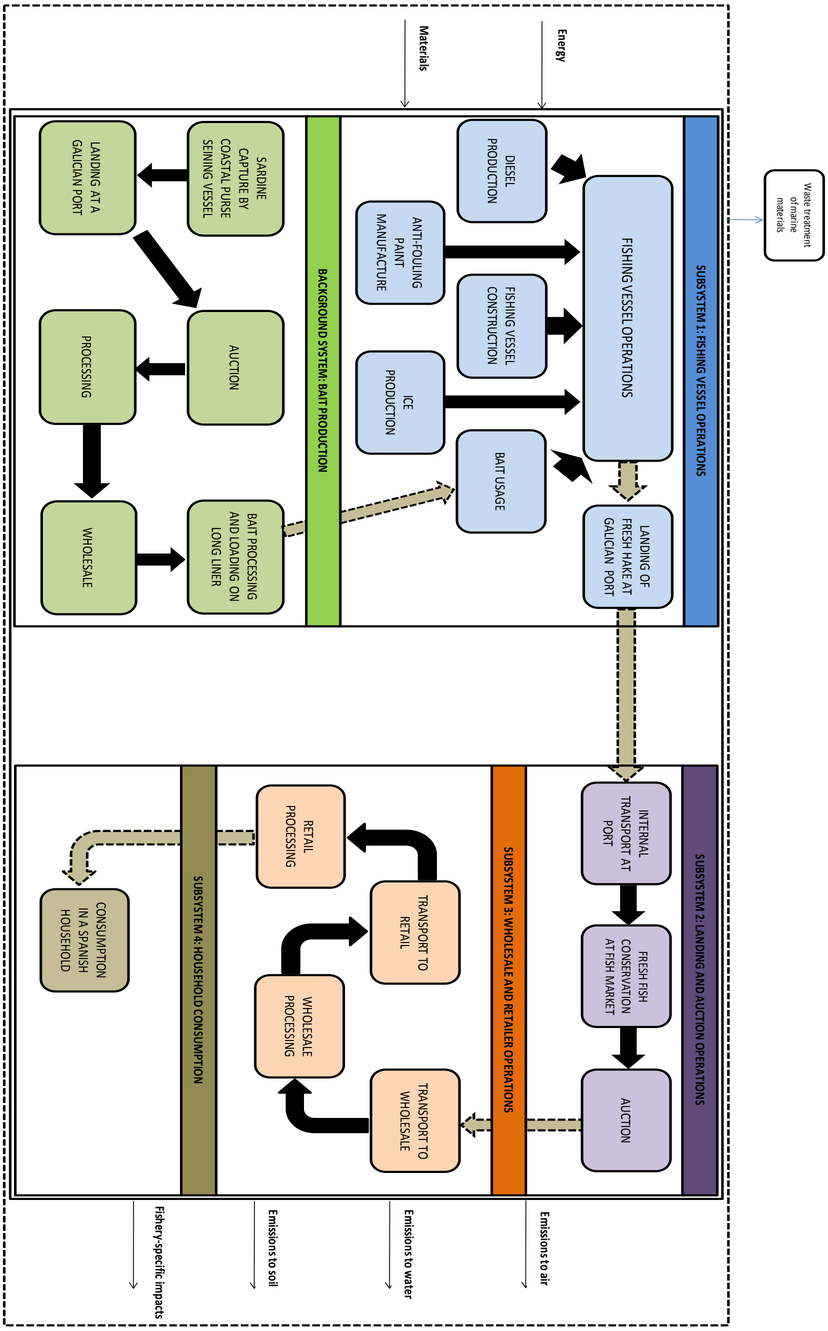

Figure 5.2. System under study for European hake fillets landed at port by long liners. Blocks presented outside the discontinuous lines have been left out of the system boundaries. Black arrows represent subsystem flows, while grey arrows represent flows between subsystems.

5.2.2. Data acquisition

The samples used for this study are a group of 12 long liners and 9 trawling vessels belonging to the Galician Northern Stock fishing fleet, representing 24% and 14% of their specific fleets, respectively (Xunta de Galicia, 2009). The primary data for fishing vessel operations (Subsystem 1-SS1) were obtained through a series of questionnaires filled out by skippers from the most important trawling and long lining ports in Galicia. The questionnaires comprised a wide range of operational aspects: annual consumption of diesel, oil and antifouling paint usage, ice and net consumption, days at sea, crew size or bait use (Figure 5.3); as well as aspects related to capital goods (hull material, vessel dimensions or life span). In the case of the long lining fleet, primary data were also obtained for the bait needs of the fleet. In this sense, a background subsystem (BSS) was established in order to include bait fishing, processing and distribution. Discards for all the assessed fleets were also included in the inventory.

Figure 5.3. Fishing nets at the port of Cudillero (Spain).

Data for landing and auction operations (SS2) were gathered from some of the main fish auctions along the Galician coast. Data relating to electric consumption and to the usage of different materials (pallets, plastic. . .) for fish market operations were the main inputs considered in this stage.

Data for wholesaler and retailer operations (SS3) were obtained mainly from primary data and studies referring to fresh fish wholesaling. The primary data for retailing operations obtained were retrieved from direct communication with local supermarkets and fishmongers, while data for wholesaling activities were taken from bibliography data and MercaMadrid (Hospido et al., 2006; Mercamadrid, 2010). An average distance of 620 km (roughly the distance of the main Galician ports to MercaMadrid) was considered from European hake landing to wholesaling activities. For retailing activities an average distance of 50 km was assumed.

Finally, the household consumption subsystem (SS4) entails a varied range of sources, including primary statistical data and different studies referring to seafood consumption in Spain (FROM, 2007; Mercados Municipales, 2010; Ministerio de Sanidad y Consumo, 2010). These data included shopping travel, waste treatment, packaging disposal, electric consumption or hake preparation in Spanish households.

Background data regarding the production of diesel fuel were obtained from the ecoinvent® database (Frischknecht et al., 2007). In all other situations where no direct data were available, background data from the ecoinvent® databases were also used.

5.2.3. Co-product allocation strategies

- Background subsystem. European pilchard bait for the long liners was considered to be fished by the Galician purse seining fleet and their landing was carried out at the most important purse seining ports along the Galician coast. This fishery is a multispecies fishery, with European pilchard, Atlantic mackerel and Atlantic horse mackerel representing over 95% of the captures. Due to the similarity in auction sale prices for the three species, mass allocation was considered for this fishery.
- Subsystem 1. Both fishing fleets present a multispecies landing pattern. Therefore, allocation is an important issue to be considered (Ayer et al., 2009). Despite the fact that most LCA studies recommend the use of economic allocation for multispecies fisheries, mass allocation was considered for this study.

This approach was selected due to the highly volatile price of European hake at Galician fish markets, depending on the time of the year, freshness of the product, size of the individual and many other factors that make the system extremely complex to analyse from an economic allocation perspective. Furthermore, as can be seen in Table 5.1, the use of the average sale price for European hake does not entail major differences in allocation factors with respect to a mass allocation perspective. In fact, the annual variation in hake prices is greater than the differences identified between these two allocation methods. Therefore, due to the lack of robust economical data, mass allocation was considered for both fleets. The characterization factor applied to discarded fish and residues from eviscerated fish (offal), which are usually treated in the same way as regular discards, was set at zero due to the lack of an environmental impact category linked to it (Porto de Vigo, 2009).

Table 5.1. Mass and economic allocation factors for selected European hake fishing fleets.

F1: Offshore long lining fleet				
Species	**Landings (t/year)**	**Mass allocation**	**Value (€/kg)**	**Economic allocation**
Hake	172.74	60.68%	3.72	72.07%
Atlantic pomfret	46.51	16.26%	1.78	9.39%
Common ling	27.82	9.68%	1.61	5.03%
Fork beard	16.63	5.74%	3.19	6.01%
Rock Fish	15.80	5.47%	3.55	6.34%
Conger eel	5.17	2.17%	2.02	1.16%
F2: Offshore trawling fleet				
Megrim	192.04	45.77%	4.50	44.70%
Angler	129.99	30.98%	5.58	37.52%
Hake	63.52	15.14%	3.72	12.23%
Norway Lobster	3.00	0.72%	15.19	2.35%
Varied species	31.01	7.39%	2.00	3.21%

- Subsystem 3. Transport distances were calculated on the base of road guides obtained online (Guía Repsol, 2010). Truck capacity for transport to wholesalers was based on data obtained from Galician ports (Portos de Galicia, personal communication, January 2010). Van transportation to retailers was assumed. Finally, for this particular study it was assumed that the marketable product was cut into fillets by the retailer at sale for the consumer. Therefore, the entire pre-cooking residue created by each individual was assigned to the retailing operations.

- Subsystem 4. It was assumed that the fresh fillets were consumed in an average Spanish household. Post-cooking residues, including bones were assigned to this subsystem.

5.2.4. Life Cycle Inventory

Inventories for the assessed subsystems are summarized in Tables 5.2–5.6. There is no background subsystem in the trawling fleet, given its direct harvesting characteristics, whereas the long lining fleet requires bait extraction by coastal purse seiners. Finally, data in SS2-SS4 were considered common for both fleets, since the study focuses on one sole product from a market perspective.

Table 5.2. Summary of the average inventory data for Subsystem 1 (data per FU).

INPUTS			
From the technosphere	**Units**	**Offshore long liners**	**Offshore trawlers**
Materials and fuels			
Diesel	g	842	1,357
Steel	g	9.07	9.72
Net	g	--	4.68
Ice	g	415	521
Boat paint	g	0.42	0.41
Anti-fouling paint	g	1.21	1.13
Marine lubricant oil	g	9.52	3.61
OUTPUTS			
To the technosphere	**Units**		
Products			
European hake	g	645.00	645.00
Co-products			
Atlantic Pomfret	g	173.7	--
Fork beard	g	62.1	--
Common ling	g	103.9	--
Rock fish	g	59.0	--
Conger eel	g	19.3	--
Megrim	g	--	1,950
Anglerfish	g	--	1,320
To the environment			
Emissions to the atmosphere			
1. CO_2	g	2,669	4,301
2. SO_2	g	8.42	13.57
3. VOC	g	2.02	3.26
4. NO_x	g	60.63	97.68
5. R22 (cooling agents)	mg	453.2	307.5

Table 5.2. Summary of the average inventory data for Subsystem 1 (data per FU) (cont.).

Emissions to the ocean			
1. Xylene	mg	110.6	103.4
2. Sea Nine 211	mg	11.25	12.12
3. Ethylbenzene	mg	26.29	28.25
Waste to treatment			
Plastic to recycling	g	1.13	--
Cardboard to recycling	g	1.83	--
Plastic to landfill	g	4.24	--
Cardboard to landfill	g	0.85	--

Table 5.3. Average inventory data for the background subsystem (data per FU).

INPUTS		
From the technosphere	**Units**	**F1**
Materials from processing stage		
Paperboard	g	4.4
Polyethylene (LDPE)	g	8.8
Detergent	g	0.27
Energy and transport		
Electric energy	kWh	0.106
Fresh sardine up to wholesale	t·km	0.019
Frozen sardine up to long liner loading	t·km	0.033
OUTPUTS	**Units**	
To the technosphere		
Products		
Bait (European pilchard)	g	265

F1: Offshore long liners

Table 5.4. Average inventory data for post-harvesting subsystem 2 (data per FU).

Subsystem 2: Landing and auction operations		
INPUTS		
From the technosphere	**Units**	**Value**
Materials from processing stage		
Fresh European hake	g	645
Pallets	u	6.39E-4
Polystyrene (GPPS)	g	0.91
Detergent	g	0.03
Fish boxes	g	0.59
Energy		
Electricity	kWh	0.01
OUTPUTS		
To the technosphere	**Units**	
Products		
European hake	g	645

Table 5.5. Average inventory data for post-harvesting subsystem 3 (data per FU).

Subsystem 3: Wholesaler and retailer operations		
INPUTS		
From the technosphere	**Units**	**Value**
Materials from processing stage		
Fresh European hake	g	645
Polyethylene (HDPE)	g	12.5
Energy and transport		
Electricity	kWh	0.06
Lorry transport, up to wholesale	t·km	0.39
Van transport, up to retailer	t·km	0.03
OUTPUTS		
To the technosphere	**Units**	**Value**
Products		
Fresh European hake fillets	g	500
Waste to treatment		
Disposal organic waste	g	145

Table 5.6. Average inventory data for post-harvesting subsystem 4 (data per FU).

Subsystem 4: Household consumption		
INPUTS		
From the technosphere	**Units**	**Value**
Materials		
Fresh European hake fillets	G	500.00
Tap water	G	100.00
Energy and transport		
Electricity	kWh	0.036
Shopping travel	p·km	0.30
OUTPUTS		
To the technosphere	**Units**	**Value**
Waste to treatment		
Plastic to recycling	G	10.50
Plastic to landfill	G	39.50
Disposal organic waste	G	50.00

The CML baseline 2000 method was used in order to perform the LCIA (Guinée et al., 2001). Seven impact categories were included in this study: ADP, AP, EP, GWP, ODP, METP and POFP. In the same way as previous chapters, SimaPro 7.3 was the software used to carry out the computational implementation of the inventories (Goedkoop et al., 2010). Additionally, three fishery-specific indicators were assessed in the study: discards and SIP, which were already included in Chapters 3 and 4, and BRU.

The use of BRU in fish systems was first approached by Papatryphon et al. (2004), even though the aim of their study was linked to salmonid aquaculture, rather than wild fishing systems. In wild fishing systems, however, the use of biotic resource indicators has started to be included only in recent years (Fulton, 2010; Parker, 2011). BRU is based on measuring the net primary productivity (NPP) needed to sustain the production of a certain mass of biotic resources consumed (Pauly and Christensen, 1995), therefore constituting a guidance regarding the dependence on ecological productivity (Parker, 2011). It represents an attractive complement to other impact categories included in fishery LCA studies, which are predominantly dependent on the energy use of the analysed fishery, since it incorporates a new dimension to seafood life cycle thinking. The calculation basis used to compute BRU is based on the following equation (Pauly and Christensen, 1995):

[Eq 5.1] $$\mathrm{NPP} = (\mathrm{M}/9)\mathrm{x}10^{\wedge(\mathrm{T}-1)}$$

where NPP= net primary productivity; M= wet weight of animal biomass and T= average trophic level of included species.

5.3. Results

5.3.1. Characterization results identified for fresh fillets of European hake fished by Northern Stock Galician long liners

The environmental impacts associated with the consumption of 500 g of fresh fillets of European hake showed a clear dominance of the fishery phase (SS1) for all the conventional impact categories included in the study. ODP, AP and EP were the impact categories with greater contribution to the environmental impact performed by SS1 (99.6%, 89.5% and 88.5%, respectively). Contributions to GWP, POFP and ADP values for SS1 were also very high, all of them above 75%. Finally, the lowest contribution of this subsystem corresponded to METP (50.7%). The bait-linked background subsystem (BSS) presented similar contribution levels for all the impact categories included in this study, ranging from 0.2% for ODP to 14.3% for METP. This subsystem was the second most significant after SS1 for ADP, AP, EP; GWP, ODP and POFP. The landing and auction operations stage (SS2) was found to be the lowest impact generating phase. The main contribution for this subsystem was to METP (0.7%), whereas for ODP the contribution was negligible.

The wholesaler and retailer operations subsystem (SS3) was identified as the second contributor to METP (19.7%). Contribution to ADP, GWP and POFP were 6.4%, 5.9% and 5.1%, respectively, while AP, EP and ODP were below 5%. Finally, the household consumption subsystem (SS4) presented highly variable contributions depending on the impact category assessed. In this sense, METP and ADP presented contributions of 14.5% and 8.0%, respectively; POFP had a contribution of 4.9% and the other three impact categories (AP, EP and ODP) all presented contributions below 4.5%. All the impact category values divided by subsystems can be observed in Table 5.7.

Table 5.7. Characterization values associated with the Galician European hake fleets in the Northern Stock (long liners and trawlers) per FU.

F1: Offshore long lining fleet						
Impact category	**BSS**	**SS1**	**SS2**	**SS3**	**SS4**	**Total**
ADP (g Sb eq)	2.39	20.68	1.34E-1	1.74	2.17	27.11
AP (g SO$_2$ eq)	3.48	46.03	8.21E-2	1.15	6.87E-1	51.43
EP (g PO$_4^{3-}$ eq)	6.91E-1	8.79	1.78E-2	3.60E-4	4.27E-1	9.93
GWP (kg CO$_2$ eq)	0.328	3.951	0.014	0.280	0.193	4.77
ODP (mg CFC 11 eq)	3.27E-2	15.8	5.54E-7	2.49E-2	8.86E-3	15.87
METP (kg 1,4DCB eq)	114.18	403.82	5.67	156.99	115.67	796.33
POFP (mg C$_2$H$_4$ eq)	94.6	883	5.32	55.73	53.05	1,091.7
F2: Offshore trawling fleet						
Impact category	**SS1**	**SS2**	**SS3**	**SS4**	**Total**	
ADP (g Sb eq)	33.15	1.34E-1	1.74	2.17	37.19	
AP (g SO$_2$ eq)	74.08	8.21E-2	1.15	6.87E-1	76.74	
EP (g PO$_4^{3-}$ eq)	14.09	1.78E-2	3.60E-4	4.27E-1	14.54	
GWP (kg CO$_2$ eq)	5.651	0.014	0.280	0.193	6.14	
ODP (mg CFC 11 eq)	11.1	5.54E-7	2.49E-2	8.86E-3	11.13	
METP (kg 1,4DCB eq)	598.16	5.67	156.99	115.67	876.49	
POFP (mg C$_2$H$_4$ eq)	1,420	5.32	55.73	53.05	1,534.1	

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrophication Potential; GWP= Global Warming Potential; ODP= Ozone Layer Depletion Potential; METP= Marine aquatic Eco-toxicity Potential and POFP= Photochemical Oxidant Formation Potential.

5.3.2. Characterization results identified for European hake fresh fillets hake fished by Northern Stock Galician trawlers

High quality fresh European hake captured by Northern Stock trawlers is known to compete with hake extracted by long liners in this same fishery. Table 5.7 also includes characterization results for the European hake caught by trawling vessels.

The fishing vessel operation stage (SS1) was the main contributor to all impact categories for the hake arriving from this fishing fleet. In fact, SS1 presented contributions higher than 89% for all impact categories, except for METP (68.3%). The landing and auction operations phase (SS2) showed very low significance regarding the overall contribution. The highest contribution for SS2 corresponded to METP (0.7%). The wholesaler and retailer and the consumption subsystems (SS3 and SS4) had relatively high contribution to the overall METP (17.9% and 13.2%, respectively). For the rest of impact categories their contribution was always below 10%.

5.3.3. Subsystem specifications regarding characterization results

The different subsystems that were used to divide the life cycle of European hake caught by the two assessed fleets were also analysed independently in order to attain more specific results regarding European hake capture. Therefore, as can be observed in Figure 5.2, the subsystems belonging to the European hake captured through long lining methods were divided into a fish harvesting activities group (BSS and SS1) and a post-harvesting activities group (SS2–SS4) in order to analyse in depth the factors contributing to the different impact categories.

The two subsystems included in the harvesting stage (BSS and SS1) showed an overwhelming dominance of transport activities. Marine transport activities, that include fuel provision and use activities, were found to represent over 90% of the contribution to environmental impacts generated in these two subsystems for all impact categories, excluding METP (86.4%) and ODP, where most impacts were attributable to the emission of cooling agents. Land transport of bait only presented contributions ranging from 0.4% (EP) to 1.8% (METP). Electricity related to bait conservation showed a 3.1% contribution for METP, while for the rest of the assessed impact categories it did not reach 2%. Finally, for the remaining activities considered, the contribution was beneath 3% for all the impact categories.

For the European hake captured by trawlers, the harvesting stage only comprised one single subsystem (SS1). For this fleet marine transport contributes to at least 95% of the environmental impact for all impact categories.

The post-fishing operations included in SS2–SS4 (common to European hake captured by both fleets) were also assessed. Transport activities were the highest contributing activities for three impact categories: ODP (89.5%), AP (51.1%) and GWP (38.6%). Waste treatment operations, including wastewater, were found to be the most contributing activities for EP (59.4%) and METP (85.5%). Finally, the packaging operations throughout the three subsystems were the main contributing factor for ADP (51.2%).

5.3.4. Fishery-specific environmental impacts

When analysing the data inventories for discarded fish, the trawling fleet presented very high levels of discards. A total of 494 g of fish were returned to sea per FU European hake, which represents 43.4% of the total catch (Table 5.8). They also reported discarding target species individuals that do not reach minimum size requirements, non-marketable species and non-profitable species for offshore fleets, such as pouting (*Trisopterus luscus*) or Atlantic horse mackerel (see Table D.1 in Appendix I). Additionally, skippers reported discarding guts of individuals captured and selected for commercialization after evisceration, but these were not included when calculating discards. The discard rate of the long lining vessels included in the study was 11 g of discards per FU. In this case, discards represented only 1.65% of the total catch.

Table 5.8. Fishery-specific indicators' results for the assessed fisheries.

Impact category	Units	F1	F2
Discards	g	10.82	494.2
SIP	m^2	0	3,102

F1= offshore long liners; F2= offshore trawlers; SIP= seafloor impact potential.

Seabed disturbance by long liners in the evaluated fishery was considered to be zero. However, it is true that incidental gear loss by these vessels may cause occasional damage on the seafloor. However, there was no data availability to support this assumption in the current case study. Regarding the trawling fleet, the total impact to the seafloor was roughly 3,100 m^2 per FU.

Finally, regarding the BRU, hake landed by long liners presented a value of 218 g C (Table 5.9). This value includes the computation of discards and the bait used. The value obtained for trawling vessels was 13.2% higher. Even though trawlers did not require the use of bait for fishing activities, this increased BRU is explained in terms of the high discard rate of this fleet with respect to the long lining fleet.

Table 5.9. Biotic resource use per FU in the assessed fisheries.

BRU	Units	F1	F2
Landed catch	g C	216.4	216.4
Discards	g C	0.15	30.21
Bait	g C	1.20	--
TOTAL BRU	g C	217.8	246.6

F1= offshore long liners; F2= offshore trawlers; BRU= biotic resource use.

5.4. Discussion

5.4.1. Identification of hot spots and fleet comparison

Previous studies analysing the environmental impacts linked to seafood products have identified fishing harvesting activities as the highest contributors to most impact categories (Edwardson, 1976; Watanabe and Okubo, 1989; Ziegler et al., 2003; Thrane, 2004; Tyedmers, 2004; Hospido and Tyedmers, 2005; Schau et al., 2009). In the current study all categories were dominated by the fish extraction subsystem (SS1). Nevertheless, it is important to highlight the increased environmental burdens related to the European hake fresh fillets caught by Northern Stock trawlers. Total environmental impacts attributed to the product arriving from this fleet ranged from an increase of 9% for METP to 33% for AP with respect to the product arriving from the long liners (Figure 5.4), despite the fact that the long liners do not rely on direct harvesting, due to the use of previously extracted pelagic fish (bait). This increased environmental impact for trawlers is linked mainly to the fuel-intensive characteristics of this fleet. However, in the case of ODP, environmental impacts in long liners were substantially higher (42.6%) than those attained by trawlers.

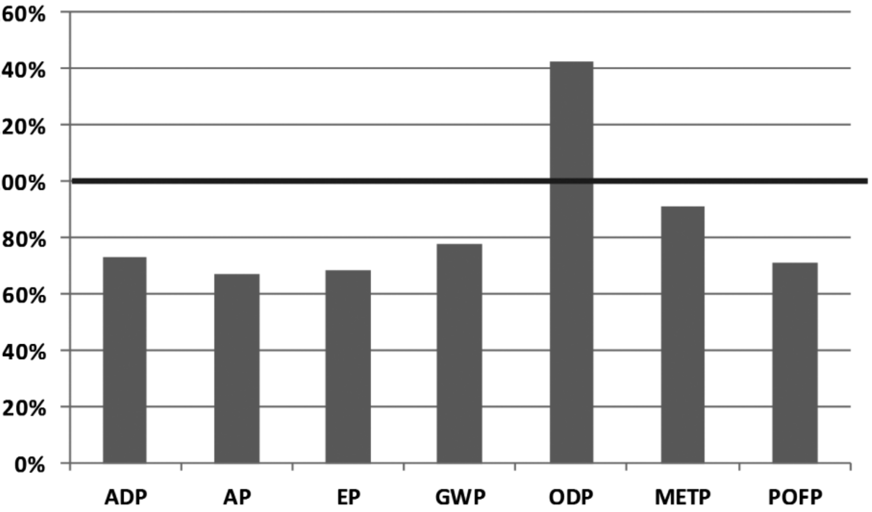

Figure 5.4. Environmental performance of Northern Stock long liners respect to that of Northern Stock trawlers.

Impact category acronyms: ADP= abiotic depletion potential; AP = acidification potential; EP = eutrofication potential; GWP= global warming potential; ODP= ozone layer depletion potential; METP= marine aquatic eco-toxicity potential; POFP = photochemical oxidant formation potential.

In fact, when the FUI of these European hake fishing fleets are compared to other hake fisheries targeted by Spanish fishing vessels, the assessed trawling fleet shows very similar values to those reported by the Basque trawling fleet in the same fishing area, the Northern Stock (Ramos et al., 2011). However, it is important to point out that both fleets have the highest FUI values when compared to any other fishing fleets elsewhere. Interestingly, even though the Northern Stock long lining fleet performs much better than trawlers in this area, its FUI showed to be substantially higher than trawlers in other fishing areas, such as the one along the Galician coast line or the one in Chile, as shown in Table 5.10 and Chapter 3. This circumstance may be attributable to the increased distance between port base and fishing area with respect to the other included vessels. Therefore, even though further research would be needed to confirm these patterns and many other factors may influence these results, the high FUI of Northern Stock vessels seems to be closely related to increased fuel propulsion requirements rather than to differing fishing operational activities between fisheries. Finally, despite the fact that all these analysed fisheries target species from the Merluciidae family, the post-harvesting supply chains that are generated by different fleets are extremely varied. Therefore, caution must be taken when comparing products from the different fisheries.

Table 5.10. Fuel use intensity (FUI) for selected Spanish fishing fleets targeting hake species.
Source: Ramos et al. (2011).

Species	Inventory year	Fishing gear	Fishing area[1]	FUI (L/tonne)
European hake	2008	driftnet	Galician coast	123
European hake	2008	trawling	Galician coast	557
European hake	2008	trawling	Northern Stock	2,363
European hake	2007	trawling	Northern Stock (Basque fleet)	2,255
European hake	2008	long lining	Northern Stock	1,466
Black hake	2009	trawling	Mauritanian EEZ	1,939
Patagonian grenadier	2010	trawling	FAO Area 87 (Chile)	469

[1] All fishing fleets are Galician unless otherwise indicated. Patagonian grenadier is landed in Chile and then freighted to Galicia, but FUI only includes fishing vessel operations.
FUI= fuel use intensity; European hake= *Merluccius merluccius*; Black hake= *Merluccius senegalensis*; Patagonian grenadier= *Macruronus magellanicus*.

Inland or post-harvesting operations after fish landing represent variable environmental burdens depending on the assessed impact category. Port and auction operations (SS2) represented very low environmental impact values, while SS3 and SS4 presented high variability in their contribution to the different impact categories. In this sense, SS3 represented roughly 6% of the GWP and ADP burdens for European hake arriving from long lining extraction. The impact for ADP and GWP was linked mainly to transport of the product to wholesale and to retail. The household consumption subsystem also presented relatively high contributions to ADP and GWP. However, in this case the highest contribution arrived from plastic usage for plastic bags, while consumer transport to the retailing point only represented around a fifth of the contribution to these impact categories. Finally, it is important to note the high contribution of SS3 and SS4 to the METP impact category. This circumstance is due mainly to the high contribution generated by the waste treatments of the organic and plastic residues generated in these processes.

Concerning fishery-specific indicators, these also suggest a higher environmental impact by hake fillets arriving from bottom trawlers. This difference is highly perceptible in terms of discarding, given that long liners discard on average 98% less in terms of live weight, and with respect to the SIP impact category, where the disturbance of ocean beds was found to be close to zero for long liners. Finally, while an increased BRU value may have been expected for hake fillets arriving from long liners, due to the use of bait for fishing activities, results showed a slightly higher value for trawled hake due to the high amounts of discards. However, it is important to note that in the current study we assumed that all the bait used in the long lining fleet was sardine. While this assumption gives a close approximation to reality, some skippers reported occasionally using other species as bait, such as sepia or Atlantic mackerel, which would vary the BRU inputs due to this fishing operation.

Finally, it is important to highlight that the inclusion of discards in BRU calculation may imply methodological concerns, not only due to the difficulty of discard reporting and sampling (Allen et al., 2001), but also due to the variable mortality rates due to discards observed in worldwide fisheries (Evans et al., 1994; Wileman et al., 1999).

5.4.2. Improvement opportunities

Any improvement action in order to reduce the overall environmental impact of the studied seafood product should focus on reducing the diesel consumption of the fishing vessels. Fuel reduction actions entail increased relevance when assessing Galician hake fisheries, due to the fact that European hake landings represent 22.5% (15.1% if only taking into account the two assessed fishing fleets) of the global carbon footprint of the Galician marine fishing activity, as will be analysed and discussed in Section V of this dissertation. However, it is important to take into account recent studies that point out that vessels belonging to fuel intensive fleets, such as offshore trawlers, show increased efficiency of fuel related inputs respect to other considered inputs (Schau et al., 2009). This phenomenon is strongly related to high fuel prices which have led these fleets to develop efficiency strategies. Therefore, further significant fuel consumption reductions are highly unlikely according to current operational patterns.

The fact that both evaluated fleets capture a variety of species suggests that increased fleet specialization should be enforced. If this were to be the case, European hake quota for Galician vessels should be assigned preferably to long liners. In the first place, this would reduce the vulnerability of the ecosystem, since the seafloor disturbance linked to hake captures, as well as the discards would be limited considerably. However, a reduction in NPP would depend on the selected bait. Secondly, it would increase the quality of most of the landed hake, and more of this seafood would be available for fresh consumption. Along this line, the use of mother ships to transport the fish of several vessels from the fishing zones to port would permit a considerable increase in the number of days per fishing tide. This scenario would entail important cost reductions, higher profitability for the fleet and an important reduction of environmental impacts. Finally, it would also increase the freshness of the fish landed at the Galician ports.

Despite the fact that harvesting operations are the major contributors to the total environmental impacts of the studied seafood product, a series of improvement actions can also be suggested for post-harvesting activities. In the first place, many retailers close to European hake-landing ports are starting to obtain the product directly from the fish auction, rather than buying the product off the wholesaler. This not only guarantees lower costs for the retailer and increased freshness of the product, but also reduces environmental impacts. However, for the particular scenario studied (retailing and consumption in an average household) this option is not feasible. Instead, minimization of environmental burdens can be approached through wide-ranging changes in fresh fish transportation. In this sense, the current improvement of the rail connection to Galicia from Madrid could be an opportunity to extend the rail network to the key fish-landing ports, such as Vigo, A Coruña or Celeiro, in order to encourage rail transportation of European hake and other marketable marine products to the rest of Spain (Tsamboulas et al., 2007).

5.5. Perspectives and conclusions

European hake fresh fillets captured by a series of Galician long liners and trawlers were evaluated in this study. The inventoried vessels accounted for 2645 tonnes of European hake landed, representing roughly one third of the total hake quota assigned to Spanish vessels in the Northern Stock (European Commission, 2007). The most representative conclusions obtained from the study are briefly summarized below:

- The Galician Northern Stock long lining and trawling fishing fleets were inventoried, representing 24% and 14% of the vessels of these fleets, respectively. As far as I was able to ascertain, it is the first life cycle assessment performed on the Spanish hake fishing fleet. It is also the first attempt to analyse the environmental impact generated through the life cycle of fresh fish consumption in Spain, one of the main fish-eating nations in the world.

- Results show increased environmental impacts for activities relating mainly to marine diesel consumption and, to a lesser extent, land transportation. Other activities, such as bait processing, electric consumption and plastic and organic waste disposal demonstrated lower contributions to the entire system.

- Fresh European hake captured by long liners presents reduced environmental burdens for all impact categories when compared to fillets arriving from the trawlers. Reductions ranging from 18% to 32% were obtained when using long lining vessels to supply the hake market in all the conventional impact categories considered. Moreover, hake caught by long liners also presented an improved environmental profile in terms of discards, seafloor impact and NPP.

- Reduction of energy consumption, through improvement of vessel design and other less conventional techniques, such as redefining fishing quotas for the different fleets or the introduction of mother ships is highly recommended in order to reduce the environmental impacts related to the fishing vessels operations. Furthermore, these key factors may represent substantial cost reductions when it comes to improving the environmental performance of the assessed product.

- Other improvement strategies can be implemented throughout the life cycle of the studied product. However, these actions would not represent significant environmental reductions in the life cycle of hake fillets. Nevertheless, they may translate into important cost reductions for skippers, retailers or wholesalers.

5.6. References

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Chapter 6

Environmental assessment of frozen common octopus (*Octopus vulgaris*) captured by Spanish fishing vessels in the Mauritanian EEZ[1]

Summary

Mauritania, one of the most fish-dependent nations in the world, has an important octopus fishery within its EEZ. Fishing treaties between the EU and this Sub-Saharan nation have permitted 24 Spanish cephalopod trawling vessels to target this species for its export as a frozen product, mainly to Spain, Italy and Japan. This chapter presents LCA methodology in order to assess and compare the environmental impacts related to the capture, processing and export of packed frozen octopus from this fishery to the main importing nations. Environmental results show that frozen common octopus presented a remarkable dominance of the fishing vessel activities, due to the high energy intensity of the fishery and to the fact that these activities include harvesting, processing and preliminary packaging. Post-harvesting activities presented low relative contributions in all impact categories, minimizing the food mile effect of exporting to Japan, thanks to the slow transportation through marine freight of frozen octopus. The results for fishery-specific indicators showed regular trends for trawling fleets, with high discard and seafloor impact rates. Therefore, improvement actions focused on the minimization of energy use and fishery-specific impacts and the shift to less ozone layer damaging cooling agents are the main targets to ameliorate the sustainability of this product, as long as the slow freighting characteristics of the imported product are maintained.

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[1] Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2012). "Environmental assessment of frozen common octopus (*Octopus vulgaris*) captured by Spanish fishing vessels in the Mauritanian EEZ". *Marine Policy,* 36: 180-188

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6.1. Introduction

Mauritania is highly dependent on fish trading (Gascuel et al., 2006). A high percentage of Mauritanian exports (18%) were linked to the fishing industry in 2007 (ONS, 2011). However, an important amount of seafood captures are performed by industrial fishing fleets from other countries that operate thanks to fishing agreements in the EEZ of Mauritania (European Union, 2006a). In fact, the overcapacity of the fishing fleet in Europe, which has been an increasing problem in the past few decades, has led the EU to implement a series of correction policies that included fishery cooperation agreements with West African countries (Villasante and Sumaila, 2010). In this context, the current Mauritania-EU agreement has a 6-year duration, finishing on July 31st 2012. The agreement includes licenses in Mauritanian waters for a wide range of fishing fleets, including the demersal trawling cephalopod fleet (European Union, 2006a). Therefore, in a scenario in which no cephalopod extraction agreements are signed with Morocco, Mauritania is the only West African country that permits this type of extraction for EU vessels (European Union, 2006a, 2006b). This fleet is made up of 32 trawlers, of which 24 are based in Spanish ports, such as Marín, Vigo or Las Palmas (Table 6.1).

Table 6.1. Cephalopod trawling vessel licenses per country of origin in the EU-Mauritania fishing agreement.
Source: European Union 2006a.

Country of origin	Number of vessels
Spain	24
Italy	4
Greece	3
Portugal	1
Total European cephalopod fleet	32

Common octopus (*Octopus vulgaris*) is the main species targeted by the Spanish cephalopod fleet in Mauritanian waters (Figure 6.1). The Northwest Africa upwelling system is known to benefit the spawning and distribution of this species in the area (Caballero-Alfonso et al., 2010; European Union, 2006b). The highest abundance patterns are found in the Dakhla region, in Western Sahara (approximately 75% of the stock), but currently European fishing vessels are only allowed to extract octopus and other cephalopods off the coast of Nouadhibou (Cap Blanc area), which accounts for 20% of the stock, and Nouakchott, 1% of the stock (Pereiro and Bravo de

Laguna, 1980; Caddy, 1983). The EU policy for re-deploying fishing fleets of member states into other fisheries worldwide has created strong criticism by some scientists regarding the sustainability of these measures, since the policy is based on lowering the fishing effort in European waters while increasing the impacts on the new target stocks, mainly belonging to underdeveloped nations (Kazcynski, 1989; Kazcynski and Fluharty, 2002; European Union, 2006c; European Commission, 2010a; Nagel and Gray, 2012). At the same time, stakeholders from the fishing sector have applauded this policy, since it has allowed relocating fleets rather than scrapping these vessels. Nevertheless, this policy may collide with the increasing awareness associated with the overexploitation and sustainability of world fisheries (Jackson et al., 2001; Worm et al., 2009; FAO, 2010). In fact, while this behavioural pattern has spread through consumers and retailers in many developed countries in recent years (Ellingsen et al., 2009), the transparency and accountability of seafood products arriving from distant fisheries must still be improved, since the partitioning of the seafood production chains in different countries may cause misleading information to stakeholders (Iles, 2007).

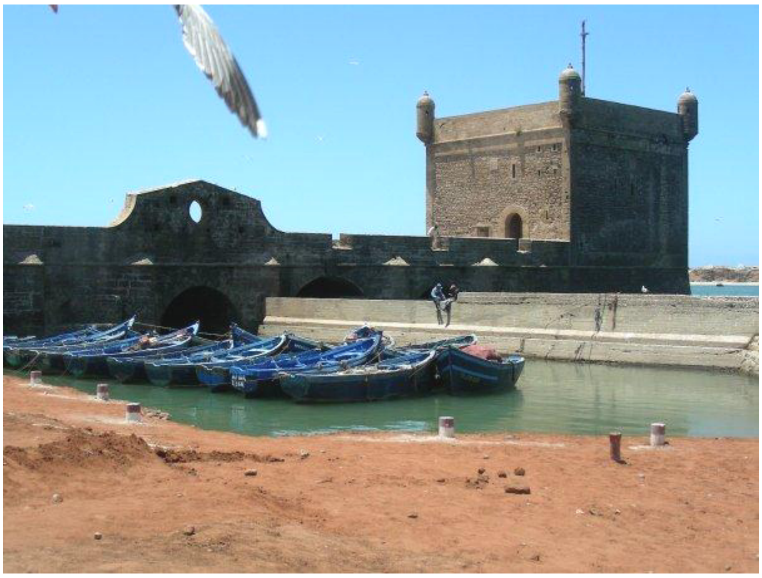

Figure 6.1. Artisanal fishing vessels at the port of Essaouira, Morocco.

Life Cycle Assessment (LCA), as seen in previous chapters, provides a standardized and relevant methodology for the environmental analysis of fish extraction and the derived seafood products throughout the supply chain (Pelletier et al., 2007). While a wide range of LCA studies on fisheries and related products have been performed in recent years in North Atlantic waters (Ziegler et al., 2003; 2011; Thrane, 2004; Schau et al., 2009), the number of fisheries assessed elsewhere is still very low and, except in the case of Southern pink shrimp (*Penaeus notialis*), limited to international waters (Hospido and Tyedmers, 2005; Ziegler et al., 2011). The current study aims at analysing the environmental impacts related to seafood products extracted by the cephalopod fishing fleet in the Mauritanian EEZ through LCA methodology. Specifically, frozen octopus constitutes the main primary sector export in Mauritania, both in tonnes and in economic value. Japan, Spain and Italy are the most important importing countries of this cephalopod, as can be observed in Figure 6.2, since their national catches are way below demand (Pasquotte and Lem, 2008). For instance, Japan extracts 50,000 tonnes of common octopus per year, accounting for only 50% of the demand. Hence, this study assesses and compares the environmental burdens linked to the capture, processing and export of packed frozen octopus to each of the mentioned countries (Figure 6.3).

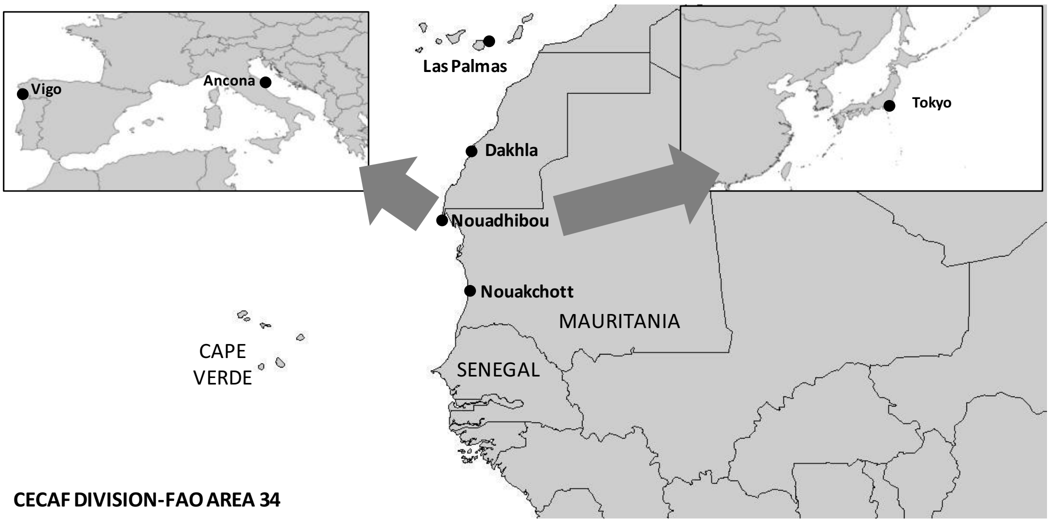

Figure 6.2. Main common octopus landing ports in the area and most relevant frozen octopus exportation routes.

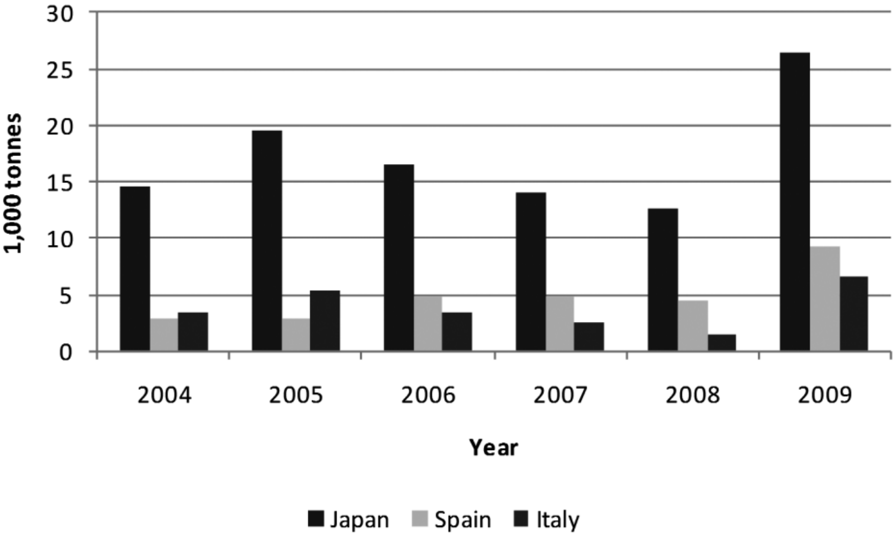

Figure 6.3. Annual imports of common octopus arriving from the Mauritanian EEZ (2011).
Source: FAO GLOBEFISH, 2010.

6.2. Methods

6.2.1. Functional unit and scope definition

The selected seafood production system under study comprised the capture and landing of common octopus in the port of Nouadhibou (Northern Mauritania) by the Spanish cephalopod trawling fleet, the freezing processing and packaging activities performed on board and the export route of this product to the three main importing countries: Japan, Spain and Italy (Figure 6.4). The approach from the fishery to the final importing country constitutes a "cradle to gate" analysis (Guinée et al., 2001). It is important to highlight that the evaluated cephalopod fleet exclusively markets frozen products, while other non-European vessels may also commercialize fresh cephalopods that are air-freighted or transported in trailers to the European market (Freiremar, personal communication, January 2011). The FU selected for this study is a 24 kg carton of frozen common octopus up to the point of import in the year 2009.

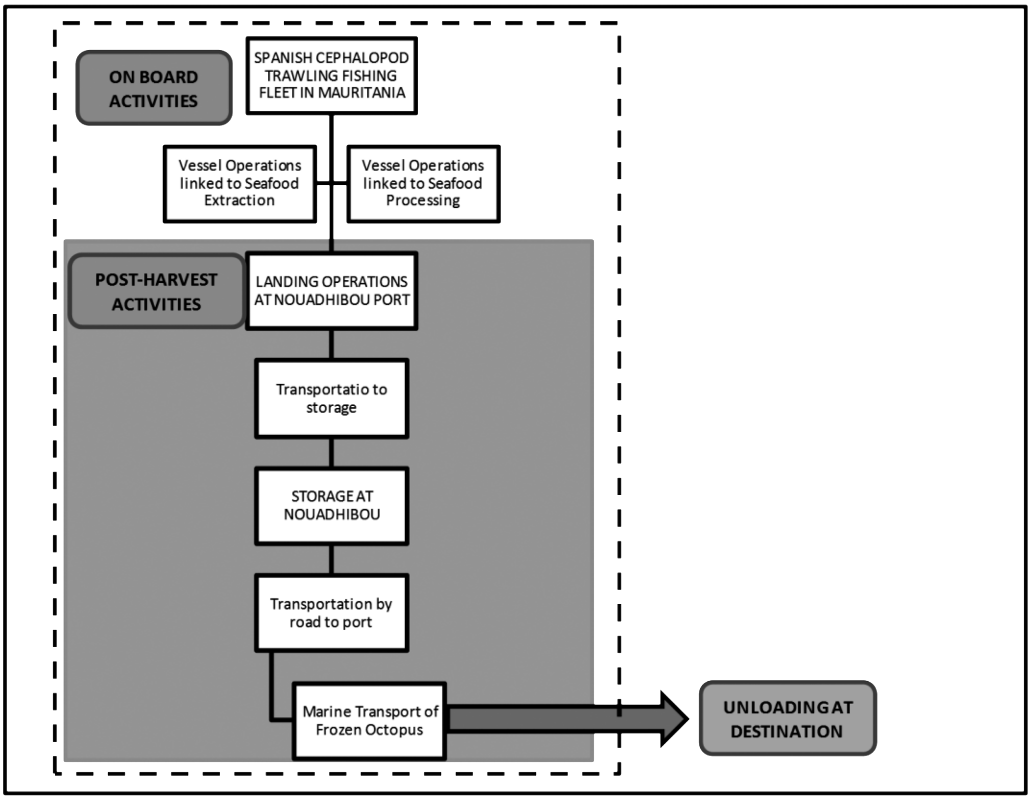

Figure 6.4. Block diagram of the studied system for the whole frozen common octopus.
Blocks presented outside the discontinuous lines have been left out of the system boundaries.

6.2.2. Data acquisition

The sample used for this research study was a group of 8 demersal trawlers belonging to the Galician trawling fleet operating in Mauritanian waters (Table 6.2), representing one third of the fleet (Xunta de Galicia, 2011). Primary data were obtained through face-to-face questionnaires answered by skippers at the ports of Marín and Vigo. These questionnaires embraced a thorough identification of the main operational aspects of the fishing vessels, such as vessel and trawl characteristics, extraction, onboard processing and landing and wholesale operations at the port of Nouadhibou, including transport to the point of import in the selected countries. Additionally, skippers were also enquired for other aspects such as by-catch or discards.

Table 6.2. Fishing vessels' characteristics and marine distances to the selected destinations.

Fleet characteristics	Total/average
Number of inventoried vessels	8
% over total cephalopods (Spain)	33.3%
% over total cephalopods (EU)	25%
Average length of vessels (m)	39.3
Average engine power (CV)	1,038
Average number of crew	19
Total catch for inventoried vessels (t)	4,632
Marine freight of frozen octopus	**Distance (in miles)**
Nouadhibou-Vigo (Scenario 1)	1,367
Nouadhibou-Ancona (Scenario 2)	2,661
Nouadhibou-Tokyo (Scenario 3)	10,944

Background data for diesel production, packaging and transoceanic transport of the exported goods were obtained from the ecoinvent® database (Frischknecht et al., 2007). Finally, frozen storage in whole sale prior to common octopus export was calculated based on the LCA Food Database (LCA Food Database, 2007).

6.2.3. Allocation

As abovementioned, allocation is an important factor to be taken into account in mixed fisheries (Ayer et al., 2007). Due to the fact that economic value represents no significant difference respect to mass allocation for octopus caught by this fleet (Table 6.3), mass allocation was considered as the most appropriate approach in this particular research. Additionally, timeline variations in the price of the targeted species were not reported as a critical factor by the interviewed skippers.

Table 6.3. Mass and economic allocation factors for the selected fishing fleet.

Species	Scientific name	Landings per vessel (t/year)	Mass allocation	Value in 2009 (€/kg)	Economic allocation
Common octopus	*Octopus vulgaris*	366.7	63.32%	4.92	63.78%
Sepia	*Sepia spp.*	55.0	9.50%	4.44	8.63%
European squid	*Loligo vulgaris*	53.1	9.17%	3.49	6.56%
Black hake	*Merluccius senegalensis*	43.3	7.47%	2.60	3.98%
Common sole	*Solea solea*	31.4	5.42%	7.25	8.04%
Tiger shrimp	*Penaeus kerathurus*	15.0	2.59%	10.44	5.54%
Sand sole	*Pegusa lascaris*	14.6	2.53%	6.71	3.47%

6.2.4. Life Cycle Inventory

The inventory data were divided into two main subsystems: on board activities (Table 6.4) and post-landing activities (Table 6.5). On the one hand, on board activities include fish extraction, certain processing tasks, such as cleaning, gutting, freezing and preliminary packaging, as well as on board landing operations (Fet et al., 2010). On the other hand, post-landing activities embrace port landing operations and logistics, transportation to and from the storage location and marine freight up to unloading in the importing port. It must be noted that the three transport scenarios in Table 6.5 were not computed simultaneously, since they refer to three different export routes.

Table 6.4. Summary of the average inventory data for onboard operations (data per FU).

INPUTS		
From the technosphere	**Units**	**Value**
Materials and fuels		
Diesel	kg	41.7
Steel	g	267
Trawl net	g	92.5
Anti-fouling paint	g	31.1
Marine lubricant oil	g	220
Polyethylene (LDPE)	g	145
Corrugated board	g	249
OUTPUTS		
To the technosphere	**Units**	**Value**
Products		
European hake	kg	24.0
Co-products		
Sepia	kg	3.60
European squid	kg	3.48
Black hake	kg	2.83
Common sole	kg	2.05
Tiger shrimp	kg	0.98
Sand sole	kg	9.59
To the environment	**Units**	**Value**
Discards		
Discarded fish	kg	5.82
Emissions to the atmosphere		
1. CO_2	kg	132
2. SO_2	g	417
3. NO_x	kg	3.00
4. Cooling agents (R22)	g	16.6
Emissions to the ocean		
1. Copper compounds	g	4.43
2. Nylon	g	10.4

Table 6.5. Summary of the average inventory data for post-harvesting activities (data per FU).

Landing, auction and wholesale operations		
INPUTS		
From the technosphere	**Units**	**Value**
Materials from processing stage		
Frozen common octopus	kg	24.0
Pallets	u	0.14
Energy		
Electric energy	kWh	0.38
Storage		
Wholesale frozen storage	m^3·day	0.82
Transport		
Lorry transport, up to wholesale	t·km	0.30
Lorry transport, up to port	t·km	0.30
OUTPUTS		
To the technosphere	**Units**	**Value**
Products		
Frozen common octopus	kg	24.0
Marine transport to destination		
INPUTS		
From the technosphere	**Units**	**Value**
Materials		
Frozen common octopus	kg	24.0
Transport		
1. Marine transport to Vigo	t·km	61.7
2. Marine transport to Ancona	t·km	119
3. Marine transport to Tokyo	t·km	488

6.2.5. Impact assessment

In the same way as previous case studies presented in Chapters 3-5, the CML baseline 2000 method was implemented in order to perform the life cycle impact assessment (Guinée et al., 2001). A total of seven conventional impact categories were analysed in this research study: abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone layer depletion potential (ODP), marine aquatic eco-toxicity potential (METP) and photochemical oxidant formation potential (POFP). The used software to execute the computational implementation of the inventories was SimaPro 7.3 (Goedkoop et al., 2010). In addition, two fishery-specific indicators were included in the study: seafloor impact potential (SIP) and discard reporting, in order to widen the scope of this environmental assessment (Nilsson and Ziegler, 2007; Pelletier et al., 2007).

6.3. Results

6.3.1. Conventional LCA impact categories

The study of the three export routes of Mauritanian frozen octopus fished by Spanish trawling vessels showed the highest environmental burdens for all the assessed categories when the product was freighted to Japan (Scenario 3), as can be seen in Figure 6.5. The highest reductions in environmental impact respect to the values obtained for Japan were identified for octopus distributed to Vigo (Scenario 1). These reductions ranged from 7% and 4.1% for POFP and AP, respectively, to 0.1% for ODP, while the reductions observed for other impact categories were roughly 2%. Finally, the environmental impacts linked to frozen octopus transported to the port of Ancona in Italy (Scenario 2) were slightly higher than those for Vigo. Please note that distance from the port of Nouadhibou to the three destination ports is shown in Table 6.2. Total characterization values for the three scenarios can be observed in Table 6.6.

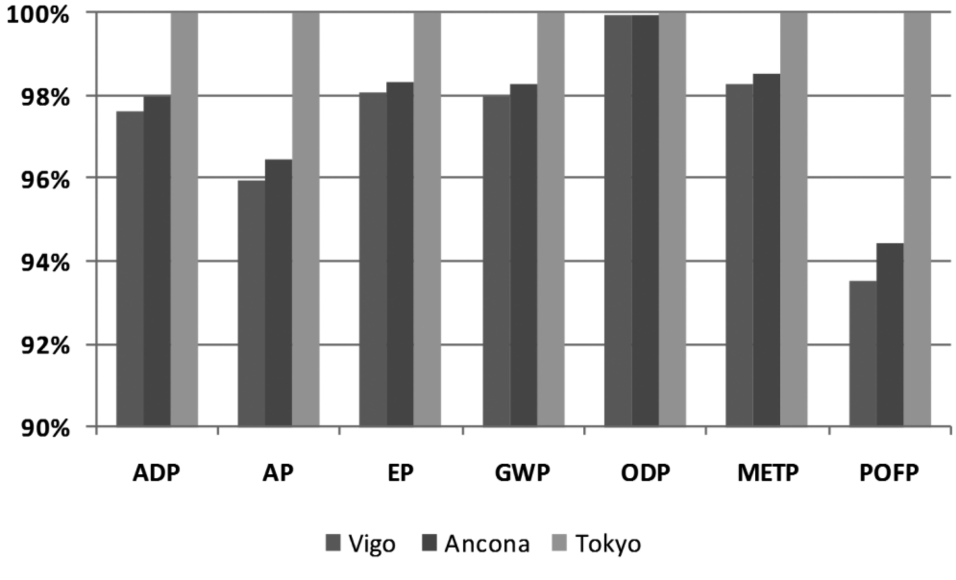

Figure 6.5. Comparison of the relative contributions for the three distribution scenarios. Impact category acronyms: ADP= abiotic depletion potential; AP = acidification potential; EP = eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; METP= marine aquatic eco-toxicity potential; POFP = photochemical oxidant formation potential.

Table 6.6. Characterization values for Mauritanian frozen octopus freighted to selected destinations.

Impact categories	Scenario 1	Scenario 2	Scenario 3
ADP (kg Sb eq)	1.027	1.032	1.051
AP (kg SO_2 eq)	2.280	2.294	2.376
EP (kg PO_4^{3-} eq)	0.432	0.433	0.433
GWP (kg CO_2 eq)	186.43	186.96	190.27
ODP (kg CFC 11 eq)	58.3E-5	58.3E-5	58.4E-5
METP (kg 1,4DCB eq)	27,496	27,562	27,980
POFP (kg C_2H_4 eq)	4.39E-2	4.43E-2	4.69E-2
Discards (kg per FU)	5.82	5.82	5.82
SIP (m^2)	46,800	46,800	46,800

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrophication Potential; GWP= Global Warming Potential; ODP= Ozone Layer Depletion Potential; METP= Marine aquatic Eco-toxicity Potential; POFP= Photochemical Oxidant Formation Potential; SIP= Seafloor Impact Potential; FU= functional unit; Scenario1= Vigo; Scenario 2 = Ancona; Scenario 3 = Tokyo.

Common octopus captured by this fleet presented an outstanding dominance of on board activities in terms of environmental impact. In fact, these represented at least 95% of the total burdens for all the scenarios considered in the study, except for POFP in Scenario 3, in which post-landing activities represented 8% of total impacts.

When the two studied subsystems were analysed in more detail (Table 6.7), seafood extraction operations were deemed as those with the highest environmental impact for most categories, ranging from 99.3% for EP to 83.6% for GWP. For ODP, however, the impact linked to these activities only represents 3.3%. More specifically, within seafood extraction operations energy use was the main contributor to environmental burdens for all impact categories, except for METP, in which anti-fouling emissions to the ocean were highlighted as the main impact. Other operations, such as net production and use, anti-fouling manufacture or vessel construction had a minor role within the assessed impact categories. It is important to note that this deeper analysis was only performed for Scenario 1 given the similar environmental profiles identified for all the scenarios and due to the fact that this scenario is closely related to the overall objectives of the entire study, in terms of better understanding the environmental implications related to fishing activities in Galicia.

Table 6.7. Individual subsystem characterization values for Mauritanian frozen octopus freighted to Vigo (Spain). Data per FU.

Impact categories	On board activities			Post-landing activities	
	Seafood extraction	On board processing	Preliminary packaging	Landing and storage	Marine freight
ADP (kg Sb eq)	1.01	0.00	6.81E-3	1.05E-2	3.61E-3
AP (kg SO_2 eq)	2.26	0.00	2.09E-3	4.17E-3	1.41E-2
EP (kg PO_4^{3-} eq)	0.43	0.00	6.69E-4	9.46E-4	1.25E-3
GWP (kg CO_2 eq)	155.8	28.18	0.58	1.28	0.56
ODP (kg CFC 11 eq)	1.93E-5	5.62E-4	2.60E-8	5.30E-8	7.00E-8
METP (1,4DCB eq)	27,037	0.00	137.2	252.1	70.07
POFP (kg C_2H_4 eq)	4.31E-2	0.00	1.10E-4	2.47E-4	4.39E-4

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrophication Potential; GWP= Global Warming Potential; ODP=Ozone Layer Depletion Potential; METP= Marine aquatic Eco-toxicity Potential; POFP= Photochemical Oxidant Formation Potential.

On board processing operations were identified as those with the highest impact for ODP (96.7%). Their contribution for GWP was 15.1%, while for the other assessed impact categories their share was close to zero. The main individual activity associated to this relative impact was cooling agent (R22) emission due to leakage in the storage freezers on board, while other activities, such as fish handling, cleaning and gutting barely created any associated burdens. Nevertheless, it is important to note that residues due to offal were not quantified in this particular study. Other on board activities, specifically those related to preliminary packaging, only reported small relative burdens, being the highest for ADP (0.7%). The main impacts related to packaging were the background production of corrugated board and low density polyethylene used to box the frozen octopus.

Finally, the two post-landing activities: landing and storage and marine freight to final destination, showed low relative contributions to all impact categories. On the one hand, landing and storage operations represented 1% and 0.9% of total contributions for ADP and METP, respectively. The transport in lorries from port to storage and vise versa was the main environmental burden identified, while unloading and port operations generated a minimal contribution to the studied categories.

On the other hand, marine freight constituted 1% and 0.6% of the total impact for POFP and AP, respectively. Nevertheless, as mentioned before, this particular operation increases its relative contribution when Scenario 2, and especially Scenario 3 are analysed, since it is the only activity that is not common to the three routes under study.

6.3.2. Fishery-specific impact categories

Discarding in the Spanish cephalopod fleet in Mauritania was calculated to be approximately 19.5% of the total catch. Therefore, a total of 5.82 kg of discard were generated per FU and returned to sea (Table 6.4). Skippers reported discarding large amounts of Cunene horse mackerel (*Trachurus trecae*), chub mackerel (*Scomber japonicus*) and sardine due to their low economic value, as well as juveniles of the targeted fish species. Additionally, this fleet is not allowed to land European spiny lobster (*Palinurus elephas*) or Golden crab (*Chaceon spp.*). Offal materials, which according to FAO should not be included as discards (Alverson et al., 1994), were not quantified in this research study.

The SIP calculated for this fishery was 46,800 m^2 for every frozen carton of common octopus landed. Unlike in other studies (Nilsson and Ziegler, 2007), due to lack of data, it was not possible to determine whether trawling effort was concentrated in specific areas within the Mauritanian EEZ.

6.4. Discussion

6.4.1. Major contributions to environmental impacts in conventional impact categories

The environmental burdens linked to the export of frozen octopus from the Mauritanian EEZ are linked mainly to on board activities of the cephalopod trawling vessels. This is due, in part, to the fact that this subsystem, unlike in previous chapters, embraces a large number of operations: extraction, processing (weighing, gutting and freezing) and preliminary packaging of the product (Fet et al., 2010). Nevertheless, the strong dominance of energy use in trawling fisheries is the main cause of this situation, which is in agreement with other previous studies (Ziegler and Valentinsson, 2008; Ziegler et al., 2011). However, even though the breakdown of fuel with respect to onboard activities is unknown for this fleet, it is expected that this fleet may present a lower proportion of fuel been used for propulsion when compared to previous trawling fishing fleets analysed in Chapters 3 and 5 (Ishikawa et al., 1987).

More specifically, the onboard activities subsystem consumed 1546 L of fuel per ton of landed octopus, which situates this fishing fleet in a high intensity energy use range, comparable to other trawling fisheries targeting demersal fish, crustacean and cephalopod species studied worldwide, as can be observed in Figures 6.6a-b (Tyedmers, 2001). When compared to cephalopod or crustacean fisheries that use other, lower fuel intensive gears, such as trammels, the FUI of the evaluated fleet is outstandingly high (Figure 6.6c), expect when contrasted with the Japanese squid angling fleet (Ishikawa et al., 1987).

The increased fuel consumption rate for the octopus fishery is reflected in the results obtained for the conventional LCA impact categories, with major impacts relating to both diesel usage and production for ADP, AP, EP, GWP and POFP. Nonetheless, this fishing fleet, as well as other assessed highly industrialized fisheries, shows increased burdens for GWP (15.1% for Scenario 1) and ODP (96.7% for Scenario 1) linked to R22 emissions due to freezing operations and storage. However, it is important to note that international legislation is slowly implementing regulations to eradicate R22 usage in vessels, and by 2015 its use should be completely eliminated (Winther et al., 2009; European Commission, 2010b). Therefore, despite the need to reduce the energy dependence of these vessels, it is currently more feasible to reduce ODP and GWP impacts by shifting to less harmful cooling agents.

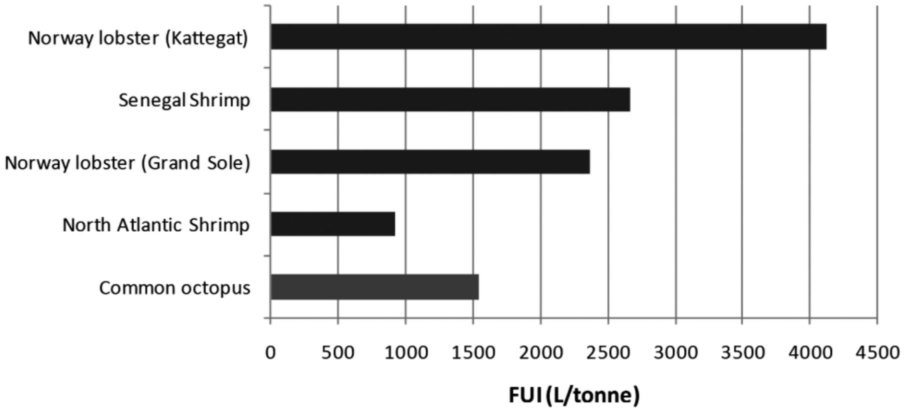

Figure 6.6a. Reported fuel intensities for selected crustacean trawling fisheries as compared to the Mauritanian common octopus fishery.

Sources: Tyedmers (2001); Ziegler and Valentinsson (2008); Ziegler et al. (2011) and Chapter 5.

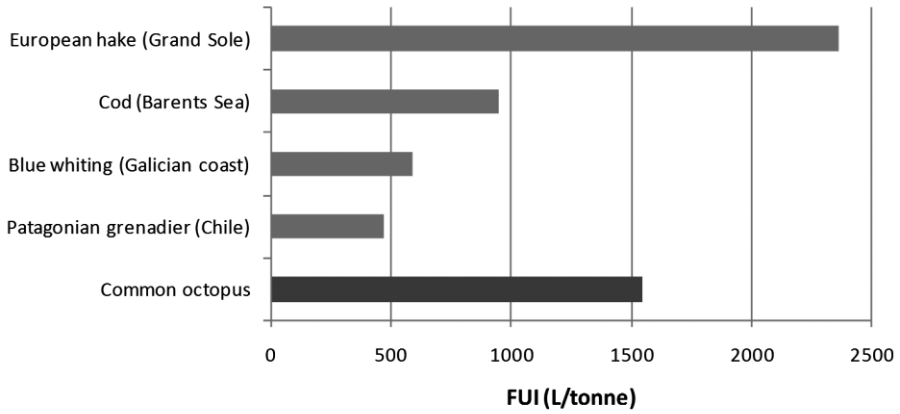

Figure 6.6b. Reported fuel intensities for selected trawling fisheries as compared to the Mauritanian common octopus fishery.
Sources: Ramos et al. (2010) and Chapters 3 and 5.

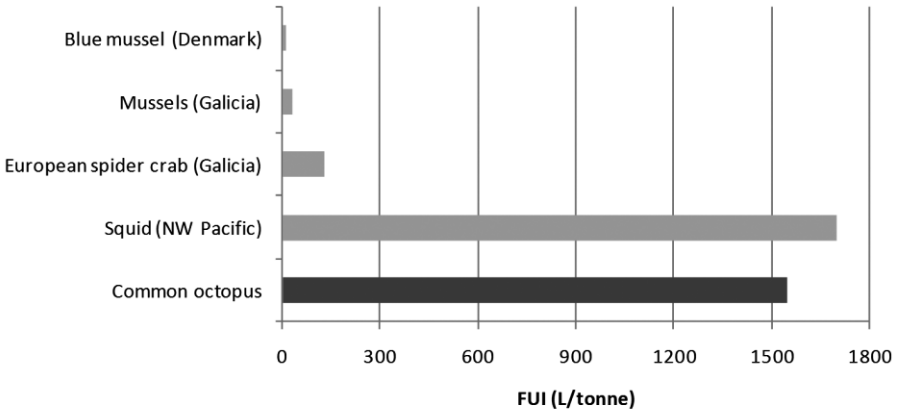

Figure 6.6c. Reported fuel intensities for selected fish species caught with non-trawling gears as compared to the Mauritanian common octopus fishery.
Sources: Iribarren et al. (2010); Ishikawa et al. (1987); Thrane (2004).

Regarding post-landing operations, it is important to highlight the low relative impacts associated with the marine freight of frozen octopus to the selected destinations. In fact, the increased freight distance related to cargo shipment to the Japanese market only created a slight influence on the final results (Figure 6.5) when compared to the European importing nations. This reduced importance of marine freight from the port of Nouadhibou to the destination port, added to the minimal difference between inter-oceanic freights (i.e. Nouadhibou–Tokyo) and North Africa–Europe transportation in the total impact of the studied product suggests the low significance of these activities in high-intensity industrialized fisheries. Hence, according to these results, over- seas seafood products, at least when they undergo simple processing treatments, such as freezing, should be analysed based on the energy use of the given fishery, rather than on the remoteness of the fishery area under study, provided that the product is transported by marine freight.

6.4.2. Fishery-specific impact categories

Discard results for the analysed fleet show a discard rate of 19.5%, which is slightly lower than the average discard rate for cephalopod trawling fishing fleets worldwide, 22.8% (Kelleher, 2005). The discards reported by Kelleher (2005) for the Moroccan cephalopod fishery, only a few miles North of Cap Blanc, one of the fishing areas in this study, was calculated to be 45% in the 1992–2001 period. Therefore, according to the obtained results, and assuming that both adjoining fishing zones belong to the same upwelling system, it is probable that discards linked to cephalopod extraction in Northwest Africa have been reduced in the course of the last decade. Nonetheless, the rate still remains way above desired values (Kelleher, 2005). However, current and previous fishing agreements between Mauritania and the EU do not analyse the discard problem in this fishery and only suggest cooperation between the parties to make use of them (European Union, 2006a). This fact is somewhat outstanding when taking into account that recent literature on the Mauritanian fishery points out discards, together with over- exploitation, as the main concern in the area (Kelleher, 2005; ter Hofstede and Dickey-Collas, 2010; Vázquez-Rowe et al., 2011b).

The impact of the trawl on the seafloor per FU was just under 5 ha. Despite the fact that this value is lower than the impact generated for the capture of southern pink shrimp (*Penaeus notialis*) in the Senegalese industrial fishery (Ziegler et al., 2011), it still represents a very high potential impact on the ecosystem, especially taking into account that in most European and Japanese fisheries, common octopus is captured with gears that are less aggressive on the seabed, such as creels or trap-pots (Boyle and Rodhouse, 2005). Regarding the global state of the analysed fishery, the Mauritanian EEZ is known to have suffered relevant reduction of octopus abundance since peak captures in the 1960s, even though the upwelling system in this area creates strong yearly abundance variance (Touileb, 2003; Gascuel et al., 2006, 2007; UNEP, 2008). However, as mentioned before, the straddling characteristics of the cephalopod stock in this area, not only demands quick and effective monitoring by the Mauritanian authorities, but would also benefit from broader regional coordination (Kazcynski and Fluharty, 2002). Therefore, future LCA studies for the assessed fishing fleet would benefit from a timeline analysis, inventorying and assessing a representative number of years, in order to detect the fluctuations in environmental burdens that occur from one year to another due to the important stock abundance variations (see Chapter 4).

6.4.3. Frozen octopus freight vs. fresh octopus freight

Other cephalopod-targeting fishing fleets in the area land fresh octopus for commercialization in the European market. Fresh seafood products landed in Mauritania are either freighted by aircraft from Nouakchott to Las Palmas and/or Lisbon, or they are transported by truck from Nouadhibou to Algeciras, Spain (Martin, 2010). Table 6.8 shows the environmental impacts observed for the transportation of one ton of fresh octopus to the country of import. Furthermore, the two export routes, aircraft freight (AF) and truck freight (TF) are compared to the marine freighting of frozen octopus to Spain (MF). Only the post-landing operations until delivery in the country of import are included.

Table 6.8. Environmental comparison among freight routes for Mauritanian cephalopod products exported to the Iberian Peninsula: characterization results per FU.

Impact categories	Aircraft freight for Fresh octopus (AF)	Truck freight for Fresh octopus (TF)	Marine freight for Frozen octopus (MF)	Ratio AF/TF	Ratio TF/MF
ADP (kg Sb eq)	23.02	13.65	1.69	1.69	8.08
AP (kg SO$_2$ eq)	12.65	2.00	2.13	6.33	0.94
EP (kg PO$_4^{3-}$ eq)	2,63	0.51	0.36	5.16	1.42
GWP (kg CO$_2$ eq)	3,430	1,943	240.45	1.77	8.08
ODP (kg CFC 11 eq)	4.62E-4	7.48E-5	3.21E-5	6.18	2.33
METP (kg 1,4DCB eq)	441,586	103,326	44,960	4.27	2.30
POFP (kg C$_2$H$_4$ eq)	5.29E-1	1.01E-1	7.10E-2	5.24	1.42

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrofication Potential; GWP= Global Warming Potential; ODP= Ozone Layer Depletion Potential; METP= Marine aquatic Eco-toxicity Potential; POFP= Photochemical Oxidant Formation Potential.

On the one hand, from the TF/MF transport ratios, it can be concluded that frozen octopus transport has considerably lower characterization values than those identified for truck transportation of fresh octopus, except for AP. Especially relevant was the increased difference for

ADP and GWP. Therefore, even though fresh and frozen octopus are not directly comparable, since they cover different consumer demands, the results presented in this table attest the increased burdens related to intercontinental fresh fish distribution for most impact categories (Abad et al., 2009; Pedersen, 2001).

On the other hand, when AF/TF ratios are confronted, aircraft transportation of fresh octopus presents higher environmental impacts for all impact categories. These results show that if truck- freighted octopus can compete in freshness and in time delivery with the aircraft-freighted product, and transportation security across Northwest Africa is guaranteed, this option is substantially less harmful to the environment for the assessed impact categories.

Given that the capacity of EU countries and Japan to expand their octopus captures is very limited and will not be possible unless further strain on their local fisheries is implemented, it is obvious that market demands in these countries will require maintaining imports from third nations such as Mauritania, as long as consumer patterns do not change (Murison, 2004; Pasquotte and Lem, 2008). Nevertheless, the fact that local and regional supply chain systems for fresh products are generally more advantageous than those imported from elsewhere, due to the use of highly intensive transportation mechanisms, such as air freight, in order to deliver the product under the correct quality requirements (McGregor et al., 2006; Saunders and Hayes, 2007), evidences the need to specialize the nature of the importing product. Hence, a series of policies should be undertaken with the aim of promoting the consumption of fresh seafood of regional origin, understood as the seafood that is captured within the EEZ of each country or of neighbouring countries, whereas intercontinental imported seafood products should develop longer shelf-life characteristics (i.e. canned or frozen products), allowing lower resource usage in transportation (Winther et al, 2009). Additionally, broader and more visible information for final retailers and consumers regarding the origin of seafood products, as well as the traceability of its processing and distribution is necessary (Garnett, 2002; Iles, 2007).

6.4.4. Economical, political and social issues around the Mauritanian cephalopod fishery

Previous studies have pointed out the difficulties that certain developing countries, such as Mauritania, have when it comes to monitoring and controlling the fishing activities that are carried out within their EEZ (Trouillet et al., 2011). This is partially due to the lack of infrastructure to do so, but most importantly to the lack of sovereignty on a wide percentage of the catches that are extracted in the frame of international agreements by foreign fleets. Therefore, unreported captures and illegal fishing are a main threat for the cephalopod fishery in this area (Gascuel et al., 2006).

In fact, the fishery policy category of the Environmental Performance Index (EPI), an index created by Yale University for measuring how close countries are to the established environmental policy objectives, points out the low scoring obtained for the Mauritanian EEZ, not only when compared to nations worldwide, but also when this is done with other Sub-Saharan African countries (EPI, 2010). In fact, only one other African nation (Mozambique) with a fisheries agreement currently in force with the EU scored less than Mauritania in this particular category (European Union, 2006a; 2007). Hence, the LCA results presented in this study seek to mitigate the lack of availability and transparency regarding fishing fleets in most Sub-Saharan fisheries, as well as providing up to date values associated with the state of the cephalopod fishery in Northwest Africa, that may contribute to update cephalopod management schemes in the region.

6.5. Perspectives and conclusions

Published fishery LCA studies to date embrace mainly fisheries belonging to European countries or other developed fishing nations. In fact, only one previous LCA study has released environmental information regarding fish extraction in an African nation's EEZ. Therefore, the cephalopod fishery evaluated in this case study attempts to increase environmental impact information regarding seafood products extracted in developing countries that are then exported to industrialized nations.

On board vessel activities for this fleet were highlighted as the main hot spots regarding environmental burdens, mainly due to the high energy use of cephalopod trawling in Mauritania, but also to the industrialized characteristics of the vessels, with processing and packaging activities prior to seafood landing. Therefore, minimization of fuel consumption, together with fishery-specific impacts, such as discards or seafloor impact, and replacement of R22 by less harmful cooling agents, are important potential improvements. Post-harvesting operations were deemed as insignificant for frozen octopus, regardless of the exporting route, provided that marine freight is the selected transport method for this long shelf-life product.

Hence, frozen common octopus extracted in Mauritanian waters, as long as the abundance of its stock is guaranteed, presents a sustainable post-harvesting supply chain up to its key importers. Therefore, the effectiveness of this tradable seafood product from an environmental point of view will depend primarily on its relative energy use in the fishery with respect to other main octopus fishing areas in the world.

Finally, future research should focus on (i) assessing other less intensive fishing fleets that extract cephalopods in Mauritanian waters, such as the existing artisanal fishing fleet, evaluating the appropriateness of shifting to other less extended fishing gears, (ii) analysing the threats that the studied fleet may face due to aquaculture diversification to promising species, such as common octopus and cuttlefish (Hormiga et al., 2010) and (iii) amplifying LCA studies to other fishing fleets in this EEZ and their supply chains may help to propose integrating fishing management policies.

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SECTION III

EFFICIENCY IN FISHING FLEETS. COMBINING LIFE CYCLE ASSESSMENT AND DATA ENVELOPMENT ANALYSIS

Chapter 7

Combined application of life cycle assessment and data envelopment analysis as a methodological approach for the assessment of fisheries[1]

Summary

The synergistic use of life cycle assessment (LCA) and data envelopment analysis (DEA) is proposed as a new methodological approach to link environmental and socioeconomic assessments of fisheries, in order to increase the assessment ability of both tools. More specifically, the joint inclusion of economic aspects and the consideration of currently underrepresented environmental impact categories are tackled. A five-step method is presented to combine LCA and DEA so that operational benchmarking and eco-efficiency verification are included together with the assessment of the environmental performance of fishing vessels. Some guidelines are also provided to orientate methodological choices in DEA. Furthermore, the applicability of the method for fisheries is discussed using a Galician coastal trawl fishery as an example. The use of the five-step LCA+DEA method demonstrated the dependence of environmental impacts on the operational performance of the vessels.

Operational inefficiencies were detected and target performance improvement values were consequently defined for the inefficient vessels. The combined method favoured quantification of potential eco-efficiency gains. Optional features of DEA models allowed the inclusion of controversial impact issues such as discarding. As demonstrated by the application of the method to the trawling case study, this methodology facilitates joint consideration of the environmental impacts of the fleet together with economic issues such as operational efficiency. Moreover, the potential inclusion of "bad outputs" in DEA models makes the proposed method suitable for quantifying the potential improvements in currently underrepresented issue areas such as discarding by-catch.

The proposed methodological approach was found as an adequate alternative to complement the mere use of LCA for fisheries. Its use avoids problems with standard deviations which usually arise when LCA practitioners work with average inventories. Moreover, the new approach facilitates the interpretation of the results for practitioners who deal with multiple individual LCAs for the same fishery. Furthermore, the joint application of LCA and DEA carry synergistic effects related to the link between operational efficiency and environmental impacts. The proposed LCA+DEA approach for fisheries is recommended for its regular use. The need of multiple input/output data for multiple vessels is not seen as a limitation in the case of fisheries research.

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[1] Vázquez-Rowe, I., Iribarren, D., Moreira, M.T., Feijoo, G. (2011). "Combined application of Life Cycle Assessment and Data Envelopment Analysis as a methodological approach for the assessment of fisheries". *International Journal of Life Cycle Assessment,* 15: 272-283

Index

7.1. Introduction

In the past few decades, due to a combination of technological developments in fishing technologies, increased fishing effort and rising demand for seafood products, there has been a great increase in marine fisheries landings worldwide. However, fishery data suggest a steady decrease in landings mainly due to the overexploitation of the world's major stocks. As a result, there is increasing demand for environmental information regarding seafood products by different social groups such as authorities, consumers, companies related to the fishing sector, and skippers (Luten et al., 2006). In an attempt to identify, quantify, and assess environmental impacts throughout the life cycle of seafood, LCA is considered a useful and powerful methodology. Thus, LCA has been proven suitable for quantifying a subset of the environmental impacts associated with fisheries and aquaculture production (Pelletier et al., 2007). However, further efforts are required to improve seafood supply transparency and accountability (Iles, 2007; Ayer et al., 2009).

Data envelopment analysis (DEA) is a performance measurement methodology used to empirically quantify the comparative productive efficiency of multiple similar entities (Cooper et al., 2007). To carry out a DEA, data for inputs and outputs from the different entities must be known. From these data, DEA formulates and solves an optimization model which facilitates benchmarking the operational performance of each assessed entity. This benchmarking provides a basis for a decrease in inputs per unit of output, usually resulting in improved eco-efficiency. Consequently, DEA enables the discrimination of inefficient operating points, therefore promoting feasible technological improvements under the perspective of an efficient operational performance.

At the same time, whereas many potential environmental impacts of fisheries are not currently accounted for using traditional LCA methodologies (e.g., seafloor impacts, discard impacts, ecosystem alteration, etc.), DEA may facilitate consideration of these underrepresented issue areas.

The goal of the present study was to propose a regular methodology to perform a joint analysis of operational efficiency and environmental impacts for fisheries by using the combined application of LCA and DEA. A case study regarding trawling vessels in NW Spain was considered as an example. A complementary goal was to use DEA to simultaneously address currently underrepresented issue areas in LCA research of fisheries; specifically, the discard of by-catch was faced.

7.2. Framework

7.2.1. The problem of multiple inventory data in LCA

Data availability and quality are critical problems in LCA studies (Weidema and Wesnaes, 1996; Reap et al., 2008a). LCA practitioners often have to gather inventory data for a high number of similar facilities in order to ensure sample representativeness for a particular case study. Therefore, it is not unusual to handle multiple input/output data. The way multiple data sets are managed may strongly influence the utility of the assessment. A common solution is to establish an average inventory which includes the average values for the different inputs and outputs. However, the high degree of variability often associated with multiple data sets (as evidenced by reported standard deviations) is a barrier. An alternative approach to dealing with multiple inventories is to carry out individual LCAs for each of the inventories. This approach may better represent variability, but the multiple results may be difficult to interpret.

In such situations, a promising alternative which simultaneously (1) avoids large standard deviations, (2) facilitates the interpretation of the results, and (3) provides useful additional information to complement LCA with a non-parametric tool called DEA is introduced in section 7.2.2. This approach is clearly relevant for LCA research of fisheries due to the need to assess many fishing vessels to guarantee representativeness.

7.2.2. An introduction to DEA

DEA (Cooper et al., 2007) is a linear programming method to measure the efficiency of multiple decision-making units (DMUs) when the production process involves multiple inputs and outputs. A DMU is defined as the entity responsible for the conversion of inputs into outputs and whose performance is the object of assessment. DEA non-parametrically estimates the relative efficiency of a number of DMUs. Therefore, DEA neither requires the user to set weights for each input and output nor demands the establishment of any functional form. Rather, DEA simply relies on the observed data for the inputs and outputs and on a minimum of basic assumptions to solve an optimization model formulated for every DMU. DEA estimates production efficient frontiers for a number of homogenous units (DMUs); in mathematical terms, these efficient frontiers are said to envelop all units. The region determined by the efficient frontiers is called production possibility set (PPS), and the DMUs on the frontiers constitute the reference set. The result for each DMU is an efficiency score and, for those DMUs identified as inefficient, a target operating point.

A wide range of literature articles have highlighted the appropriateness of using this tool in fishing systems, given its capacity to measure vessels individually in multiple vessel fishing fleets (FAO, 2000; Maravelias and Tsitsika, 2008) and the wide number of inputs and outputs that can be assessed simultaneously (Kirkley and Squires, 2003). Most of these studies have focused on assessing the technical efficiency (TE) and capacity utilization (CU) of fishing vessels. The stand-alone use of DEA has already been proposed for environmental performance analysis and for eco-efficiency assessments (Kuosmanen and Kortelainen, 2005; 2007; Kortelainen, 2008). However, if LCI data are available, it is possible to synergistically link the use of LCA and DEA in order to more effectively detect and remedy the technical inefficiencies that are sources of unnecessary environmental impact (Lozano et al., 2009).

7.2.3. Specific framework for fisheries

When performing an LCA for fisheries, an accurate study requires the assessment of a representative number of vessels. From a DEA perspective, each vessel represents a DMU. The rule of thumb to determine the minimum sample size in DEA is: $n \geq \max\{m \times s, 3 \times (m + s)\}$ (Cooper et al., 2007), where m is the number of inputs used in the DEA study and s is the number of outputs involved. For example, the simplest case for DEA would just consider one input (diesel consumption) and one output (catch rate), so at least six vessels should be studied. However, the number of inputs and outputs of interest for a DEA study on fisheries is expected to be much higher. Nevertheless, this fact is not a problem for fishery case studies since the number of vessels which guarantees sample representativeness must be high enough to allow LCA practitioners to include DEA in their case study. Consequently, the LCA+DEA method proposed in this section will generally prove feasible in fisheries LCA research and can be understood as a regular procedure for fisheries.

7.3. Proposed methodology

This study develops how LCA and DEA should be jointly applied for the study of the environmental and economic performance of fisheries. The recommendation is that LCA practitioners use the most relevant LCI data in order to carry out a complementary DEA study. This will lead to virtual feasible targets that will be object of further treatment by using LCA to check and quantify eco-efficiency.

In this section, a guide to the steps to be undertaken is presented together with some guidelines to perform a DEA. Finally, this section highlights the benefits of using this extended method for LCA. These benefits refer mainly to the inclusion of issues for which well established impact assessment methods have not been developed (Pelletier et al., 2007), such as the consideration of by-catch and discards in fisheries (Ziegler et al., 2003; Ziegler and Valentinsson, 2008).

7.3.1. LCA+DEA steps

As summarized in Figure 7.1, the proposed LCA+DEA methodology for fisheries comprises five main steps:

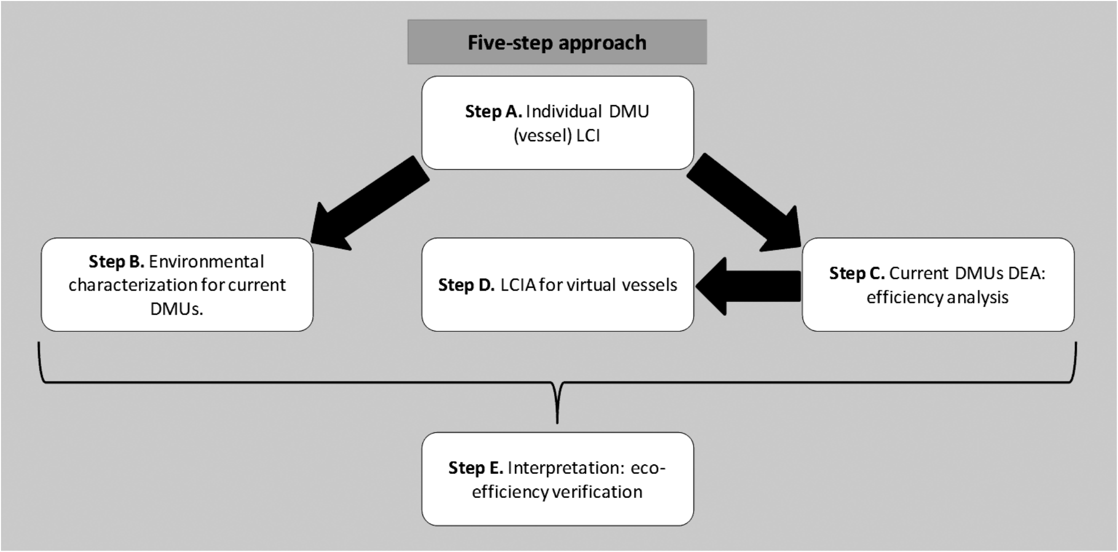

Figure 7.1. Schematic representation of the LCA+DEA methodology for fisheries.

1. LCI for each of the DMUs (vessels). In this stage, input and output data for the assessed system are collected.
2. Life cycle impact assessment for every vessel from the LCI developed in the first step. This second stage constitutes the environmental characterization of the current vessels' performance.
3. DEA from the LCIs of the first step: Determination of the operational efficiency of each DMU and calculation of the target DMUs. The use of DEA on the most relevant input/output data leads to computing the relative efficiency of each vessel and setting appropriate efficiency targets. The DEA targets represent virtual vessels which consume less input and/or produce more output. These targets are calculated by projecting each DMU on the efficient frontier determined by the reference set. Note that each DMU has its own reference set, so this step should not be misunderstood as a simple calculation of a distance-to-target for the less efficient vessels through a simple scan of the inventory data sets. Therefore, at this point, the performance of multiple vessels is benchmarked from an economic/operational perspective.
4. Environmental characterization of the target vessels. In this fourth stage, the potential environmental impacts are determined for the virtual DMUs by performing a life cycle impact assessment with the new LCI data arising from the previous step.
5. Comparison of the potential environmental impacts for the virtual vessels versus those for the current vessels. This step shows how environmental impacts depend on the efficiency with which operations are carried out. Links between operational efficiency and environmental impacts are then established and the environmental consequences of operational inefficiencies can be estimated.

An alternative approach would consist of only three stages. The first two steps would be the same as those described above. However, the third stage would comprise a DEA with a higher number of inputs given the consideration of the potential environmental impacts determined in the second step as inputs for the DEA along with the selected LCI inputs (Lozano et al., 2010). In this sense, the benchmarking results would directly estimate targets for both LCI inputs/outputs and the potential environmental impacts. For LCA practitioners, this alternative is considered as less interesting than the previous one since DEA itself is not a method conceived for environmental management but for operational (economic) management. Therefore, the recommendation is to benchmark the operational performance of the vessels and then carry out an LCA with the new target LCI. Moreover, according to the rule of thumb for sample size, the second approach would result in an increased number of DMUs to be assessed so as to guarantee an adequate number of degrees of freedom for the efficiency discrimination among DMUs in DEA; this is due to the higher number of inputs (m). Note that if $n < m + s$, then a large portion of the DMUs will be deemed efficient, and efficiency discrimination turns disputable.

7.3.2. Recommendations to perform DEA

A wide range of models to perform DEA are available (Zhu, 2002). Three factors have to be taken into account when selecting a model (Cooper et al., 2007; Lozano et al., 2009): (1) metric (radial or non-radial), (2) orientation (towards inputs, towards outputs, or mixed orientation), and (3) PPS display. This third factor merits further attention. In this sense, even though DEA does not rely on assumptions that the data come from any specific production function, some assumptions are usually made to perform DEA. The three common assumptions are convexity, scalability, and free disposability of inputs and outputs. When the three assumptions are made, the PPS is said to display constant returns to scale (CRS). On the other hand, if convexity and free disposability but not scalability are assumed, then the PPS displays variable returns to scale (VRS). A model which meets the features required by the user should be selected. It can be difficult to choose between CRS and VRS. The general recommendation is to assume VRS where the user suspects that not all the DMUs operate at an optimal scale (Banker, 1984).

Lozano et al. (2009) carried out a joint application of LCA and DEA for mussel aquaculture by adopting a five-step LCA+DEA approach; the DEA model used was the enhanced Russell graph measure model. Model features included mixed orientation, non-radial metric, and CRS. On the other hand, in (Lozano et al., 2010), a three-step approach is proposed for the combined application of LCA and DEA also in mussel aquaculture with the same model features, but resorting to the slacks-based measure (SBM) model.

7.3.3. Advantages of the LCA+DEA method

LCA for fisheries presents a number of challenges. Some of them are related to LCA itself, such as the current lack of accepted methodologies to assess the social and economic dimensions of product or service systems. Other challenges arise in accounting for fishery-specific impacts, such as benthic disturbance due to bottom trawling or the biodiversity impacts caused by discards and by-catch. Some methodological development efforts have to be made in these areas (Pelletier et al. 2007). The LCA+DEA method may also contribute to partly resolving these challenges, for example by providing an economic perspective or benchmarking the discard levels.

LCA is traditionally focused only on environmental impacts. In fact, ISO documentation limits LCA's purview to environmental effects (ISO, 2006a, 2006b). From a sustainable development perspective, this may limit the capability of LCA to support decisions (Reap et al., 2008b). In this sense, the LCA+DEA methodology adds an economic dimension to the assessment by evaluating the operational performance of the vessels. Therefore, complementary use of DEA provides LCA with a stronger potential to support decision making because it facilitates benchmarking both the environmental and the operational performance of the assessed vessels.

Eco-efficiency is based on creating more goods and services while using fewer resources and creating less waste and pollution. The term eco-efficiency was coined by the World Business Council for Sustainable Development to demand the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life cycle to a level at least in line with the Earth's estimated carrying capacity (Schmidheiny, 1992). The joint application of DEA and LCA allows the benchmarking of the environmental and operational performance of vessels, which provides a basis for targeting effective means of reducing environmental impacts if the determined operational targets are achieved. The proposed LCA+DEA method for fisheries is in accordance with the eco-efficiency concept and arises as a simple approach geared towards sustainability and not limited to environmental impacts.

Application of DEA models gives rise to other advantages related to the specific model chosen by the user. For instance, weighted models enable users to assign weights to inputs and outputs corresponding to the relative importance of items; for example, instead of giving the same priority to every input reduction, the reductions in each of the inputs can be differently weighed by giving more priority to the reduction of those inputs that contribute more to the environmental impact categories (Thanassoulis and Dyson, 1992).

DEA models can also be used to address certain issue areas for which accepted impact assessment methods have not been developed. For example, DEA OBad models, which minimize "bad outputs" from product or service systems, might be used to account for discards from fisheries. DEA usually assumes that producing more outputs relative to less input resources is a criterion of efficiency. However, this clearly does not apply to undesirable outputs, such as polluting emissions or wasted resources. In the presence of undesirable outputs, technologies with better (desirable) outputs and less undesirable outputs relative to less input resources should be recognized as efficient (Cooper et al., 2007). The LCA+DEA method for fisheries can employ an OBad model to integrate discarding in the assessment by benchmarking its values on the basis of real discard LCI data (i.e., minimizing discard values from a DEA perspective) rather than by implementing a new impact category from an LCA perspective.

The LCA+DEA approach has previously been successfully applied to the evaluation of extensive aquaculture production (Lozano et al., 2009). Moreover, in the next section, the potentials of the new methodological approach for fisheries are shown and discussed on the basis of a specific case study.

7.4. Application of the proposed LCA+DEA method to coastal trawling

As previously described, a joint LCA and DEA approach can be implemented to assess the operational efficiency and environmental impacts of fisheries. The fact that the extraction phase of most fisheries typically involves a great number of vessels makes this methodology useful and applicable to nearly every fishery in the world.

7.4.1. Case study

The example proposed is an LCA of a sample of trawling vessels belonging to the Galician fishing ground. The study aimed at quantifying the environmental impact associated with the landing of various fish species caught by Galician trawling vessels on the Galician continental shelf during

2008. The main tradable species that are sold by Galician trawlers are European hake, Atlantic horse mackerel, Atlantic mackerel, and blue whiting. Hake was sold that year at 3.72€/kg, being the most expensive of these species at the fish market. All the other species had a similar value at the fish market ranging from 0.89€/kg for blue whiting to 0.51€/kg for Atlantic mackerel (Xunta de Galicia, 2008).

The considered FU was 1 kg of landed fish. The rationale behind this FU choice, rather than adopting a product perspective, is its ability to analyse the operational and environmental performance of the different vessels. In other words, an FU referred to only one specific product would prevent the assessment from getting a realistic perception of the vessels' performance. The system under study comprised the different stages considered for fish extraction performed by the different vessels in the fishery, including diesel consumption, anti-fouling, oil and trawl nets use, and ice consumption. The construction and maintenance of the vessels was also included. The product was followed from the fishery until landing for sale, constituting a "cradle to gate" analysis (Guinée et al., 2001).

7.4.2. Data acquisition

The sample used for the case study is a group of 24 trawling vessels belonging to the Galician fishing fleet (Figure 7.2). Data from these vessels have already been used in Chapter 3 in order to determine the environmental profile of one of their products: Atlantic horse mackerel. As mentioned in that chapter, these fishing boats represent 24% of the total Galician continental shelf trawling fleet (Xunta de Galicia, 2008). The data were obtained through a series of questionnaires filled out by skippers from three of the most important trawling ports in Galicia (see Figure 3.4 in Chapter 3).

Figure 7.2. Trawlers anchored at the port of Celeiro, Galicia.

The input and output data for the DEA for the 24 DMUs are shown in Table 7.1 and correspond to the most important primary data from the questionnaires. A total of six inputs and two outputs were considered, all of which related to the vessels main activities. Therefore, the rule of thumb for minimum sample size is satisfied (24 vessels required). It is important to point out that the emissions to air due to diesel combustion or emissions to seawater from anti-fouling agents were not considered in the table, owing to their direct proportion with respect to the amounts of diesel and anti-fouling consumed. Consequently, by minimizing these inputs, at the same time, we are minimizing the direct emissions from the DMUs. The outputs considered were the discarded fish and the catch value of each vessel. Global catch value for all the species was chosen as an output instead of their individual catch rates for two main reasons.

Table 7.1. Input and output data for DEA.

DMU	**O** Catch value (€/year)	**OBad** Discards (kg/year)	**I-1** Diesel (l/year)	**I-2** Lubricating oil (l/year)	**I-3** Paint (l/year)	**I-4** Trawl net (kg/year)	**I-5** Steel for vessel (kg/year)	**I-6** Ice (kg/year)
1	443,996	868,600	404,000	1,650	408	2,059	3,933	237,350
2	718,655	849,915	404,000	1,200	362	1,416	3,074	230,000
3	718,655	849,915	404,000	1,316	261	1,416	2,416	220,000
4	917,952	1,167,508	440,000	1,600	460	1,294	4,333	180,000
5	917,952	444,766	480,000	1,600	460	1,294	4,333	172,000
6	796,224	981,888	404,000	1,200	527	1,416	4,840	161,600
7	1,214,898	605,025	350,000	1,350	509	1,392	4,707	200,160
8	1,214,898	605,025	347,000	1,300	401	1,392	3,330	198,000
9	521,226	326,203	404,000	1,250	289	1,392	3,032	215,000
10	521,226	326,203	404,000	1,450	460	1,392	3,712	202,000
11	808,032	244,273	500,000	1,650	390	1,877	3,800	343,400
12	554,040	206,353	480,000	2,400	390	2,333	4,560	202,000
13	1,466,566	472,208	440,000	2,750	390	1,877	3,800	363,600
14	701,036	395,074	396,000	2,400	390	2,150	3,257	222,200
15	1,005,718	747,434	330,000	1,800	256	1,051	2,781	171,700
16	1,005,718	215,173	355,000	1,800	299	1,051	2,390	171,700
17	1,326,989	199,770	292,900	1,496	390	1,051	3,257	202,000
18	1,326,989	431,775	305,000	1,316	190	1,051	1,827	202,000
19	1,353,235	781,943	383,800	4,000	231	2,796	2,222	202,000
20	575,377	272,575	242,400	6,00	387	2,024	3,234	212,100
21	575,377	272,575	250,400	13,00	387	2,024	3,773	212,100
22	660,298	315,060	303,000	800	355	1,416	3,029	202,000
23	928,290	37,870	378,750	600	321	1,173	2,809	303,000
24	565,931	75,098	242,400	1,800	355	1,568	3,029	161,600
Total	20,839,278	11,692,229	8,940,650	38,628	8,868	37,906	81,479	5,187,510

DMU= decision making unit; O= output; I-1= input 1; I-2= input 2; I-3= input 3; I-4= input 4; I-5= input 5; I-6= input 6.

Firstly, the species captured by the vessels were not uniform. Therefore, catch value was included as the output to standardize all captures of the fleet. Secondly, including the separate catch rates of the different species would increase the "good" outputs to four, so a larger sample would be needed to carry out the DEA. It should also be noted that the discarded fish is referred to as a "bad output" due to its undesirable character. Initially, selecting the global catch value as the output for DEA may seem inconsistent with previous FU defined for LCA; however, the output reference for DEA must observe the economic nature of the tool. In fact, a global catch rate may distort the real purpose of the benchmarking pursued by fishers, which is not to fish more but to increase earnings. Given the difference in species value, an increase in fish captures does not guarantee a greater turnover. Furthermore, in this study, the choice of the global catch value does not entail problems when transferring the target percentage reductions of the inputs and bad outputs to the LCI data for the environmental characterization of the target vessels, due to the invariance of the target outputs related to the original ones, then maintaining the same catch rate distribution.

7.4.3. Justification of the case study

DEA implementation in LCA studies is useful in situations with a large range of data characterized by significant standard deviations. In these cases, an average inventory does not provide a realistic assessment of the operational and environmental performance of the inventoried units. For the proposed study, the standard deviation for the main inputs and outputs was evaluated to determine the appropriateness of using an average inventory. Table 7.2 presents the obtained data.

Table 7.2. Standard deviation determination for the main data of the Galician coastal trawling.

DMU	OBad (kg/FU)	I-1 (l/FU)	I-2 (l/FU)	I-3 (l/FU)	I-4 (kg/FU)	I-5 (kg/FU)	I-6 (kg/FU)
1	2	0.93	3.8E-3	9.4E-4	4.7E-3	9.1E-3	0.55
2	1.5	0.71	2.1E-3	6.4E.4	2.5E-3	5.4E-3	0.41
3	1.5	0.71	2.3E-3	4.6E-4	2.5E-3	4.3E-3	0.39
4	1.49	0.57	2.1E-3	5.9E-4	1.7E-3	5.6E-3	0.23
5	0.57	0.62	2.1E-3	5.9 E-4	1.7E-3	5.6E-3	0.22
6	1.52	0.62	1.8E-3	8.0 E-4	2.2E-3	7.4E-3	0.25
7	0.67	0.39	1.5E-3	5.6 E-4	1.5E-3	5.2E-3	0.22
8	0.67	0.38	1.4E-3	4.4 E-4	1.5E-3	3.7E-3	0.22
9	0.67	0.83	2.6E-3	5.9 E-4	2.8E-3	6.2E-3	0.44
10	0.67	0.83	3.0E-3	9.4 E-4	2.8E-3	7.6E-3	0.41
11	0.29	0.60	2.0E-3	4.7 E-4	2.2E-3	4.6E-3	0.41
12	0.23	0.55	2.7E-3	4.4 E-4	2.7E-3	5.2E-3	0.23
13	0.35	0.33	2.1E-3	2.9 E-4	1.4E-3	2.9E-3	0.27
14	0.42	0.42	2.6E-3	4.2 E-4	2.3E-3	3.5E-3	0.24
15	1.71	0.76	4.1E-3	5.9 E-4	2.4E-3	6.4E-3	0.39
16	0.49	0.81	4.1E-3	6.9E-4	2.4E-3	5.5E-3	0.39
17	0.35	0.51	2.6E-3	6.8E-4	1.8E-3	5.7E-3	0.35
18	0.75	0.53	2.3E-3	3.3E-4	1.8E-3	3.2E-3	0.35
19	0.57	0.28	2.9E-3	1.7E-4	2.0E-3	1.6E-3	0.15
20	0.83	0.74	1.8E-3	1.2E-4	6.2E-3	9.9E-3	0.65
21	0.83	0.77	4.0E-3	1.2E-4	6.2E-3	1.2E-2	0.65
22	0.75	0.72	1.9E-3	8.4E-4	3.4E-3	7.2E-3	0.48
23	0.06	0.55	9.0E-4	4.7E-4	1.7E-3	4.1E-3	0.44
24	0.22	0.70	5.2E-3	1.0E-4	4.5E-3	8.7E-3	0.46
Mean	0.80	0.62	2.6E-3	6.4E-4	2.7E-3	5.8E-3	0.37
SD	±0.54	±0.17	±1.0E-3	±2.7E-4	±1.4E-3	±2.4E-3	0.14

DMU= decision making unit; O= output; I-1= input 1; I-2= input 2; I-3= input 3; I-4= input 4; I-5= input 5; I-6= input 6.

As shown in Table 7.2, high standard deviations were observed for all inputs and outputs, ranging from 27% (diesel consumption) to 68% (discarded fish). These values recommend against the use of average inventory data set which would mask the considerable variability in operational and environmental performance within the fleet. Other alternatives to face high standard deviations include the modelling of representative and coherent facility types based on accountancy data for use in environmental assessments (Dalgaard et al., 2004; 2006). In this sense, within each facility type, there must be a consistent relation between resource use, production, and emissions.

Although Table 7.2 reflects a specific situation, high standard deviations are expected to be a common characteristic when fisheries are inventoried. The reasons behind this relevant variability include the migratory nature of most species, the lack of a standard operation of the different vessels (Schau et al., 2009), the variable characteristics of these vessels, and even the skipper skill (Ruttan and Tyedmers, 2007).

7.4.4. Methodology application

Step 1: DMUs LCI

The first step of the methodology is to obtain all the data that need to be included in the LCI. It is also important to have the DEA matrix well defined with the selected inputs and outputs, making sure that they meet the rule of thumb for sample size.

Step 2: Environmental characterization of current DMUs

Once the LCI stage is complete, individual LCAs for each of the vessels are carried out. The specific software used for the computational implementation of the LCIs was SimaPro 7.3 (Goedkoop et al., 2010) using CML baseline 2000 as the environmental impact assessment method. In this particular study, six impact categories were taken into account, excluding the toxicity and ecotoxicity impact categories due to the uncertainties in the results (Ziegler and Valentinsson, 2008). The impact categories included were ADP, AP, EP, GWP, ODP and POFP. It must be noted that this case study is only an example for the application of the proposed LCA+DEA method; therefore, other environmental impact assessment methods could be equally applied if judged more convenient. For example, given the importance of fuel use, the application of the cumulative energy demand method (VDI-Richtlinien, 1997) might be also interesting in order to add cumulative energy demand as another impact category.

This second step of the LCA+DEA method is here performed by adopting an attributional (retrospective) LCA; however, the latter target values from step 3 could be useful for future change-oriented (prospective or consequential) assessments (Ekvall et al., 2005).

Step 3: Current DMUs DEA

The following step is to calculate the efficiency scores of the different DMUs in the DEA program. The software used to implement this model was DEA Solver Professional Release 6.0 (Saitech, 2009) using in this case an SBM-Undesirable Outputs model. The rationale of this model is the inclusion of a so-called bad output in order to take into account the discarded fish in the system. The model demands the inclusion of two additional numbers: the total weight assigned to good outputs and the total weight assigned to bad outputs. In this case, no weighting was considered necessary, so the default 1 and 1 values were introduced in the program. The DEA model was then used to identify the efficient and the non-efficient DMUs and to formulate a new virtual and efficient value for the different inputs and outputs of the inefficient DMUs by projecting the inefficient values on the efficient frontiers established by the efficient DMUs (i.e., by the reference set, which can be different for each of the vessels). Obviously, efficient DMUs did not experiment any changes, with their corresponding target coinciding with their actual operating point. Table 7.3 shows the efficiency scores computed with the SBM Undesirable outputs model. As observed, only four of the 24 vessels were deemed efficient (i.e., efficiency score of 100%). This allowed important input target reductions (larger than 60% in some cases), which are expected to entail significant reductions in environmental impacts. Note that efficient vessels do not involve identical performances since efficiency only means that according to the real data observed and the three basic assumptions (convexity, scalability, and free disposability of inputs and outputs), it is not possible to produce more without increasing resource consumption.

Table 7.3. Efficiency scores (Φ_0) for the 24 vessels according to the SBM-Undesirable outputs model for DEA.

DMU	Φ_0 (%)	DMU	Φ_0 (%)
1	15.13	13	60.29
2	30.42	14	27.36
3	32.46	15	51.57
4	36.00	16	72.31
5	42.38	17	100.00
6	33.50	18	100.00
7	56.86	19	100.00
8	60.98	20	37.36
9	25.14	21	29.23
10	22.82	22	39.59
11	36.49	23	100.00
12	23.05	24	47.00

DMU= decision making unit.

Step 4: Environmental characterization of target DMUs

Once the target values obtained in the DEA model for the inefficient trawling vessels were available, they underwent a new environmental impact assessment through LCA in order to calculate the impacts of these vessels if they are operated in an efficient way. Once again, note that target vessels usually show a different environmental performance because of the differences in their target input (and undesirable output) inventories, even though they are all deemed efficient. This second environmental characterization should not be understood as a pure consequential LCA (Ekvall et al., 2005) but as a descriptive assessment of the current vessels if they are operated at an optimized scale.

Step 5: Interpretation and eco-efficiency verification

Finally, as seen in Figure 7.3, the environmental impacts per kilogram of output (i.e., per FU) of the original DMUs were compared to those associated with their virtual targets. Usually, the environmental impacts in the virtual targets were lower than the ones of the original DMUs due to the optimization of the resources.

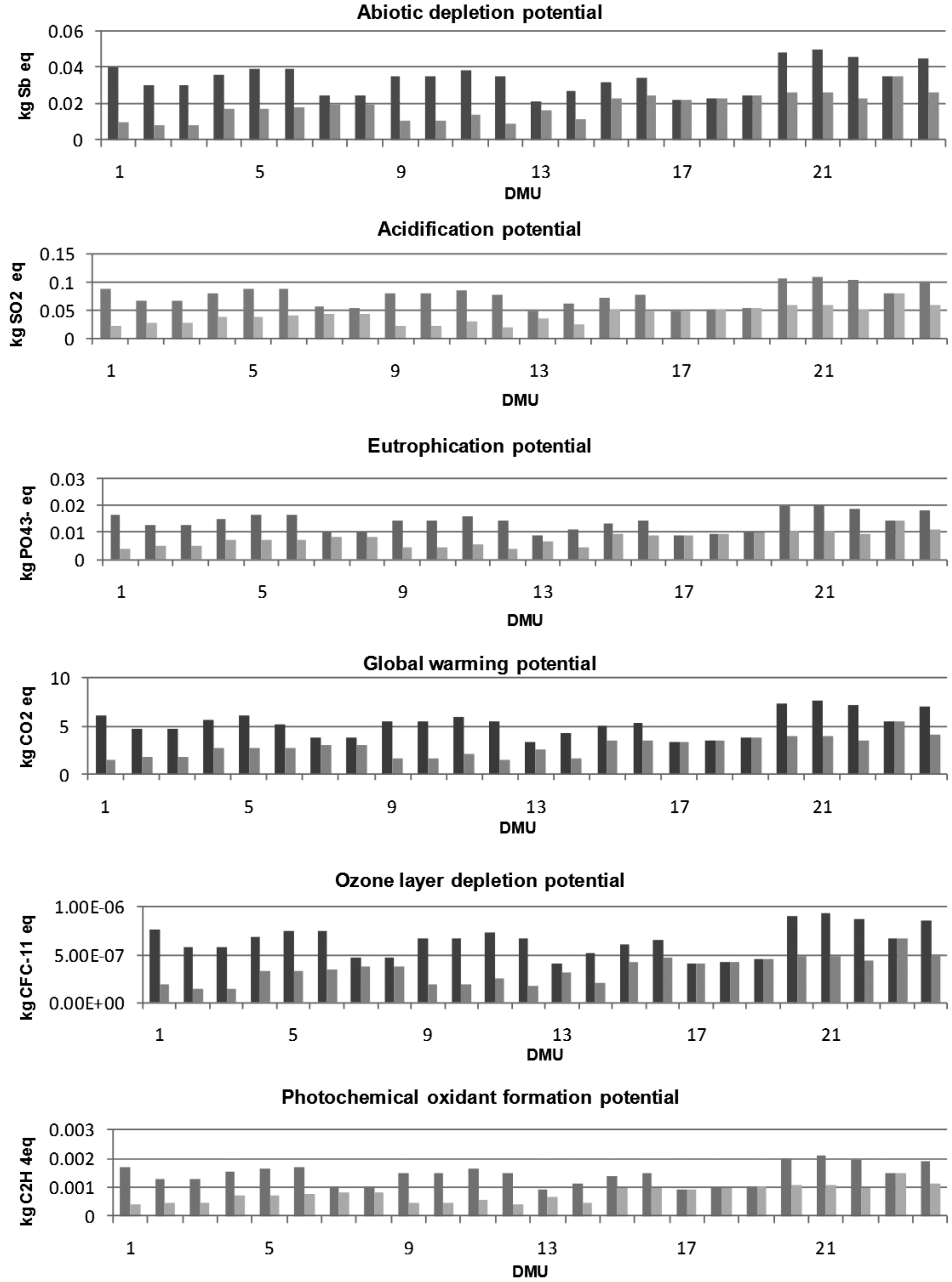

Figure 7.3. Environmental impact potentials of original DMUs (dark bar) and virtual targets (clear bar) per kilogram of output.

Moreover, Figure 7.4 represents how the total target environmental impact was considerably lower than the current one for all the impact categories when evaluating the entire fleet. The categories that benefited the most from operational optimization were ODP and ADP (roughly 44% improvements). At the same time, Figure 7.4 also shows that the reduction in input consumption was notable with respect to the current values. In this sense, inputs I-3 and I-5 had reductions of up to 60%, while I-6 and I-2 presented reductions below 40%. OBad (discards) presented a 47% reduction with respect to the current figures. DEA estimated these important reductions in resources just resorting to the observed input/output data and extending to every DMU the best practices observed in the sample.

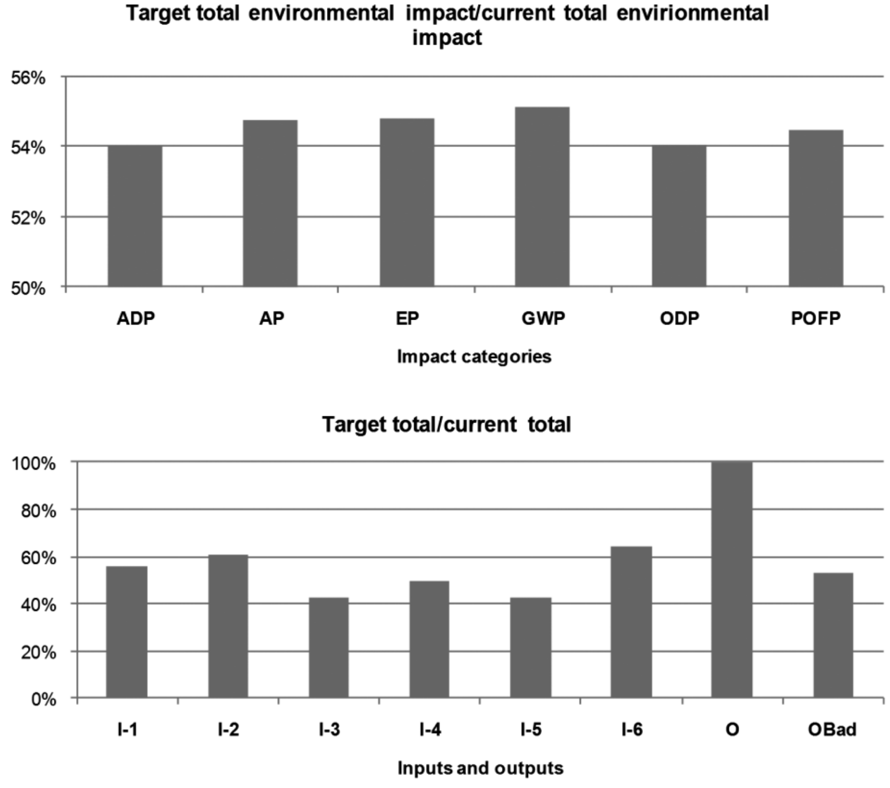

Figure 7.4. Target versus current total inputs consumption and environmental impacts for the fleet as a whole.

ADP= abiotic depletion potential; AP = acidification potential; EP = eutrophication potential; GWP= global warming potential; ODP= ozone layer depletion potential; POFP = photochemical oxidant formation potential; I-1= input 1; I-2= input 2; I-3= input 3; I-4= input 4; I-5= input 5; I-6= input 6; O= output; OBad= bad output.

7.4.5 Brief discussion of the case study

The results presented within this methodology achieved the important objective of integrating the environmental impacts of the fleet together with economic issues, such as operational efficiency. In this sense, the results presented in Figures 7.3 and 7.4 show how the link between operational efficiency and environmental impacts is possible by optimizing resource usage (waste reduction, unproductive inputs, or incorrect use of processes) in order to reduce the potential environmental impacts in different impact categories. Therefore, the use of DEA in this methodology introduces operational benchmarking into LCA. However, this methodology does not integrate social issues in LCA studies.

The proposed DEA model for this case study was the SBM-Undesirable Outputs model. This model was chosen for trawling activities due to the fact that these produce a great amount of discarded fish (around 40% of total capture for the studied fishery). Even with the inclusion of this bad output, the environmental impacts generated by discards still cannot be assessed, but it proved a feasible and suitable method for quantifying the potential improvements in fish discarding. For other fishery and gear case studies, the convenience of using the SBM-Undesirable Outputs model should be assessed regarding the significance of discards. For some gears that have very small amounts of discarding, such as creels or purse seiners, a regular SBM model would be sufficient.

7.5. Perspectives and conclusions

Given the need to inventory a representative number of vessels to conduct a fishery LCA, the proposed LCA+DEA method arises as a general methodology for fisheries. Consequently, the proposed LCA+DEA method should become a common practice in LCA case studies for fisheries. Nevertheless, among the perspectives for this five-step method, its potential application to other facilities such as farms or wastewater treatment plants has been proven (Iribarren et al., 2011; Vázquez-Rowe et al., 2012). Actually, whenever LCI data for multiple similar facilities are available, the proposed method can be applied just following the five steps detailed in Section 7.3.1.

The new methodological approach for fisheries proved to entail appealing characteristics, among which, the following are highlighted:

– Avoidance of the use of average inventories when assessing a high number of similar facilities. In this sense, undesirable standard deviations are prevented.

– Facilitation and enrichment of the interpretation of the results for multiple LCAs. The LCA+DEA method is not limited to environmental impacts but adds an economic dimension to the sustainability assessment of fisheries by integrating an operational benchmarking of the vessels' performance.

– Means for eco-efficiency verification. The LCA+DEA approach reveals the link between operational efficiency and environmental impacts, quantifying the environmental consequences of operational inefficiencies. The application of LCA to the virtual targets quantitatively verifies whether the operational benchmarking leads to a better environmental performance.

– As shown for the trawling case study, in those cases where impact categories are not yet established or are out of consensus, the complementary use of DEA enables the quantification of potential improvements for controversial issues such as fish discarding. This advantage is possible due to the availability of a wide range of DEA models. Examples of specific models with interesting potentials of use include, among others, weighted models and OBad models.

The underlying philosophy for the LCA+DEA method is to join the strengths and minimize the weaknesses attributable to both methodologies so that a synergistic effect is achieved by maintaining a quantitative character. Therefore, the final recommendation is to adopt this LCA+DEA approach as the regular methodology for the LCA of fisheries.

7.6. References

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Chapter 8

Further potentials in the joint implementation of LCA+DEA. Case study: Intra- and inter-assessment within selected Galician fishing fleets[1,2]

Summary

The combined application of LCA and DEA has been proposed to provide a tool for the comprehensive assessment of the environmental and operational performance of multiple similar entities. Among the acknowledged advantages of LCA+DEA methodology, eco-efficiency verification and avoidance of average inventories have been highlighted in Chapter 7. However, given the novelty of LCA+DEA methods, a high number of additional potentials remain unexplored. In this sense, there are some features that are worth detailing given their wide interest to enhance LCA performance.

Emphasis is laid on the improved interpretation of LCA results through the complementary use of DEA with respect to: (i) super-efficiency analysis to facilitate the selection of reference performers, (ii) inter- and intra-assessments of multiple data sets within any specific sector with benchmarking and trend analysis purposes, (iii) integration of an economic dimension in order to enrich sustainability assessments, and (iv) window analysis to evaluate environmental impact efficiency over a certain period of time. Furthermore, the capability of LCA+DEA methodology to be generally implemented in a wide range of scenarios is discussed. These further potentials are explained and demonstrated via the presentation of brief case studies based on real data sets.

Moreover, the "five-step LCA + DEA method" was applied to a wide range of vessels for selected Galician fisheries, including open sea, offshore, and coastal fleets in order to perform a sectorial intra- and inter-assessment of these fishing fleets. The environmental consequences of operational inefficiencies were quantified and target performance values benchmarked for inefficient vessels. The potential environmental performance of target vessels was assessed to verify eco-efficiency criteria (lower input consumption levels, lower environmental impacts).

Results revealed the strong dependence of environmental impacts on one major operational input: fuel consumption. The most intensive fuel-consuming fleets, such as cephalopod trawlers, were found to entail the diesel consumption levels nearest to the efficiency values. Despite the reduced environmental contributions linked to other operational inputs, such as hull material, antifouling paint, or nets, these may contribute to substantial economic savings when minimized. Finally, given that Galicia is a major fishing region, many of the conclusions and perspectives obtained in this study may be extrapolated to other fishing fleets at an international level.

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[1] Iribarren, D., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2010). "Further potentials in the joint implementation of Life Cycle Assessment and Data Envelopment Analysis". *Science of the Total Environmental,* 408: 5265-5272

[2] Vázquez-Rowe, I., Iribarren, D., Hospido, A., Moreira, M.T., Feijoo, G. (2011). "Computation of operational and environmental benchmarks within selected Galician fishing fleets". *Journal of Industrial Ecology,* 15: 776-795

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8.1. Introduction

In a scenario where data are available for multiple similar entities, the implementation of DEA in combination with LCA was proposed and encouraged in Chapter 7. This methodology aims at jointly assessing the operational and environmental performances of multiple units. The novel alternative avoids the use of average inventory data (i.e., standard deviations are prevented) and enriches result interpretation through eco-efficiency verification. In fact, this approach, according to the World Business Council for Sustainable Development's concept of eco-efficiency (Schmidheiny, 1992), arises as a valuable tool towards the target of sustainable development (Syrrakou et al., 2006).

The innovative nature of LCA+DEA methodology may develop into a challenging identification of potential uses. This chapter facilitates this task by revealing unexplored potentials in the use of DEA to complement LCA, serving as a guide to enhance LCA results. Specific potentials were selected in order to deal with common situations in LCA studies of multiple entities. Therefore, the aim of the whole text is to open the path for LCA+DEA methodology by widening its range of advantages and applications.

Moreover, the use of LCA+DEA methodology was applied to a wide range of Galician fishing vessels belonging to varied fishing fleets, with different fishing gears and operating in different geographical areas, with the goal of attaining operational benchmarking and eco-efficiency verification, as well as analysing the environmental performance of the Galician fishing fleet from an integrated perspective.

8.2. Framework

As mentioned in Chapter 7, the application of LCA+DEA methodological approaches entails appealing characteristics such as the avoidance of average inventories and the enrichment of results interpretation for multiple LCAs.

Furthermore, LCA+DEA methodology adds an operational dimension to the environmental assessment. Many other benefits originate from the joint implementation of LCA and DEA, related mainly to the use of specific DEA models (e.g. super-efficiency and window models) and the operational/economic nature of DEA. In particular, this chapter aims to detail the following LCA+DEA potentials: (i) super-efficiency analysis, (ii) sectorial intra- and inter-assessments within any specific sector, (iii) enhancement of the economic dimension, and (iv) environmental impact efficiency evaluation over a selected period of time. Moreover, the feasible standard use of the five-step LCA+DEA method for the assessment of multiple similar units can be understood as a potential itself.

8.3. Further potentials in LCA+DEA implementation

8.3.1. Super-efficiency analysis

The identification of a set of best-performing units for environmental benchmarking is among the possible reasons to undertake an LCA+DEA study. In this sense, DEA leads to identify the best performers from an operational perspective by means of the formulation and solution of a certain DEA model. Thus, efficiency scores are calculated from the observed input/output data making some basic assumptions (e.g. convexity, scalability and free disposability of inputs and outputs). Best performers will be those DMUs whose efficiency score is found to be 1. The subsequent application of LCA provides the corresponding environmental characterization results for a selection of impact categories. However, if the number of DMUs to be assessed is considerably high, a wide set of DMUs is expected to be deemed efficient. In this context, the implementation of super-efficiency DEA models is highly useful, ranking efficient DMUs by assigning an efficiency score greater than 1 (Cooper et al., 2007). In this sense, a super-efficiency analysis discriminates between efficient units and, therefore, facilitates the identification of a shorter range of best performers, which can facilitate the detection of best operational practices.

With the aim of exemplifying the performance of super-efficiency analyses, a brief case study is here presented for the calculation of environmental benchmarks in the field of extensive mussel aquaculture. Tables 8.1a and 8.1b show the DEA matrix for this case study, including the most relevant input/output data for a sample of 67 mussel cultivation sites (i.e., 67 mussel rafts as DMUs) located in Galicia (NW Spain). As the number of DMUs is significantly high, the use of a super-efficiency DEA model is proposed. In particular, an input-oriented slacks-based measure of super-efficiency model was selected (Tone, 2002), and CRS assumed. DEA performance led to identify 1 efficient unit (efficiency score=1) and 17 super-efficient cultivation sites, 4 of which involved an efficiency score above 1.05. Consequently, this super-efficiency analysis helped to refine the search for best performing entities. After the identification of best performers, an LCA study was carried out with the aim of defining environmental benchmarks for mussel aquaculture practices. Table 8.2 gathers the characterization results of the 4 selected super-efficient sites for 5 environmental impact categories: ADP, GWP, ODP, METP and POFP.

Table 8.1a. DEA matrix for the super-efficiency analysis of Galician mussel cultivation sites.

DMU	Input 1	Input 2	Input 3	Input 4	Input 5	Input 6	Input 7	Input 8	Input 9	Output
1	600	15.0	22.5	2.72	0.91	0.80	23.0	110	222	67.3
2	750	10.4	10.4	5.33	1.89	1.58	25.5	150	245	74.9
3	825	11.5	11.5	5.35	1.89	1.58	28.2	150	272	82.6
4	975	13.5	13.5	5.38	1.89	1.58	33.1	150	319	96.9
5	1,050	14.6	14.6	5.40	1.89	1.58	35.9	150	346	105
6	1,681	10.7	7.64	4.60	1.54	1.26	28.2	80.0	272	115
7	1,833	11.7	8.33	4.62	1.54	1.26	30.7	80.0	296	125
8	1,986	12.6	9.03	4.64	1.54	1.26	33.1	80.0	319	135
9	571	3.88	4.08	4.40	1.54	1.17	17.5	200	169	68.4
10	714	4.85	5.10	4.41	1.54	1.17	21.8	200	210	85.2
11	857	5.82	6.12	4.42	1.54	1.17	26.4	200	254	103
12	1,000	6.79	7.14	4.43	1.54	1.17	30.7	200	296	120
13	1,143	7.76	8.16	4.45	1.54	1.17	35.0	200	337	137
14	1,286	8.72	9.18	4.46	1.54	1.17	39.6	200	381	155
15	1,429	9.69	10.2	4.47	1.54	1.17	43.9	200	423	172
16	1,141	22.8	5.70	3.83	1.28	0.97	23.3	200	228	77.4
17	1,219	24.4	6.09	3.84	1.28	0.97	24.8	200	243	82.5
18	1,297	25.9	6.48	3.86	1.28	0.97	31.9	200	307	88.4
19	1,344	26.9	6.72	3.86	1.28	0.97	33.1	200	319	91.8
20	1,333	16.7	2.50	5.12	1.77	1.92	20.5	50	198	60.3
21	1,444	18.1	2.71	5.13	1.77	1.92	22.1	50	213	64.8
22	2,556	31.9	4.79	5.21	1.77	1.92	39.3	50	378	115
23	2,667	33.3	5.00	5.22	1.77	1.92	40.8	200	393	120
24	2,000	20.0	20.0	2.85	0.92	0.60	17.4	200	174	80.0
25	2,667	26.7	26.7	2.94	0.92	0.60	32.8	200	316	107
26	3,083	30.8	30.8	2.99	0.92	0.60	37.7	200	364	123
27	1,896	21.7	21.7	4.85	1.65	1.07	18.6	100	185	72.9
28	2,421	27.7	27.7	4.90	1.65	1.07	27.9	100	273	93.6
29	2,683	30.7	30.7	4.93	1.65	1.07	35.3	100	340	104
30	2,000	50.0	50.0	3.38	0.80	1.50	25.6	200	251	90.0
31	1,250	12.5	8.33	3.68	1.18	0.90	25.5	20.0	245	66.4
32	1,750	17.5	11.7	3.82	1.18	0.90	35.9	20.0	346	93.6
33	1,200	20.0	4.00	1.10	0.64	1.60	24.5	12.5	237	40.0
34	467	29.1	20.0	4.30	1.51	1.26	20.5	110	198	60.1

DMU= decision making unit; Input 1: Diesel (l/year); Input 2: Oil (l/year); Input 3: Anti-fouling paint (l/year); Input 4: Wood (t/year); Input 5: Iron (t/year); Input 6: Concrete (t/year); Input 7: Cotton (kg/year); Input 8: Tar oil (kg/year); Input 9: Nylon (kg/year); Output: Commercial mussels (t/year).

Table 8.1b. DEA matrix for the super-efficiency analysis of Galician mussel cultivation sites.

DMU	Input 1	Input 2	Input 3	Input 4	Input 5	Input 6	Input 7	Input 8	Input 9	Output
35	933	58.2	40.0	4.57	1.51	1.26	40.8	110	393	119
36	800	48.0	32.0	3.48	1.15	0.65	24.5	100	237	64.0
37	2,177	41.7	41.7	4.69	1.54	1.26	25.5	110	245	83.0
38	3,048	58.3	58.3	4.82	1.54	1.26	35.9	110	346	117
39	250	3.50	10.0	3.34	1.15	0.85	14.7	50.0	142	50.0
40	500	7.00	20.0	3.99	1.36	1.00	36.5	50.0	352	125
41	600	8.40	24.0	4.02	1.36	1.00	39.9	50.0	384	138
42	750	10.5	30.0	4.58	1.54	1.13	40.8	50.0	393	140
43	598	17.1	8.55	2.50	0.92	0.60	31.9	100	307	80.0
44	1,197	34.2	17.1	2.99	0.92	0.72	39.9	100	384	100
45	2,393	68.4	34.2	4.26	1.49	0.77	19.9	200	192	50.0
46	833	8.33	4.17	1.77	0.88	0.63	20.5	110	198	50.0
47	2,500	25.0	12.5	1.97	0.88	0.50	40.8	110	393	100
48	7,667	131	11.0	2.09	0.92	1.00	19.4	150	191	68.4
49	7,889	135	11.3	2.09	0.92	1.00	20.2	150	198	71.1
50	8,889	152	12.7	2.10	0.92	1.00	22.7	150	223	80.1
51	10,000	171	14.3	2.11	0.92	1.00	25.6	150	251	90.0
52	10,556	181	15.1	2.12	0.92	1.00	27.1	150	266	95.4
53	11,667	200	16.7	2.13	0.92	1.00	29.9	150	294	105.3
54	13,333	229	19.1	2.15	0.92	1.00	34.0	150	334	120
55	4,583	34.4	8.02	3.34	1.15	0.90	17.6	300	173	27.6
56	5,167	38.8	9.04	3.35	1.15	0.90	19.7	300	193	30.8
57	5,833	43.8	10.2	3.36	1.15	0.90	22.5	300	221	35.2
58	6,667	50.0	11.7	3.37	1.15	0.90	25.6	300	251	40.0
59	8,750	65.6	15.3	3.41	1.15	0.90	33.5	300	329	52.4
60	9,000	67.5	15.8	3.41	1.15	0.90	34.5	300	339	54.0
61	14,000	200	40.0	2.29	1.13	0.74	25.6	300	251	40.0
62	6,000	90.0	9.00	1.48	0.77	0.67	19.2	100	188	37.5
63	6,933	104	10.4	1.50	0.77	0.67	22.2	100	218	43.5
64	8,000	120	12.0	1.53	0.77	0.67	25.6	100	251	50.0
65	10,267	154	15.4	1.59	0.77	0.67	32.7	100	321	64.0
66	11,719	188	14.1	1.43	0.92	0.80	24.0	150	236	42.3
67	13,281	213	15.9	1.46	0.92	0.80	27.1	150	266	47.7

DMU= decision making unit; Input 1: Diesel (l/year); Input 2: Oil (l/year); Input 3: Anti-fouling paint (l/year); Input 4: Wood (t/year); Input 5: Iron (t/year); Input 6: Concrete (t/year); Input 7: Cotton (kg/year); Input 8: Tar oil (kg/year); Input 9: Nylon (kg/year); Output: Commercial mussels (t/year).

Table 8.2. Environmental characterization results (per tonne of mussels) for the selected super-efficient mussel cultivation sites.

DMU	Output (t)	Efficiency (%)	ADP (kg Sb eq)	GWP (kg CO_2 eq)	ODP (kg CFC-11 eq)	METP (kg 1,4-DB eq)	POFP (kg C_2H_4 eq)
22	115.2	110.30	3.86	526.2	1.24E-4	89,337	1.68E-1
32	93.6	109.51	3.74	501.7	1.08E-4	85,481	1.64E-1
47	100.0	107.02	4.24	569.8	1.58E-4	95,248	1.79E-1
33	40.0	105.37	3.82	515.7	1.33E-4	85,881	1.64E-1

DMU= decision making unit; ADP= Abiotic Depletion Potential; GWP= Global Warming Potential; ODP= Ozone Layer Depletion Potential; METP= Marine aquatic Eco-toxicity Potential and POFP= Photochemical Oxidant Formation Potential.

This type of studies may be interesting for policy makers in order to establish reference values for environmental regulations, therefore arising as a support tool for environmental decision making (Pollard et al., 2008). For instance, in the case of mussel aquaculture in Galicia, if policy makers look for climate change benchmarks, the following values could be proposed according to the characterization results in Table 8.2: 516 kg CO2e per tonne of commercial mussels for low production levels (<50 t/year of commercial mussels), 536 kg CO2e/t for intermediate production levels (ranging from 50–100 t/year), and 526 kg CO2e/t for high production levels (>100 t/year).

8.3.2. Sectorial intra- and inter-assessments

LCA+DEA methodology application usually leads to the internal evaluation of the operational and environmental behaviour of a certain sample of DMUs. Therefore, the most conventional purpose of an LCA+DEA study is to undertake an intra-assessment with respect to the environmental and operational performance of a set of multiple similar entities. However, it is common to assess multiple units that belong to a specific sector where other alternative units that perform a similar function exist. In this regard, the compilation and comparison of individual LCA+DEA results for two or more sets of DMUs within a certain sector allow the identification of operational and environmental patterns. In this sense, the scope of the LCA+DEA study is widened so that a sectorial inter-assessment is attained.

Intra- and inter-assessments are exemplified through the application of the five-step LCA+DEA method to a group of six Galician fishing fleets. Given the wide range of vessels that have been collected to perform this particular analysis, results and discussion for intra- and inter-assessment are discussed in section 8.4 of this chapter.

8.3.3. Enhancement of the economic dimension

The limitation of LCA to the evaluation of environmental impacts is considered a major drawback as it constrains sustainability assessments to the environmental dimension, therefore questioning LCA capability for decision making (Reap et al., 2008). Chapter 7 highlights the usefulness of LCA+DEA methodology to add an economic nuance to the environmental assessment by including an evaluation of the operational performance. Nevertheless, LCA+DEA methods can further enhance this economic dimension. In particular, three different approaches are here proposed, none of them being a substitute of other techniques such as Life Cycle Cost Analysis.

Firstly, from an operational efficiency perspective, target input consumption levels calculated by DEA entail a reduction in inputs' demand. Hence, economic savings arise from the modification of current operational patterns in inefficient units. These can be estimated based on the unit price of the inputs subject to reduction. This procedure is here exemplified for a sample of 15 Galician coastal purse seiners. For this particular sample, an SBM-I model with CRS was implemented in order to identify inefficient vessels and benchmark target input consumption levels. Table 8.3 shows the attainable economic savings if all vessels were operated in an efficiently. Used unit prices were 0.45 €/l for diesel (MITYC, 2010), 1.76 €/kg for nets (Porto de Celeiro, personal communication) and 95.4 €/t for hull material (i.e., stainless steel) (ArcelorMittal, 2011).

Table 8.3. Economic savings due to reduced input consumption levels benchmarked by DEA.

DMU	Input 1	Input 2	Input 3	Total savings (€/year)
1	34,262	5,880	170	40,312
2	37,210	4,914	103	42,227
3	33,519	5,104	159	38,782
4	34,560	5,424	164	40,148
5	22,264	14,399	132	36,795
6	7,668	4,213	23	11,904
7	32,856	1,971	125	34,952
8	22,861	6,142	57	29,060
9	24,797	5,892	173	30,862
10	24,667	5,826	172	30,665
11	0	0	0	0
12	0	0	0	0
13	10,660	4,286	109	15,055
14	31,690	3,420	63	35,173
15	11,594	1,123	18	12,735

DMU= decision making unit; Input 1: Diesel (€/year); Input 2: Net consumption (€/year); Input 3: Hull material (€/year).

A second alternative raises the use of economic inputs in the DEA matrix, rather than input consumption levels. The operational efficiency perspective is then turned to a strictly economic efficiency approach. In this sense, all operational inputs need to be converted into economic values through the use of their unit price. Thus, the objective function of DEA optimization models will try to define feasible operating points that minimize current economic expenses, without decreasing output levels. Moreover, the calculated target values will directly correspond with target economic costs. For the case study of coastal purse seining, the new DEA matrix is gathered in Table E.1 in Appendix I. Furthermore, the percentage reductions in costs associated with an efficient economic performance are shown in Figure 8.1 for each selected input (use of an SBM-I model with CRS). Note that, although target values correspond to economic values, they can be reconverted into operational terms by means of their unit price. Therefore, eco-efficiency verification via LCA remains possible.

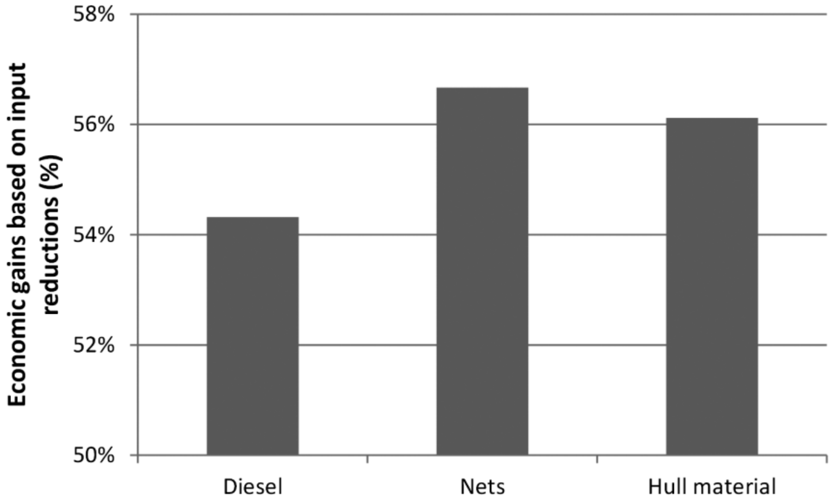

Figure 8.1. Economic gains directly estimated through DEA.

Finally, a third option involves the use of weighted DEA models. This type of models allows the assignment of weights to inputs and outputs according to the relative importance of items (Cooper et al., 2007). These weights shall reflect the intentions of the decision maker. The relevance of the economic value of each operational item can be used to define these weights. Taking into account the unit prices and the average consumption values of the selected inputs included in the DEA matrix, weights were defined for the coastal purse seining example. The weights used relating to diesel, nets and hull material (steel) were 0.830, 0.166 and 0.004, respectively. The use of an input-oriented weighted slack-based measure of efficiency model with CRS led to the identification of inefficient vessels and to the quantification of operational target values. Similarly to the first procedure suggested, reductions in input consumption levels result in economic savings. Table 8.4 shows a comparison among the efficiency scores calculated through the three different approaches for the case study of coastal purse seining in Galicia. As observed, the first two procedures report very similar efficiency scores, whereas the third approach – even though it identifies the same efficient units – involves slightly different results when ranking DMUs according to their weighted efficiency score.

Table 8.4. Operational efficiency (Φ), economic efficiency (Ω) and weighted efficiency (ψ) scores for a selected sample of Galician coastal purse seiners.

DMU	Φ (%)	Ω (%)	Ψ (%)
1	30.53	30.55	31.17
2	29.67	29.62	25.33
3	38.93	38.94	38.84
4	36.77	36.78	36.78
5	40.29	40.32	47.65
6	67.13	66.95	67.47
7	49.43	49.48	43.84
8	48.49	48.42	44.77
9	33.49	33.51	37.91
10	34.18	34.19	38.58
11	100.00	100.00	100.00
12	100.00	100.00	100.00
13	47.26	47.32	57.40
14	44.58	44.54	35.78
15	79.25	79.13	70.11

DMU= decision making unit.

8.3.4. Environmental impact efficiency over a selected time period

DEA is sometimes used as a single tool for environmental performance analysis (Tyteca, 1997; Zaim and Taskin, 2000; Kuosmanen and Kortelainen, 2005; Munksgaard et al., 2007). However, LCA+DEA approaches provide a more suitable framework for the analysis of the link between operation and environmental impacts (Iribarren, 2010). Lozano et al. (2010) proposed the implementation of environmental impact categories characterized through LCA as inputs into the DEA model in order to provide a measure of environmental impact efficiency.

An interesting further potential related to environmental impact efficiency lies in the use of environmental impact categories as the only inputs of a DEA window analysis (Charnes et al., 1985). This approach involves a slight modification of the three-step LCA+DEA method, omitting the inclusion of selected LCI inputs in the DEA matrix. The objective of window analysis is to assess environmental impact efficiency over a specific time period. This type of studies can be undertaken provided that LCIA characterization results concerning selected impact categories are available for a set of DMUs and for different time periods. Window analyses try to provide a meaningful overall measure of efficiency, directing management toward the improvement of DMUs' performance. A DEA window analysis is used to identify performance trends within a set of DMUs over time. Each entity in a different period is considered a different DMU. Hence, the performance of a DMU during a particular period is compared not only to the performance of other units, but also to its own performance in other periods (Asmild et al., 2004).

For instance, Tables 8.5a and 8.5b show the environmental characterization results for 3 environmental impact categories (ADP, GWP and METP) relating to 10 Galician coastal purse seiners (i.e., 10 DMUs), all based at the same fishing port (Portosín: N 42° 45'N 08° 56'W), at four different time periods (years 2006, 2007, 2008 and 2009). The use of an input-oriented window model with CRS on this DEA matrix led to the calculation of the average efficiency scores gathered in Table 8.6. As observed, environmental performance trends over time can be detected. For instance, DMU 5 showed a clear trend toward environmental impact inefficiency since an annual gradual decrease in its average efficiency score was observed. Note that this example corresponds to a mere intertemporal panel data analysis where the observation in each time period is assessed taking into account the observations of all DMUs in all time periods (Mátyás and Sevestre, 2008).

Table 8.5a. DEA matrix for the window analysis of 10 coastal purse seiners over a four year period (years 2006 and 2007).

DMU	ADP (t Sb eq)	GWP (t CO_2 eq)	METP (t 1,4-DB eq)	Output (€)
2006				
1	2.21	345.87	27,504.39	125,725
2	1.99	331.98	24,307.11	130,444
3	2.07	332.37	28,171.17	69,278
4	2.01	324.62	26,913.20	221,451
5	2.27	342.71	28,123.03	292,320
6	1.96	313.90	23, 248.74	182,565
7	1.90	272.53	20,311.35	345,223
8	2.32	370.66	30,449.36	317,667
9	2.33	358.00	33,571.54	210,282
10	2.13	349.03	29,355.88	103,509
2007				
1	2.64	365.88	26,241.33	135,900
2	2.52	348.26	24,359.58	165,824
3	2.54	350.62	28,190.81	94,657
4	2.50	332.21	30,103.14	250,991
5	2.63	402.23	29,127.89	329,030
6	2.45	344.85	25,742.27	210,752
7	1.93	321.17	23,587.43	379,013
8	2.70	411.20	34,663.75	356,848
9	2.70	429.49	35,652.97	245,896
10	2.68	387.24	32,982.62	159,067

DMU= decision making unit; ADP= abiotic depletion potential; GWP= global warming potential; METP= marine aquatic eco-toxicity potential.

Table 8.5b. DEA matrix for the window analysis of 10 coastal purse seiners over a four year period (years 2008 and 2009).

DMU	ADP (t Sb eq)	GWP (t CO_2 eq)	METP (t 1,4-DB eq)	Output (€)
		2008		
1	2.87	438.13	33,524.68	142,656
2	2.70	411.62	31,953.56	158,764
3	2.71	412.73	34,119.98	101,247
4	2.70	409.86	33,903.21	300,151
5	2.90	442.01	34,423.33	372,043
6	2.65	403.89	32,724.77	236,314
7	2.17	330.54	25,914.34	438,061
8	2.92	443.76	36,536.36	416,246
9	2.92	447.67	36,561.78	389,291
10	2.88	439.86	35,753.68	66,750
		2009		
1	2.61	391.28	30,675.24	137,000
2	2.58	379.93	29,900.93	155,693
3	2.63	387.09	33,226.90	140,673
4	2.56	378.12	30,952.58	286,559
5	2.70	428.74	31,985.62	282,905
6	2.34	369.13	30,424.81	239,018
7	2.12	360.38	24,847.40	436,234
8	2.89	404.57	33,629.79	400,616
9	2.99	419.11	33,653.81	356,470
10	2.72	400.77	32,388.22	87,580

DMU= decision making unit; ADP= abiotic depletion potential; GWP= global warming potential; METP= marine aquatic eco-toxicity potential.

Table 8.6. Environmental impact efficiency scores (%) through window analysis.

DMU	Efficiency 2006	Efficiency 2007	Efficiency 2008	Efficiency 2009
1	41.32	32.23	8.48	28.93
2	47.62	42.36	11.32	33.85
3	24.31	22.88	4.63	30.02
4	80.03	64.02	39.84	62.61
5	93.54	70.30	56.37	54.51
6	67.66	51.79	25.55	53.49
7	100.00	100.00	100.00	100.00
8	99.46	73.54	72.98	81.80
9	73.23	48.52	63.20	67.42
10	35.30	34.81	1.82	18.05

DMU= decision making unit.

8.4. Intra- and inter-assessment case study: Computation of operational and environmental benchmarks within selected Galician fishing fleets

The Galician fishing fleet, in keeping with global trends and in an effort to remain competitive in the international market, must focus on reducing the environmental and economic costs of vessel operational activities. This policy is clearly in accordance with the traditional eco-efficiency concept. Under this perspective, the current case study presents the use of a LCA+DEA to implement operational efficiency in the environmental assessment of fishing fleets so that eco-efficiency verification is achieved in quantitative terms. Hence, key operational items are to be benchmarked to support decision making by different stakeholders of fishery supply chains, such as skippers, managers, and policy makers, verifying quantitatively that optimized consumption levels lead to a better environmental performance. In this study, the eco-efficiency scope is therefore limited to its operational dimension and does not cover biological issues suggested in recent studies (Willison and Côtè, 2009).

Although researchers usually tend to approach environmental and operational issues independently, an attempt to integrate both aspects was presented to obtain a more comprehensive view of some of the most important fishing fleets in Galicia. To do so, LCA+DEA methodology was applied to a broad number of vessels within selected Galician fishing fleets that use different types of fishing gear and work in several geographical areas. We use this approach to attain operational benchmarking and eco-efficiency verification while assessing the environmental performance of the different fishing vessels from an intra- and inter-assessment perspective. Consumption levels of fuel, as well as of other relevant operational inputs, such as hull material, nets, and antifouling paint, were benchmarked for each vessel, which links environmental improvements to optimized values.

8.4.1. Fishing fleet selection

As mentioned in Chapter 1, the Galician fishing fleet as a whole is composed of more than 6,000 vessels, with a total capture of 368,631 tonnes of landed fish (landing of cultured species included) in 2008. In this study, the application of an LCA+DEA approach was proposed for six Galician fleets that comprise the main fishing zones (coastal, offshore, and open sea) and gear types, to cover major fleets and fisheries of the Galician fishing sector. In particular, the assessed fleets include the following: auxiliary mussel raft vessels (*n*=12 vessels), coastal purse seiners (*n* = 15), coastal trawlers (*n* = 20), offshore long liners (*n* = 12), cephalopod trawlers (*n* = 8), and tuna purse seiners (*n* = 9).

8.4.2. Goal and scope of the case study

The main goal of this LCA+DEA study is to attain the operational benchmarking of individual fishing vessels within the selected fleets. Furthermore, the environmental gains linked to optimized consumption levels are quantified through the implementation of a five-step LCA+DEA methodological approach. In particular, the following objectives are pursued:

- Inclusion of an economic dimension to the environmental assessment of the Galician fishing fleets by evaluation and targeting of the operational performance of the vessels, through resource usage optimization.
- Benchmarking of the environmental and operational performance of the vessels to provide a basis for targeting effective means of reducing environmental impacts if the determined operational targets are achieved (inter-assessment).
- Comparison of the operational and environmental performance among the selected fleets (intra-assessment), with the aim of finding trends in the environmental consequences of operational choices, such as fishing zone, energy intensity, and catch rates.

The FU considered for the LCA of all fishing fleets was 1 tonne of landed fish. The reasoning behind the FU choice, in the same terms as explained in Chapter 7, is linked to the fact that the analysis of this study focuses on the operational and environmental performance of the different vessels, rather than a product perspective. Since most of the fishing fleets in this study extract in multispecies fisheries, a FU that refers to only one specific product would prevent the assessment from obtaining a realistic perception of the vessels' performance.

All LCAs carried out in this study comprised the operational stages of fish extraction up to landing at port, which involved key operational aspects, such as the production and use of fuel, antifouling, nets, and lubricant oil. Vessel construction was also considered within the system boundaries. This approach from the fishery until landing for sale corresponds with a "cradle-to-gate" analysis (Guinée et al., 2001).

A series of processes and inputs were excluded from the system boundaries. In the first place, emissions that arose from cooling agent leakage were not included in the life cycle inventory (LCI) due to the lack of feasible data regarding the entire fishing fleets assessed. Nevertheless, further efforts to provide data in this field have been followed in other chapters. Secondly, certain issues, mainly related to biological aspects, were left out of the system, given the increased difficulty of comparing fishing fleets in terms of fishery-specific indicators.

Unlike LCA, DEA does not use all the items included in the life cycle of the fishing activity but considers a subset of the relevant inputs and outputs for each fleet. The inputs and outputs chosen for the DEA of each fishing fleet are detailed in Table 8.7. A total of three inputs and one output were considered for the six fishing fleets, which are related to the vessels' main activities. Emissions to air due to diesel consumption and emissions to oceanic waters due to net loss or antifouling agents were not considered in the DEA matrix, given their direct proportion with respect to the amounts of diesel, nets, or antifouling consumed. Note that other aspects potentially related to inefficiencies, such as the age of the boat or the type of engine, are regarded indirectly in some of the considered inputs (e.g., diesel consumption). Finally, all the fishing fleets assessed met minimum sample size requirements (Boussofiane et al. 1991; Cooper et al. 2007).

Table 8.7. Selection of input/output items for DEA.

Fishing fleet	**Input 1** (l/year)	**Input 2** (kg/year)	**Input 3** (l/year or kg/year)	**Output** (€/year)
Auxiliary mussel raft vessels	Diesel	Hull material	Anti-fouling	Catch value
Coastal purse seining	Diesel	Hull material	Net	Catch value
Coastal trawling	Diesel	Hull material	Net	Catch value
Offshore long lining	Diesel	Hull material	Anti-fouling	Catch value
Cephalopod trawling	Diesel	Hull material	Net	Catch value
Tuna purse seining	Diesel	Hull material	Anti-fouling	Catch value

Diesel consumption and steel for hull construction as inputs for each vessel in all the assessed fleets are highlighted as the major common features identified. The third input included for the different fleets was variable (antifouling paint consumption or net usage), depending on the characteristics of the fleets or data availability. Catch value was the selected output for the entire study. The rationale behind this selection is linked, in the first place, to the attempt to standardize captures due to the fact that species captured by different vessels are not uniform. Secondly, an inclusion of the catch rates for the different species would increase the number of outputs and, hence, the number of vessels needed for each fishing fleet, especially those with an increased number of species. Finally, the use of catch value as the output allows DEA to enhance the economic nature of this tool (see Section 8.3.4).

8.4.3. Methodology application

Step 1: Data Acquisition and Current Life Cycle Inventories

The six fishing fleets assessed are briefly described in Table 8.8. Primary data were obtained through a series of questionnaires filled out by skippers from several Galician ports, as described in previous chapters, for four of the evaluated fleets (coastal purse seiners, coastal trawlers, offshore long liners and trawlers in the Mauritanian EEZ). On the basis of this census, the data collection strategy focused on inventorying the highest possible number of vessels in key Galician ports, according to availability criteria. The assessed fish-farming vessels take charge of mussel rafts in the ría of *Arousa*, the main mussel culture zone in Galicia, with roughly 70% of the total rafts (ASESMAR, 2010). Data from this fleet were obtained through similar questionnaires in the frame of previous research studies (Iribarren, 2010). Finally, data for the tuna purse seining fleet were also obtained on the framework of a previous study (Hospido and Tyedmers, 2005). In this case three Galician tuna fishing companies were surveyed.

Table 8.8. Brief description of the samples of the selected Galician fishing fleets.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
Sample size	12	15	20	12	8	9
Percentage over fleet (%)	1.01	9.04	20.41	20.69	29.63	24.32
Inventory year	2007	2008	2008	2008	2009	2000-2004
Total landings (tonnes)	3,703	7,500	12,093	3,416	5,000	72,000
Catch value (€/year)	22,442,732	4,912,747	17,309,604	10,534,064	13,053,600	371,320,440
Main target species	Mussels	European pilchard Horse mackerel Atlantic mackerel	Blue whiting Horse mackerel Atlantic mackerel	European hake Fork beard Common ling	Varied cephalopods Varied flatfish Senegal hake	Yellowfin tuna Skipjack tuna

F1 = auxiliary mussel raft vessels; F2 = coastal purse seining; F3 = coastal trawling; F4 = offshore long lining; F5 = cephalopod trawling; F6 = tuna purse seining

Background processes were considered for LCA by using the ecoinvent® database as the main source of secondary data (Frischknecht et al., 2007). When possible, specific data for the Galician fishing context was included: (1) antifouling paint production (Hempel 2009), and (2) net production for a series of specific gear types, such as trawlers and coastal purse seiners (Teresa Costa, personal communication).

The emissions resulting from fuel combustion were calculated on the basis of the EMEP-Corinair emission inventory handbook of 2006 for all the selected fishing fleets (EMEP-Corinair, 2006). The loss of antifouling to the marine environment was set as two-thirds of the total used (Hospido and Tyedmers, 2005). Table 8.9 supplies key information on data acquisition regarding each of the selected fleets. Specific data for each vessel within each fleet are shown later when the DEA matrices are displayed.

Table 8.9. Brief summary of the average inventory data for the selected fishing fleets (data per FU).

				INPUTS			
From the technosphere	**Units**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**
Materials and fuels							
Diesel	kg	28.29	158.9	524.3	1,305	1,726	419
Steel	kg	--	3.64	5.46	14.07	11.04	5.35
Wood	m^3	3.37E-3	--	--	--	--	--
Nylon	kg	--	7.42	1.99	--	3.11	--
Lead	kg	--	1.64	0.44	--	0.69	--
Cork	g	--	0.07	0.02	--	0.03	--
Anti-fouling	g	336.4	371.7	639.5	1,878	--	190.9
				OUTPUTS (to the technosphere)			
Products							
Catch rate	t	1.00	1.00	1.00	1.00	1.00	1.00
				OUTPUTS (to the environment)			
Emissions to the atmosphere							
CO_2	kg	89.68	503.8	1,662	4,138	5,470	1,329
SO_2	kg	0.283	1.59	5.24	13.05	17.26	4.19
VOC	g	67.90	381.5	1,258	3,133	4,142	1,007
NO_x	kg	2.04	11.44	37.75	93.99	124.3	30.20
CO	kg	0.21	1.18	3.88	9.66	12.77	3.10
Emissions to the ocean							
Xylene	g	28.03	30.62	60.44	171.2	--	15.90
Copper oxides	g	69.72	76.15	132.5	425.7	--	39.55
Zinc oxides	g	31.53	--	--	192.5	--	17.89
Nylon	kg	--	0.91	0.25	--	0.38	--
Lead	g	--	205.4	55.13	--	86.18	--

F1 = auxiliary mussel raft vessels; F2 = coastal purse seining; F3 = coastal trawling; F4 = offshore long lining; F5 = cephalopod trawling; F6 = tuna purse seining

Step 2: Environmental characterization of selected Galician fishing fleets

The LCIA phase was carried out, in the same way as throughout the entire dissertation, according to the CML baseline 2000 method (Guinée et al. 2001). The impact categories considered were ADP, AP, EP, GWP, and METP. Moreover, the cumulative energy demand (CED) indicator was also included, according to the method developed by VDI-Richtlinien (1997). SimaPro 7.3 was the software used to lead the computational implementation of the different inventories (Goedkoop et al., 2010). The results of this step are discussed in the interpretation phase (Step 5) when compared to the target environmental characterization results determined in Step 4.

Step 3: Efficiency scores and target values for the current selected fishing vessels

The DEA matrix for each fleet is presented in Table 8.10a-f. In this case study, an input-oriented slacks-based measure of efficiency (SBM-I) model was chosen to compute the different matrices. Further details on the formulation of this model are included in Appendix II. For the different DMUs, these results were calculated with the DEA-Solver Professional Release 6.0 software (Saitech 2009).

Table 8.10a. Input/output DEA matrices for the auxiliary mussel raft vessels (F1).

DMU	Input 1	Input 2	Input 3	Output
F1-1	3,600	816	50	2,175,221
F1-2	5,500	816	25	2,272,500
F1-3	7,000	612	50	5,090,400
F1-4	5,000	904	25	2,060,400
F1-5	10,000	1,233	100	2,424,000
F1-6	7,000	707	80	1,636,200
F1-7	3,000	816	20	969,600
F1-8	1,400	816	60	1,087,611
F1-9	5,225	816	100	1,212,000
F1-10	5,000	612	25	1,515,000
F1-11	40,000	592	70	1,454,400
F1-12	25,000	493	30	545,400

DMU= decision making unit, F1= auxiliary mussel raft vessels.

Table 8.10b. Input/output DEA matrices for the coastal purse seiners (F2).

DMU	Input 1	Input 2	Input 3	Output
F2-1	110,000	2,467	5,000	274,505
F2-2	110,000	1,592	4,100	214,399
F2-3	120,000	2,587	5,130	368,961
F2-4	120,000	2,587	5,198	350,205
F2-5	103,700	2,477	10,838	439,576
F2-6	64,500	1,129	4,667	372,569
F2-7	120,000	2,258	3,422	380,904
F2-8	96,750	1,458	5,690	360,694
F2-9	90,000	2,516	5,058	282,878
F2-10	90,500	2,516	5,058	289,285
F2-11	32,250	649	1,580	261,438
F2-12	33,000	621	1,580	259,051
F2-13	60,000	1,871	4,214	294,364
F2-14	107,500	1,355	3,718	291,064
F2-15	86,000	1,321	3,522	472,854

DMU= decision making unit, F2= coastal purse seiners.

Table 8.10c. Input/output DEA matrices for the coastal trawlers (F3).

DMU	Input 1	Input 2	Input 3	Output
F3-1	404,000	3,933	2,059	443,996
F3-2	404,000	3,074	1,416	718,655
F3-3	404,000	2,416	1,416	718,655
F3-4	440,000	4,333	1,294	917,952
F3-5	480,000	4,333	1,294	917,952
F3-6	404,000	4,840	1,416	796,224
F3-7	350,000	4,707	1,392	1,214,898
F3-8	347,000	3,330	1,392	1,214,898
F3-9	404,000	3,032	1,392	521,226
F3-10	404,000	3,712	1,392	521,226
F3-11	330,000	2,781	1,051	1,005,718
F3-12	355,000	2,390	1,051	1,005,718
F3-13	292,900	3,257	1,051	1,326,989
F3-14	305,000	1,827	1,051	1,326,989
F3-15	383,800	2,222	2,796	1,353,235
F3-16	242,400	3,234	2,024	575,377
F3-17	250,400	3,773	2,024	575,377
F3-18	303,000	3,029	1,416	660,298
F3-19	378,750	2,809	1,173	928,290
F3-20	242,400	3,029	1,568	565,931

DMU= decision making unit; F3= coastal trawlers.

Table 8.10d. Input/output DEA matrices for the offshore long liners (F4).

DMU	Input 1	Input 2	Input 3	Output
F4-1	680,000	3,138	298	1,633,578
F4-2	654,000	3,450	290	1,583,310
F4-3	952,000	6,320	340	945,792
F4-4	349,550	4,067	250	472,936
F4-5	315,000	3,983	274	726,600
F4-6	300,000	4,240	274	691,900
F4-7	340,000	4,182	290	690,700
F4-8	325,000	2,829	221	792,410
F4-9	320,000	2,954	233	643,910
F4-10	258,400	5,000	320	771,328
F4-11	163,200	2,819	156	732,448
F4-12	353,600	5,067	325	849,152

DMU= decision making unit; F4= offshore long lining.

Table 8.10e. Input/output DEA matrices for the Mauritanian EEZ vessels (F5).

DMU	Input 1	Input 2	Input 3	Output
F5-1	1,080,000	3,533	1,792	2,016,000
F5-2	920,000	5,667	2,242	1,702,400
F5-3	900,000	5,933	2,242	1,685,600
F5-4	1,155,000	7,000	2,615	1,492,400
F5-5	1,140,000	7,000	2,242	1,408,400
F5-6	930,000	5,667	2,242	1,534,400
F5-7	870,000	7,000	2,242	1,596,000
F5-8	1,050,000	9,667	2,242	1,618,400

DMU= decision making unit; F5= cephalopod trawlers.

Table 8.10f. Input/output DEA matrices for the tuna purse seiners (F6).

DMU	Input 1	Input 2	Input 3	Output
F6-1	3,311,656	32,135	750	46,274,160
F6-2	3,387,186	25,417	750	39,535,400
F6-3	3,432,000	32,135	600	38,547,660
F6-4	3,421,379	26,616	750	56,218,620
F6-5	4,360,683	32,979	750	58,848,660
F6-6	3,164,000	32,479	960	52,625,040
F6-7	4,360,452	42,683	750	46,377,180
F6-8	3,988,933	35,550	750	32,893,680
F6-9	4,712,000	49,792	984	67,708,380

DMU= decision making unit; F6= tuna purse seiners.

Target vessels were defined within each fleet. Table 8.11a-f shows the percentage reductions in input consumption that would enable current vessels to perform efficiently, as well as the efficiency score (Φ) calculated for each vessel. As shown, relevant improvements are possible for all inputs, with significant differences between fleets and between vessels from the same fleet.

Table 8.11a. Input reduction (%) for the definition of the target vessels and efficiency (Φ) of the individual vessels for the auxiliary mussel raft vessels (F1).

DMU	Input 1 (%)	Input 2 (%)	Input 3 (%)	Efficiency (Φ)
F1-1	16.91	67.95	57.27	52.62
F1-2	43.18	66.52	10.71	59.86
F1-3	0.00	0.00	0.00	100.00
F1-4	43.33	72.59	19.05	55.01
F1-5	66.67	76.35	76.19	26.93
F1-6	67.86	72.16	79.91	26.69
F1-7	55.56	85.71	52.38	35.45
F1-8	0.00	0.00	0.00	100.00
F1-9	68.10	82.14	88.10	20.55
F1-10	58.33	70.24	40.48	43.65
F1-11	95.00	70.44	79.59	18.32
F1-12	97.00	86.70	82.14	11.39

DMU= decision making unit; F1= auxiliary mussel raft vessels.

Table 8.11b. Input reduction (%) for the definition of the target vessels and efficiency (Φ) of the individual vessels for the coastal purse seiners (F2).

DMU	Input 1 (%)	Input 2 (%)	Input 3 (%)	Efficiency (Φ)
F2-1	69.22	72.37	66.82	30.53
F2-2	75.17	67.72	68.11	29.67
F2-3	62.07	64.58	56.53	38.94
F2-4	64.00	66.38	59.28	36.78
F2-5	47.71	55.94	75.49	40.29
F2-6	26.42	20.90	51.31	67.12
F2-7	60.84	58.11	32.73	49.44
F2-8	52.51	40.70	61.34	48.48
F2-9	61.23	72.08	66.20	33.50
F2-10	60.57	71.45	65.44	34.18
F2-11	0.00	0.00	0.00	100.00
F2-12	0.00	0.00	0.00	100.00
F2-13	39.48	60.93	57.79	47.27
F2-14	65.51	48.50	52.25	44.58
F2-15	29.96	14.19	18.12	79.24

DMU= decision making unit; F2= coastal purse seiners.

Table 8.11c. Input reduction (%) for the definition of the target vessels and efficiency (Φ) of the individual vessels for the coastal trawlers (F3).

DMU	Input 1 (%)	Input 2 (%)	Input 3 (%)	Efficiency (Φ)
F3-1	74.74	84.46	82.92	19.29
F3-2	59.11	67.82	59.80	37.76
F3-3	59.11	59.05	59.80	40.68
F3-4	52.05	70.84	43.82	44.43
F3-5	56.04	70.84	43.82	43.10
F3-6	54.70	77.35	55.46	37.50
F3-7	20.22	64.47	30.86	61.48
F3-8	19.53	49.78	30.86	66.61
F3-9	70.35	76.34	76.34	27.66
F3-10	70.35	80.67	70.34	26.21
F3-11	29.95	50.22	24.21	65.20
F3-12	34.89	42.07	24.21	66.28
F3-13	0.00	0.00	0.00	100.00
F3-14	0.00	0.00	0.00	100.00
F3-15	18.96	16.16	61.66	67.74
F3-16	45.44	75.51	77.48	33.86
F3-17	47.19	79.01	77.48	32.11
F3-18	49.91	69.99	63.06	39.01
F3-19	43.67	54.51	37.30	54.84
F3-20	46.34	74.28	71.41	35,99

DMU= decision making unit.

Table 8.11d. Input reduction (%) for the definition of the target vessels and efficiency (Φ) of the individual vessels for the offshore trawlers (F4).

DMU	Input 1 (%)	Input 2 (%)	Input 3 (%)	Efficiency (Φ)
F4-1	0.00	0.00	0.00	100.00
F4-2	0.00	10.38	0.12	96.50
F4-3	58.65	71.25	49.26	40.28
F4-4	43.68	77.66	65.49	37.72
F4-5	48.60	29.79	43.29	59.44
F4-6	48.61	37.19	46.00	56.06
F4-7	54.74	36.43	49.14	53.23
F4-8	0.00	44.48	34.18	73.78
F4-9	16.24	58.13	49.59	58.68
F4-10	33.49	40.63	48.53	59.12
F4-11	0.00	0.00	0.00	100.00
F4-12	46.49	35.50	35.50	57.93

DMU= decision making unit; F4= offshore trawlers.

Table 8.11e. Input reduction (%) for the definition of the target vessels and efficiency (Φ) of the individual vessels for the Mauritanian EEZ vessels (F5).

DMU	Input 1 (%)	Input 2 (%)	Input 3 (%)	Efficiency (Φ)
F5-1	0.00	0.00	0.00	100.00
F5-2	0.87	47.35	32.49	73.09
F5-3	0.00	0.00	0.00	100.00
F5-4	30.78	62.64	49.27	52.44
F5-5	33.82	64.74	44.15	52.43
F5-6	11.61	52.55	39.15	65.56
F5-7	1.72	60.04	36.71	67.17
F5-8	17.43	70.66	35.82	58.70

DMU= decision making unit; F5= cephalopod trawlers.

Table 8.11f. Input reduction (%) for the definition of the target vessels and efficiency (Φ) of the individual vessels for the tuna purse seiners (F6).

DMU	Input 1 (%)	Input 2 (%)	Input 3 (%)	Efficiency (Φ)
F6-1	14.96	31.82	17.69	78.51
F6-2	28.97	26.36	29.68	71.67
F6-3	31.64	43.21	14.29	70.29
F6-4	0.00	0.00	0.00	100.00
F6-5	0.00	0.00	0.00	100.00
F6-6	0.00	0.00	0.00	100.00
F6-7	35.27	48.56	17.51	66.22
F6-8	49.81	56.19	41.49	50.83
F6-9	12.55	35.62	8.20	81.21

DMU= decision making unit; F6= tuna purse seiners.

These results constitute the operational benchmarking for each individual vessel. Fisheries managers are highly encouraged to take this information into account as a relevant support for decision making. Tables 8.11a-f proves that relevant amounts of operational inputs are wastefully consumed, gathering reduction percentages as high as 97%. Individual skippers could use the computed operational benchmarks to plan corrective actions.

Furthermore, we calculated the efficiency score for the average vessel of each fleet by including the average vessel for each fleet as an additional DMU over the total number of vessels considered. The rationale behind this approach is to optimize and calculate the efficiency of the average vessel, rather than to just calculate the average efficiency of the fleet. Consequently, as can be observed in Figure 8.2, the two open sea fleets, purse seiners and trawlers, were highlighted as those with the most efficient average vessel, presenting an efficiency score of 76.2% and 65.5%, respectively. Offshore long liners had an average vessel efficiency of 62.8%, whereas the two coastal fleets analysed (trawlers and purse seiners) achieved average vessel efficiencies of 46% and 44.3%, respectively. Finally, auxiliary vessels for mussel cultivation rafts had the lowest average vessel efficiency score (30.1%).

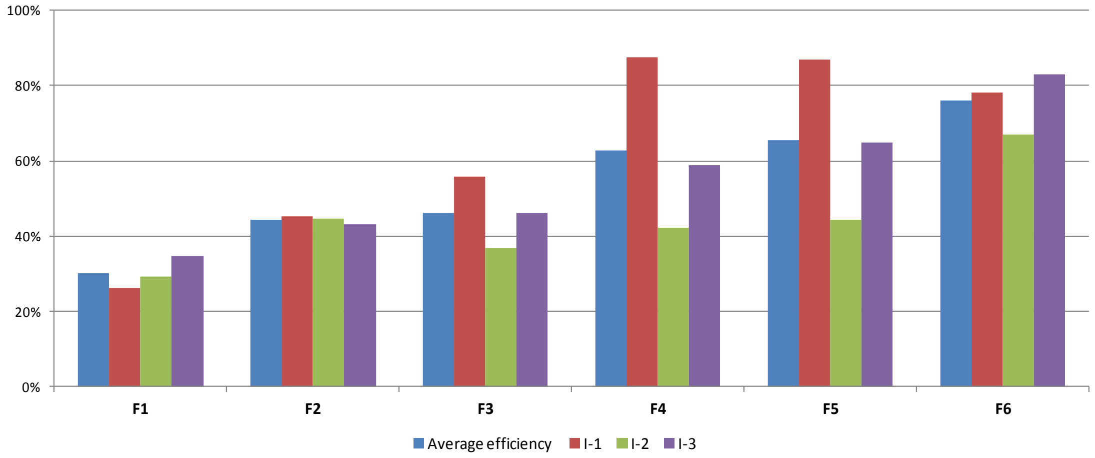

Figure 8.2. Efficiency score of the average vessel as compared to the individual input efficiencies of the averages vessel in the selected fleets.

Fishing fleet acronyms: F1 = Auxiliary mussel raft vessels; F2 = Coastal purse seining; F3 = Coastal trawling; F4 = Offshore long lining; F5 = Cephalopod trawling; F6 = Tuna purse seining; I-1= input 1; I-2: input 2; I-3= input 3.

Taking into account that these values are the result of averaging out the individual input efficiencies for the average vessel, Figure 8.2 depicts the differences in efficiency for the individual inputs. The diesel input efficiency of the average vessel was found to be higher than the total efficiency of the average vessel for each fleet, except for the auxiliary vessels' fleet, whose diesel efficiency was only 26.2%. The highest diesel input efficiency values corresponded to the average vessels of the offshore long lining and the cephalopod trawling fleet; these reached a diesel efficiency of 87.5% and 86.9%, respectively, which represents a 20% to 25% increase with respect to the total efficiency score of the average vessel. The coastal fleets (trawling and purse seining) presented diesel efficiency values close to the total scores obtained for the average vessels.

The efficiency of the vessel construction input of the average unit generally showed lower values when compared to the total efficiency of the average vessel, except for the coastal purse seining fleet. In this particular case, the average coastal purse seiner presented an individual input efficiency value close to the total score. The lowest vessel construction input efficiency was related to the auxiliary vessels fleet (29.2%), whereas the highest corresponded to the tuna purse seining fleet (67.1%). Overall, hull material was the input that presented lowest efficiency values.

Finally, the individual input efficiency computed for the third input (antifouling paint or nets) generally showed values close to the total efficiency of the average vessel for each fleet.

Step 4: Environmental characterization of target values

Once the target values were obtained with the DEA model for the inefficient vessels, the target vessels underwent a new LCIA, in order to calculate the potential environmental impacts of these vessels if they are operated in an efficient way. This procedure entails the environmental benchmarking of the sample. Figure 8.3 presents the average potential environmental impacts per tonne of output (i.e., per FU) of the current vessels versus those of the associated target vessels for each fleet. The average environmental impacts for the virtual DMUs were lower than the ones of the original DMUs, due to the optimization of resources, except for those vessels that were found to be efficient, for which the target vessels were the same as the current ones.

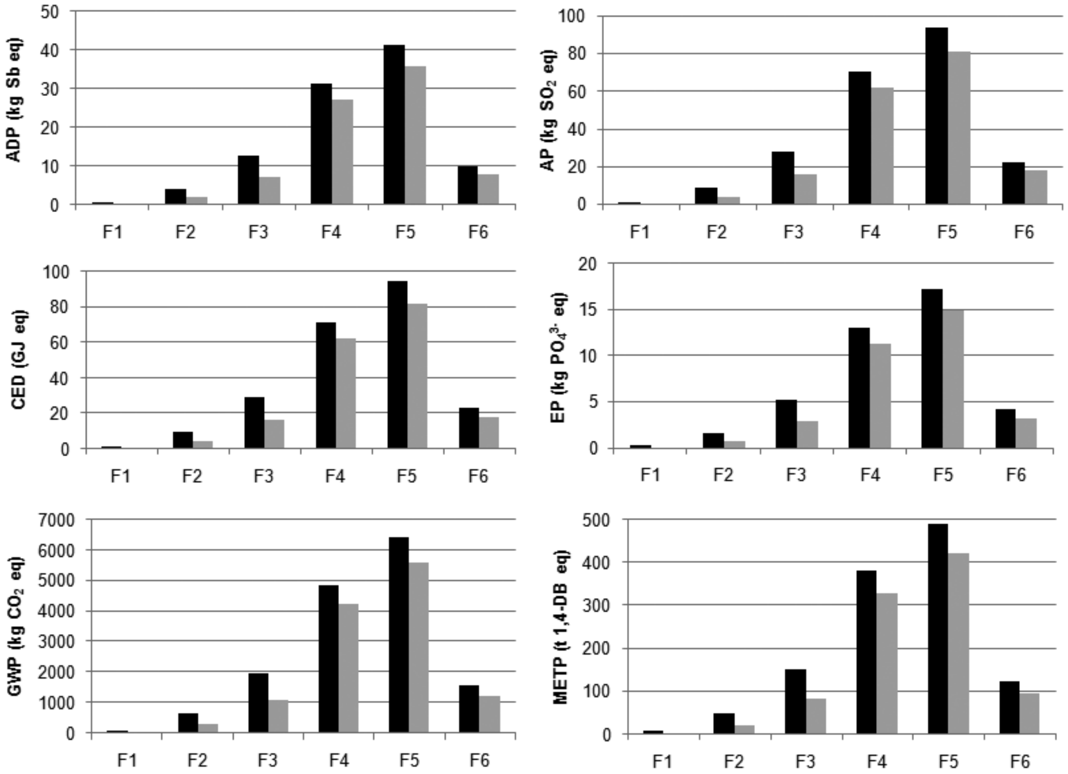

Figure 8.3. Average environmental impact potentials of the original vessels (black bars) and the virtual targets (grey bars) per FU.

Fishing fleet acronyms: F1 = Auxiliary mussel raft vessels; F2 = Coastal purse seining; F3 = Coastal trawling; F4 = Offshore long lining; F5 = Cephalopod trawling; F6 = Tuna purse seining. Impact category acronyms: ADP = Abiotic Depletion Potential; AP = Acidification Potential; EP = Eutrophication Potential; GWP = Global Warming Potential; METP = Marine Eco-Toxicity Potential; CED = Cumulative Energy Demand.

Step 5: Interpretation and eco-efficiency verification

The five-step LCA+DEA method, as mentioned in Chapter 7, allows the comparison between the potential environmental impacts of the current DMUs and those of the associated targets. Therefore, the environmental consequences of operational inefficiencies are revealed, and eco-efficiency criteria (less input, less environmental impact) can be verified.

The fleet that would benefit the most from operational optimization was the auxiliary mussel raft vessels fleet: All the impact categories assessed achieved consequential improvements around 74%. Coastal purse seiners achieved improvements of around 55% for all impact categories, and for coastal trawlers the benefit was slightly above 44%. The only offshore fleet assessed was the long-lining Galician fleet in the Northern Stock fisheries (ICES Division VII). This fleet achieved environmental gains ranging from 12.5% for AP to 14.1% for METP. Finally, open sea fleets reached advances of around 22% and 10.5% for all impact categories for purse seiners and trawlers, respectively.

8.4.4. Further outcomes and discussion of the case study

The operational and environmental benchmarking of the assessed vessels is the main outcome from the application of the five-step LCA + DEA method. Nevertheless, further results can be derived from this analysis, such as a profitability study on the basis of the reductions computed for input consumption levels. Moreover, a discussion of the LCA + DEA results is presented in this section.

Prioritization of Operational Inputs and Profitability Study

The dominance of energy use in the potential life cycle environmental impact is clearly visible in all the assessed fleets. This statement, which is in agreement with findings in Section II and in previous LCA studies on fisheries (Edwardson, 1976; Watanabe and Okubo, 1989; Ziegler et al., 2003; Thrane 2004; Tyedmers, 2004; Schau et al., 2009), is stressed with operational benchmarking. Thus, the total reduction of environmental impact for the global warming impact category and the total input reduction for diesel entailed very similar results. Similar results were found when the input reduction for diesel was compared with the other impact categories used in this study. Hence, activities related to fuel production, distribution, and combustion were the main sources of environmental burdens for all the assessed fleets; all the other activities analysed had a secondary role with respect to environmental impact minimization.

From an economic perspective, however, and taking into consideration operational benchmarking, other inputs, such as hull material (strongly related to the vessel size), antifouling, and nets, had a significant influence in terms of reducing economic costs. According to conventional prices in the Spanish market for the selected inputs (Hempel, 2009; Provimar, sales manager, personal communication; FEARMAGA, 2010; MITYC, 2010) and the target values benchmarked for the average vessels, Table 8.12 gathers the corresponding economic savings. As observed, non-fuel-related inputs can be an important feature for those fleets that present lower energy intensity, such as auxiliary vessels for mussel culture and tuna purse seiners. In this respect, around 32% of the estimated economic savings for mussel raft auxiliary vessels would be attributable to minimization of antifouling paint use, whereas approximately 40% of the savings for tuna purse seiners would be related to reductions in hull material consumption.

Table 8.12. Total annual input reduction for the average vessel of the selected fleets and associated economic savings estimation.

		F1	F2	F3	F4	F5	F6
I-1	Reduction (l/year)	7,239	49,212	157,307	52,150	131,500	824,408
	Savings (€/year)	3,258	22,145	70,788	23,467	59,175	370,983
I-2	Reduction (kg/year)	545	1,014	2,112	2,318	3,574	339,765
	Savings (€/year)	52	730	1,521	1,669	2,573	244,631
I-3	Reduction (l/year or kg/year)	35	2,606	798	112	782	132
	Savings (€/year)	1,555	2,085	638	5,058	626	5,935
I-1,2,3	Total savings (€/year)	4,865	24,960	72,947	30,194	62,374	621,549

I-1= input 1; I-2= input 2; I-3= input 3; F1= auxiliary mussel raft vessels; F2= coastal purse seiners; F3= coastal trawlers; F4= offshore long liners; F5= Mautitanian EEZ trawlers; F6= tuna purse seiners.

Determining fleet performance through operational efficiency

When the fleets are analysed following an intra-assessment perspective, there is a considerable difference in the operational efficiency of the average vessel. The results obtained in this study show a regular trend that open sea and offshore vessels, which are more specialized than coastal vessels, have a significantly higher operational efficiency than coastal vessels.

Open sea fleets—which had highest global fuel consumption and therefore spent more financial resources on fuel-related operations—not only had the highest operational efficiencies for the average vessel (76% for tuna purse seiners and 65% for cephalopod trawlers) but also had the highest percentages of vessels operating in an efficient manner. This issue is strongly related to the increase in fuel prices in the past decade, which has led these fleets to develop efficiency strategies. Some fuel reduction methods are related to a series of operational activities linked mainly to on board decisions, such as speed, engine maintenance, or route selection (Le Floc'h et al., 2007; Parente et al. 2008). Other factors, however, relate to hull design (e.g., diminishing vessel resistance or improving the propelling system), engine improvement (FAO, 1980, 1986; Valls-Vilaespasa et al., 2010), and gear design (e.g., introducing innovative trawl designs; Sterling and Eayrs, 2008; Priour, 2009).Additionally, the trawling fleet that extracts mainly cephalopods and hake in Mauritanian waters has developed further actions to optimize energy use by implementing a remote sensing and geographic information system (GIS) in cooperation with several Galician organizations (Torres-Palenzuela et al., 2010). It is not surprising that the specific diesel input efficiency for this fleet (F5) reached 87% (Figure 8.2). In the same direction, the only offshore fleet analysed (Northern Stock long liners) presented similar results to open sea fleets, with an operational efficiency of 63% for the average vessel (88% efficiency for diesel), which also shows the efforts in input reduction already taken by the vessels.

In contrast, the vessels belonging to fleets with a lower rate of energy consumption, mainly coastal fleets, such as auxiliary mussel raft vessels and coastal purse seiners, had very low operational efficiencies: 30% and 44%, respectively. Data from auxiliary vessels must be taken with caution due to the different characteristics of this fleet. Auxiliary vessels for mussel rafts do not compete with each other for a limited resource (wild fish), like every other fleet included in this study. Instead, these vessels transport variable amounts of farmed mussels between two fixed positions: the mussel raft served, and the port where the mussels are landed. Therefore, the efficiency of this fleet is strongly dependent on three key factors: (1) the distance covered by the vessels, (2) the number of mussel rafts assigned to each vessel, and (3) the mussel production of each raft. Thus, auxiliary vessels that cover increased distances should try to assist a higher number of rafts.

Another important issue is the lack of consistency in divisions regarding the fishing gear used in the different fleets. Coastal and tuna purse seiners showed lower consumption of fuel per FU than coastal and cephalopod trawlers, respectively. The efficiency score of the average coastal trawler is higher than that of coastal purse seiners, however, whereas in the open sea fleets assessed, the highest efficiency score was identified for the purse seining fleet with respect to the trawling fleet working in Mauritanian waters. The highest recorded average vessel efficiency for all fleets corresponded to the tuna purse seining fleet. This outstanding finding could be linked to the fact that open sea vessels are integrated into highly commercialized, competitive, and specialized fleets, whereas coastal vessels, mainly purse seiners, show intermediate operational and target market characteristics between commercial and artisanal vessels.

Fleet trends in input efficiency

The individual input efficiencies computed for the average vessels showed different trends depending on the specific fishing fleet. Diesel input efficiency values for the average vessel of each fleet had been previously computed, therefore including average fuel consumption rates as additional observed data. The diesel input efficiency of the average vessel for the offshore and open sea fleets was significantly higher than the operational efficiency score, especially for the most fuel-intensive fleet, cephalopod trawling. In addition, the coastal trawling fleet presented higher diesel efficiency (56%) compared to the efficiency score of the average vessel (46%). It is interesting to note that this fleet had a higher energy consumption rate than tuna purse seining vessels, but its efficiency was considerably lower than the efficiency of the latter. This low efficiency value for coastal trawlers is probably linked to the heterogeneous nature of this fleet, as many of the vessels were originally designed for fish extraction in the Northern Stock or other offshore fisheries; due to the heavy restructuring of these fleets in recent years (EEA, 2010), they had to redeploy their target stocks.

The diesel input efficiency of the average vessel for the coastal purse seining fleet was not significantly different from the operational efficiency score of the average vessel. This low difference may be due to the non-intensive fuel consumption and semi-artisanal characteristics of the vessels. The only fleet that presented a lower diesel input efficiency when compared to the average vessel efficiency score was the auxiliary mussel raft vessels fleet, linked to the lower importance of the operation of the boat in the overall mussel culture (Iribarren et al., 2010, 2011).

In addition, the hull material input efficiency of the average vessel was significantly lower than the operational efficiency in all the selected fishing fleets, apart from the coastal purse seining fleet. These reduced efficiency levels may be related to the increasing overcapacity of European fishing fleets in the case of commercial fishing fleets (Martínez-López et al., 2010; Villasante, 2010). In fact, recent studies suggest that the harvest capacity of European fishing fleets is way too high for it to be in balance with available stocks (Villasante and Sumaila, 2010). Coastal fleets showed a higher degree of inefficiency for this particular input (e.g., 37% for coastal trawlers), whereas the fishing fleet with the highest hull construction input efficiency was the tuna purse seining fleet (67%).

Finally, antifouling and net input efficiencies presented efficiency scores similar to that of the operational efficiency of the average vessel, regardless of the fishing fleet. The fact that two different inputs were used depending on the selected fleet hinders the comparative analysis of the individual efficiency of the third operational input among fleets.

Environmental gains through operational benchmarking

With respect to the environmental improvement linked to operational benchmarking, clear tendencies were identified in the six independent fleets assessed. Results proved, as seen in the case study in Chapter 7, that the link between operational efficiency and environmental impacts is achieved through the optimization of resource usage, which creates a reduction in the potential environmental impacts.

Compared to other assessment alternatives, the key strength of LCA+DEA methodology lies in its quantitative nature (Iribarren, 2010). The applied method not only provides a qualitative proof of the environmental benefits linked to efficient operational practices but also quantifies these environmental gains. Moreover, unlike LCA sensitivity analyses, the five-step LCA+DEA method itself provides the benchmarking of the operational and environmental targets. In other words, this method quantitatively establishes the environmental consequences of operational inefficiencies, relying not on the mere assumption of hypothetical reductions in selected parameters but on the target operational values defined from observed data through DEA.

Coastal fisheries showed a higher relative potential reduction of their environmental burdens, due to the increased inefficiency of their vessels. Nonetheless, the environmental burdens of coastal fleets, mainly when they were not fuel intensive, were extremely low compared to those of more fuel-intensive fleets, such as trawlers and offshore and open sea fleets in general. Another important characteristic of fleets with non-intensive fuel-consuming vessels is that the minimization of other inputs besides fuel consumption, such as antifouling or net consumption not only had an important influence on economic costs but also showed more significant environmental impact reductions.

Environmental target values obtained after operational benchmarking can provide a reference for policy making in the fishing sector, as mentioned in Chapter 7. In this way, LCA +

DEA methodology can guide correcting measures on the basis of environmental impact efficiency and economic sustainability in fisheries.

Finally, in addition to inter-fleet observations, the usefulness of the LCA+DEA outcomes highly relies on the results obtained for the individual vessels regarding operational benchmarking and environmental assessment. In this respect, LCA+DEA methodology leads not only to an inter-fleet analysis but also to intra-fleet assessments. In fact, this methodology usually focuses on the evaluation of a single set of DMUs (in this case, a single fishing fleet), which permits a thorough, individualized assessment of each vessel. This way, skippers have a valuable supporting tool for decision making that can help identify the main environmental burdens related to their vessels while assessing their operational performance for the purpose of optimization. Thus, LCA+DEA approaches guide skippers and fisheries managers towards environmental and economic gains that arise from the minimization of operational consumption levels to an extent deemed currently feasible. This integration of operational, economic, and environmental concepts in quantitative terms into only one methodology makes LCA+DEA a promising novel management tool for fisheries, among other potential application fields.

8.5. Perspectives and conclusions

In Chapter 7 the main benefits of the joint application of LCA and DEA were highlighted: the avoidance of average inventories (and, therefore, standard deviations), as well as the achievement of eco-efficiency verification. The brief case studies presented go beyond this perspective, and illustrate other relevant advantages that encourage the application of LCA+DEA approaches.

In particular, the regular use of LCA+DEA methodology when multiple input/output data are available for a wide range of units was demonstrated. Furthermore, where the number of units to be evaluated is considerably high and numerous entities are expected to be deemed efficient, the usefulness of super-efficiency analyses was proved. Moreover, if data for two or more sets of multiple DMUs within a certain sector are available, not only operational and environmental intra-assessments are possible, but also inter-assessments leading to the identification of operational and environmental patterns. Additionally, it was proved that the economic dimension of LCA+DEA approaches is not limited to an operational assessment but it also deals with the quantification of economic savings through the minimization of either operational or economic inputs. Finally, the availability of environmental characterization results for multiple units at different time periods allows the assessment of environmental performance trends over time by means of a DEA window analysis.

More specifically, the use of the five-step LCA+DEA method for intra- and inter-assessment for a broad number of vessels belonging to six different Galician fishing fleets, permitted the computation of operational and environmental benchmarks regarding key consumption inputs. Results demonstrated the strong dependence of environmental impacts on one major operational input: fuel consumption. The potential for minimization of energy resources was greater for the less intensive fuel-consuming fleets, such as coastal purse seining and auxiliary mussel rafts vessels. Vessels belonging to fuel-intensive fleets generally showed an increased efficiency of the fuel-related inputs with respect to other operational inputs. Other secondary issues besides fuel activities, such as vessel construction or net consumption, have slight impacts on the total environmental burdens of the vessels of the different fleets. The reduction of these inputs through operational benchmarking may offer the skippers substantial decrease in operational costs, however.

The operational efficiency of the average vessel for the open sea and offshore fleets analysed was significantly higher than that for the coastal fleets. The percentage of vessels that were deemed efficient was also reduced for coastal fleets. Future research dealing with the joint assessment of fleets could focus on determining relations between the degree of exploitation of the different fisheries and the efficiency shown by the fleets working in them, to assess whether low efficiencies can also be linked to overexploitation. Skippers, fisheries managers, and policymakers are expected to use this set of results as a valuable support for decision making. Finally, given that Galicia is one of the major fishing regions in the European Union, many of the conclusions and perspectives obtained in this study may be extrapolated to other fishing fleets at a European or international level.

To sum up, the appropriateness of the use of LCA+DEA methodology for studies on the operational and environmental performance of fisheries is shown by the robustness of the obtained results, not only when the intra- and inter-assessment of fisheries is pursued, but also when other potentials of the methodology are applied to case studies. In fact, LCA + DEA methodology is of use for any case study in which multiple input and output data are available for multiple similar units of assessment (i.e., multiple DMUs). The use of this method is recommended to enrich the results provided by the mere use of LCA or DEA as single tools when assessing multiple similar entities.

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Chapter 9

Identifying the importance of the “skipper effect” within sources of measured inefficiency in fisheries through DEA computation[1]

Summary

A wide set of different factors have been identified in literature as potential sources of fishing vessel inefficiency. In fact, besides technical efficiency (TE) differences that can be detected in fishing fleets, there are two added factors linked to efficiency. In the first place, epistemic uncertainties in data quality and availability, as well as illegal, unreported and unregulated (IUU) fishing activities, on the one hand, and fluctuations due to natural variability of stocks, on the other, can have important effects on data quality and availability. Secondly, there is ongoing debate in the scientific community to whether the skill of the skipper is a determining factor when analysing efficiency in fishing fleets.

Therefore, the main objective in this chapter is to monitor, calculate and quantify the inefficiency caused by the skipper effect, if any, through the use of DEA, aiming at determining if the best practice target operational values in DEA and their associated environmental impact reductions through LCA+DEA methodology are achievable beyond the theoretical baseline they involve, or if they imply a difficult practical target. A DEA window analysis model is applied to the US menhaden (*Brevoortia* spp.) fishery, a purse seining fleet with a high degree of homogeneity, since the entire fleet is owned by the same company, with similar vessel characteristics, operational patterns, identical technological features, equal incentives to fish in an optimized manner and no quota restrictions.

Results revealed relevant inefficiency levels in the fisheries targeting US menhaden, suggesting the existence of a skipper effect in the four evaluated ports. In the first place, remarkably strong variances between vessels were identified, not only on an annual mean basis, but also within each week of study. Secondly, these strong variances between vessels could be attributed to random variation through time, if it were not for the fact that best performing vessels in each port managed to repeatedly perform at high efficiency rates throughout the selected period. Moreover, the standard deviations of low efficiency vessels were outstandingly higher in all ports. Finally, best performing vessels also showed less dependence on spotter support in Ports 2 and 3.

Based on these results, target reductions in the environmental profile of fishing vessels calculated in LCA+DEA would maintain their validity as a theoretical baseline, but in some cases, especially when the existence of a strong skipper effect is observed, these best performing targets may be difficult to achieve through resource minimization, unless specific measures are taken to improve the individual skills of low performing skippers and crews.

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[1] Vázquez-Rowe, I., Tyedmers, P., (2011). “Identifying the importance of the “skipper effect” within sources of measured inefficiency in fisheries through data envelopment analysis (DEA)”. *Fisheries Research,* (under review).

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9.1. Introduction

The fishing capacity of many fisheries and nations, which can be defined as the amount of biomass that can be extracted by vessels when fully utilizing their available resources (FAO, 2000), has shown to be above desirable levels, leading to difficulties to guarantee the sustainability of fishing operations (García and Newton, 1997; Pauly et al., 1998). This overcapacity has given rise to an increasing number of deployments in the past three decades. For instance, the entry of the Iberian Peninsula countries (Spain and Portugal) in the EU was strongly conditioned by a strong reduction in their fleets' tonnage (Villasante, 2010). The main aim of these policies, which focus mainly on reducing the number of vessels, but have also been extended to a series of on board protocols, such as reduction of the number of days at sea or fishing moratoria, is to maintain not only the fishing stock levels at adequate abundance rates that do not put at risk the survival of a given stock, but also to maintain the efficiency of fishing fleets throughout the world from an economic and technical perspective.

There has been an increasing interest in the literature regarding the main factors influencing the efficiency of fishing fleets and vessels (Tingley et al., 2003). In fact, a whole set of different factors have been identified as potential sources of vessel inefficiency. These features include, but are not limited to, differences in vessels characteristics, such as size, age, engine power or tonnage (Pascoe et al., 2001), management changes in a specific fishery, geographical distribution of the vessel, including landing and base ports (Eggert, 2001), technological improvements or backwardness (Pascoe and Coglan, 2002; Villasante and Sumaila, 2010) and a set of operational issues relating to the use of resources, such as gear, fuel or ice usage (Lozano et al., 2009).

Nevertheless, besides TE differences that can be identified in fishing fleets, there are two major added factors linked to vessel efficiency. In the first place, uncertainties due to measurement errors, data misreporting by skippers, referred to technically as epistemic uncertainties in data quality and availability (Reid and Squires, 2007; Pascoe et al., 2001), and IUU fishing activities (Agnew et al., 2009, MRAG, 2005), on the one hand, and fluctuations due to natural variability of stocks, on the other, can have important effects on data quality and availability (Parker and Tyedmers, 2011). Secondly, there is ongoing debate in the scientific community on whether the skill of the fishermen, especially the skipper, is a determining factor when analysing efficiency in fishing fleets (Barth, 1966; Acheson et al., 1981; Pálsson and Durrenberger, 1990; Ruttan and Tyedmers, 2007). This phenomenon, usually named the "skipper effect", has arisen increasing interest, since it suggests that fishing fleet reduction schemes in order to face overcapacity may not be an effective policy to increase efficiency in fisheries (Ruttan and Tyedmers, 2007). However, as pointed out by Russell and Alexander (1996), the exigency of highly detailed data through time to assess the skipper effect has limited the number of studies that have dealt with this issue.

Moreover, recent publications, as well as discussion in Chapters 7 and 8 from this dissertation, suggest that efficiency in fishing fleets has also important implications regarding the environmental profile of a fishery. In fact, the environmental impacts linked to a particular production system or product, have shown to depend on the efficiency with which operations are carried out (Lozano et al., 2009). In this context, eco-efficiency has been analysed numerous times in literature in order to maximize the output services or goods while reducing material and energy flow inputs. In other words, eco-efficiency, as defined by the World Business Council for Sustainable Development, attempts at satisfying the needs of the human population while reducing gradually the environmental impacts linked to goods throughout their entire life cycle, in order to avoid endangering the Earth's estimated carrying capacity (Schmidheiny, 1992).

While eco-efficiency has been a major matter of concern in a wide range of production systems, efforts to determine its relevance in the fishing sector have been very limited (Thrane et al., 2009). In fact, most studies have focused on quantifying and benchmarking the potential environmental reduction linked to increased technical and operational efficiencies. However, the specific sources of inefficiency that are causing increased environmental impacts have not been analysed in depth in prior studies. This circumstance is probably due to the difficulties in independently identifying the effects that these factors have on vessel inefficiency, as stated by Pascoe and Coglan (2002) and Squires and Kirkley (1999).

Additionally, an added issue that makes it difficult to identify the sources of measured inefficiency in fisheries is the fact that efficiency in fisheries is not based on a theoretical maximum efficiency, but on a set of best performing items (i.e. fishing vessels) with respect to the other sampled units. Therefore, this relative efficiency does not detect any inefficiency in those elements that display best practices.

In this context, a wide range of literature articles have highlighted the appropriateness of using DEA in the calculation of TE in fishing systems, given its capacity to measure vessels individually in multiple vessel fishing fleets (FAO, 2000; Maravelias and Tsitsika, 2008) and the wide number of inputs and outputs that can be assessed simultaneously (Kirkley and Squires, 2003). Moreover, DEA has been applied to fisheries at a global scale, including all major fishing gears, such as long lining vessels (Tingley et al., 2003), purse seiners (Vestegaard et al., 2003; Maravelias and Tsitiska, 2008), trawlers (van Hoof and de Wilde, 2005; Färe et al., 2006) or artisanal vessels (Fousekis and Klonaris, 2003; Oliveira et al., 2009).

More recently, as seen in Chapter 7, DEA has been combined with LCA, presenting a series of strengths with respect to the use of the two tools independently, including the relation between environmental burdens and inefficiencies in fishing vessels. While the objectives of the LCA+DEA studies presented in Chapters 7 and 8 are linked to the underlying environmental consequences of inefficiencies in vessels, the heterogeneity in vessel efficiency identified in DEA analyses was also confirmed when using the LCA+DEA approach to aquaculture (Lozano et al., 2009, 2010) and fishery systems (see Chapter 8).

In the present study, DEA is applied to the US menhaden (*Brevoortia* spp.) fishery, a purse seining fishing fleet with a high degree of homogeneity (Figure 9.1), due to the fact that the entire fleet is owned by the same company, with similar vessel characteristics, operational patterns, identical technological features and equal incentives to fish in an optimized manner, as explained in more detail in Ruttan and Tyedmers (2007). Moreover, the analysed sample corresponds to the entire 40 vessels of the fleet, with a high degree of detail regarding data availability and quality, where intentional misreporting or IUU is not expected. Finally, fishing management did not consider any type of quota or seasonal restriction in this fishery. These three characteristics of the evaluated inventory data lead to presume that the inefficiencies identified in this fleet will be overwhelmingly associated with the skipper effect, while TE and data quality are expected to be close to zero. Hence, the main objective is to calculate and quantify the inefficiency caused by the so called skipper effect through the use of DEA in the US menhaden fishery, in order to determine if the best practice target operational values in DEA and their associated environmental impact reductions through LCA+DEA methodology are achievable beyond the theoretical baseline they involve.

Figure 9.1. Fishermen on auxiliary purse boat extending the seine net (Mississippi, US).
Source: NOAA Photo Library (2009).

9.2. Framework. DEA in fishing systems

The applied software tool in this particular case study (DEA), as mentioned in section 9.1, has been used in an increasing manner to assess the efficiency in fishing systems. However, the specific model implemented for each study is based on the approach given by DEA practitioners and on the level of disaggregation shown by the inventory data available (Reid and Squires, 2006). In fact, orientation and the PPS display, two of the three main factors that have to be taken into account when selecting a model (see Section 7.3.2), have shown to be major issues of controversy in the application of DEA to fishing systems

On the one hand, concerning orientation, the use of DEA as a stand-alone tool in fisheries, has assumed in most studies an output oriented perspective (Tingley et al., 2005), based on the rationale defended by Greene (1993) that the degree of efficiency in a production system is described by the function of the current production with respect to a potential production value. However, some studies, linked mainly to eco-efficiency through the combined use of LCA+DEA, use the input oriented approach, arguing that this perspective focuses on reducing input consumption and their associated environmental burdens (when LCA+DEA is applied) as much as possible (Chapters 7 and 8; Lozano et al., 2009, 2010; Vázquez-Rowe et al., 2012). Hence, input oriented studies aim at detecting inefficient input utilisation and estimating the potential improvements in fishing systems that are constrained by a limited wild ecosystem output (usually fish catch) and the unpredictability of stock availability.

Regarding the display of the PPS, the criteria followed to assume CRS or VRS is controversial. According to Banker (1984), if the evaluated units operate at their Most Productive Scale Size, that is, they work in a competitive market, the CRS approach should be implemented. However, in cases where the DMUs may not work at an ideal scale (e.g. international fisheries with transnational fishing fleets and differing quotas) the VRS should be used.

9.3. Materials and Methods

9.3.1. Data acquisition

Inventory data for this study were obtained for an entire year of operation (2001) for a set of 41 US purse seining vessels belonging to Omega Protein Inc. The assessed vessels, as can be seen in Table 9.1, were based at four different ports along the US coast, 3 on the Gulf coast, targeting gulf menhaden (*Brevoortia patronus*) and one on the Atlantic coast, targeting Atlantic menhaden (*Brevoortia tyrannus*). More information on the nature of these two fisheries and on the technological aspects driving the fishing fleet can be consulted in Ruttan and Tyedmers (2007), who previously used this data set in order to analyse the skipper effect in these fleets using the general linear models (GLM) and MIXED models in SPSS. While the data provided were more extensive, the main vessel-specific data supplied were: vessel length, gross tonnage, engine power, weeks and days of operation in 2001, total catch per day, fuel consumption, lost fishing time and reasons for lost time, name of the skipper of each vessel, base location, number of sets and number of sets undergone with the aid of spotter aircrafts (see Table 9.1).

Table 9.1. Brief description of the samples for the selected fishing vessels per port.

	Port 1	Port 2	Port 3	Port 4
Number of vessels	10	13	8	10
Sampled vessels	10	10	8	10
Location	Gulf Coast	Gulf Coast	Gulf Coast	Atlantic Ocean
Average vessel length (m)[1]	49.2	47.8	49.8	52.1
Average vessel tonnage (GT)[1]	506.7	476.7	520.8	552.2
Average engine power (kW)[1]	1,219	1,789	1,267	1,320
Total weeks assessed[1]	25	23	25	24
Total catch (tonnes)[1]	130,541	105,818	80,297	181,962
Fuel consumption (tonnes)[1]	4,187	3,383	4,140	3,709
Average sets per vessel[1]	577.3	404.7	414.1	472.2
Sets with air support per vessel[1]	362.5 (62.8%)	285.4 (70.5%)	190 (45.9%)	N/A[2]

[1] The data provided refer to the vessels included in the sample, rather than the total number of vessels collected.

[2] The reported data for this port is 100% of sets used spotter support. However, as discussed in section 9.3.2, there are motives to consider that this result corresponds to an incorrect value.

9.3.2. Inventory data quality

Even though the entire set of purse seiners collected operate under extremely similar technical and technological conditions, the fact that they were roughly evenly divided throughout the analysed ports implied different environmental conditions linked to distance to the fisheries or the fact that the species targeted by the Atlantic vessels and their fishing season was different. Therefore, the fishing vessels belonging to the four different ports were assessed separately, in order to maximize the level of homogeneity between the vessels. The fact that data were supplied directly from the registrar of Omega Protein Inc. leads to assume that the quality of the data is as high as it can possibly get, with a low random error.

However, despite the expected excellence of the provided data, certain reporting errors were identified within the data sheets. On the one hand, as mentioned in Ruttan and Tyedmers (2007), the fact that all sets for the Atlantic coast fleet were reported to be aided by spotter planes does not seem feasible for the studied year, given that the US air space was closed after 9/11 for several days. On the other hand, a total of three vessels from Port 2 suffered outstandingly high time loss with respect to other vessels from the same port, due to a series of technical and equipment issues. This circumstance implied a lack of data reporting for these specific vessels for an extended period of time in a relatively low assessment period (23 weeks for this specific port). Hence, given that the data available for these three vessels were not available for the level of disaggregation that the present study was conducted at, they were left out of the assessed sample (Table 9.1).

9.3.3. Selected DEA model

The selected DEA model to assess the US menhaden fishery in terms of expected inefficiencies was the windows analysis model. Given the detailed weekly data provided by the fishing company for an entire fishing season, the different DMUs were disaggregated per week in order to conduct the DEA windows analysis (Charnes et al., 1985), which aims at identifying performance patterns of the fishing vessels over time. However, it is important to note that from a methodological point of view each unit confers an independent DMU within each time period, allowing comparison not only between vessels, but also individual efficiency variations through the assessed period (Asmild et al., 2004). In other words, an extended assessment through time is implemented in order to identify if the efficiency of a particular DMU is maintained through time or if an efficient performance in a particular window is only due to random or extraneous situations (Yue, 1992). Nevertheless, it is important to note that analysing DEA scores throughout a long time frame may be misleading due to changes in technology and policies (Yue, 1992). In fact, this point is crucial when evaluating fishing fleets due to faster growing technological advances with respect to vessel deployment actions (Villasante and Sumaila, 2010) and to changing fishing policies and treaties. More information on the formulation of the window analysis DEA model is provided in Appendix II.

Based on the available data, four different matrices were created for each of the analysed fishing ports with a set of inputs and outputs that are discussed in section 9.3.4. Moreover, a series of three complementary matrices (for Ports 1-3) were created in order to support the validity of the results obtained for the four main matrices.

9.3.4. Input and output selection for the DEA matrices

A total of 7 different inputs were identified for the assessed vessels on a weekly basis, excluding the name of the skipper of each vessel, which turned out to be invariable throughout the entire year under study. However, out of these 7 inputs only three were considered for computation in the DEA matrices.

In the first place, data referring to vessel characteristics, such as length and tonnage were disregarded from the DEA analysis. The rationale behind this decision is linked to the low standard deviation shown in the 4 ports for these two features, as well as the fact that fishing operations in this fleet are not accomplished directly by the vessel itself, since an auxiliary boat (named a purse boat) is used for seine net deployment (Ruttan and Tyedmers, 2007). Secondly, another vessel characteristic, the engine power was also excluded from the matrices given the low standard deviation between vessels. Finally, the number of days lost at sea showed relevant differences between ports, but this was not so when performing an intra-assessment within each port. This was mainly due to the fact that most vessels were affected evenly by bad weather conditions. Therefore, three inputs were disregarded due to close to identical vessel characteristics in each port, while one final input was disregarded due to its minimal effect on the analysed system.

Hence, only the weekly fuel consumption, number of sets and the number of sets with spotter support were included as inputs in the main matrices, since they were found to be the only data sets, which together with the output (total catch per week), had outstanding fluctuations throughout the assessed period (Table 9.2). The three complementary matrices were used as control matrices in order to the effect that the suspected misreporting of sets with spotter backup in Port 4 had on that specific fleet. Moreover, the comparison between main and complementary matrices for Ports 1-3 may help to assess the influence that spotter support may have on the vessels.

Table 9.2. Selection of input/output items for data envelopment analysis (DEA).

	Input 1	Input 2	Input 3	Ouput
Main port matrices	Fuel (l/week)	Sets per week	Sets with spotter support per week	Catch (t/week)
Complementary port matrices	Fuel (l/week)	Sets per week	--	Catch (t/week)

[1] The data provided refer to the sample vessels, rather than the total number of vessels collected.

Finally, regarding the output, the fact that an overwhelming majority of landings are used in reduction plants for fish meal, fish oil and fish soluble production, and the fact that menhaden (Gulf or Atlantic) is the only landed species, led this research not to consider any other output approaches, such as economic output (June and Reintjes, 1976; Smith, 1991; Vaughan et al., 2007). Hence, the selected units for the production output, as observed in Table 9.2, were tonnes of landed catch per week.

9.3.5. DEA computation

The chosen software programme to implement the selected DEA models was the DEA-Solver Professional Release 6.0 (Saitech, 2009). As mentioned above, window analysis in the slacks-based measure (SBM) framework was the selected model to compute the eight matrices included in this study (see Appendix II). Window length was set at 1 week, since it would not be feasible to compare the catch rates between weeks, given the changes in stock distribution and abundance throughout the fishing season (Smith, 1999; Vaughan et al., 2007). Given the enormous amount of data included in the DEA matrices, these were included in a CD which is provided with this dissertation.

An input-oriented approach was determined for the developed matrices, based on the assumptions placed by prior LCA+DEA studies, which understand the establishment of efficiency targets in terms of identifying inefficient input use, rather than giving priority to an increase in catches with the existing inputs (Lozano et al., 2009). While the output oriented perspective would also be a useful method to implement, since it would calculate the potential catches in the absence of sources of inefficiency, this perspective runs the risk of underestimating the limited wild resources available in the fishery. Non-radial metrics was assumed, since it allows individual improvements throughout each individual input and output dimension. Therefore, the use of non-radial metrics will help understand the role of spotter planes when calculating vessel efficiency. Finally, given that all the assessed vessels work for the same company, under the same incentive and competitiveness conditions, CRS were considered in the current study.

9.4. Results

9.4.1. Main DEA matrices

Average efficiency scores for each of the assessed vessels throughout the entire period for the main matrices can be observed in Table 9.3. Results reveal high average efficiency rates in all ports. In fact, the mean efficiency score for the average vessel ranged from 80.3% in Port 3 to 84.5% in Port 1. The highest range between vessels was found in Port 2, with an average score of 98.1% for the best performing vessel and 67.8% for the vessel with the lowest value. The lowest range was identified for Port 4 (12.3% average efficiency difference between best and worst performing vessels). However, it should be noted that this set of vessels presented a known error regarding spotter support.

Table 9.3. Average efficiency scores (Φ_0) per fishing vessel for the main DEA matrices.

Port	Port 1		Port 2		Port 3		Port 4	
Vessel	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Vessel 1	84.8	±15.0	83.0	±12.7	77.4	±18.6	83.3	±14.4
Vessel 2	76.8	±15.7	75.5	±17.1	78.6	±17.1	76.6	±13.5
Vessel 3	85.8	±13.0	85.9	±16.5	83.4	±17.8	77.5	±11.4
Vessel 4	77.2	±20.1	85.4	±15.8	76.1	±16.7	88.6	±11.5
Vessel 5	86.0	±13.9	74.2	±15.3	77.9	±20.1	86.8	±15.0
Vessel 6	85.0	±14.4	68.7	±20.5	95.5	±11.6	85.1	±13.1
Vessel 7	91.8	±15.5	67.8	±18.4	71.2	±24.0	87.3	±14.3
Vessel 8	82.3	±16.7	98.1	±6.2	82.4	±15.1	88.9	±12.2
Vessel 9	81.6	±14.4	94.3	±11.2	--	--	84.7	±15.2
Vessel 10	93.7	±8.9	71.1	±20.6	--	--	83.8	±17.2
Average	84.5	±14.8	80.4	±15.4	80.3	±17.6	84.3	±13.8

SD= standard deviation.

The mean standard deviation for the different ports ranged from ±17.6 in Port 3 to ±13.8 in Port 4. Therefore, the difference between ports was considerably low. However, whenever an intra-assessment analysis is done in each port, outstanding differences are observed between vessels. For instance, in Port 2, vessel 8 presented a standard deviation of ±6.2, whereas vessel 10's deviation was ±20.6. Weekly efficiency scores for the individual vessels can be observed in Appendix I (Tables F1a-F1d).

Finally, regarding the mean weekly efficiencies scores, no regular pattern was identified in any of the assessed ports (Figure 9.2). However, considerable differences were observed from week to week in all ports. Lowest range differences on a weekly basis were identified in Port 4 (between 91.7% in week 12 and 74.1% in week 13), while the highest were those registered in Port 3, ranging from 61.1% in week 15 to 90.8% in week 7.

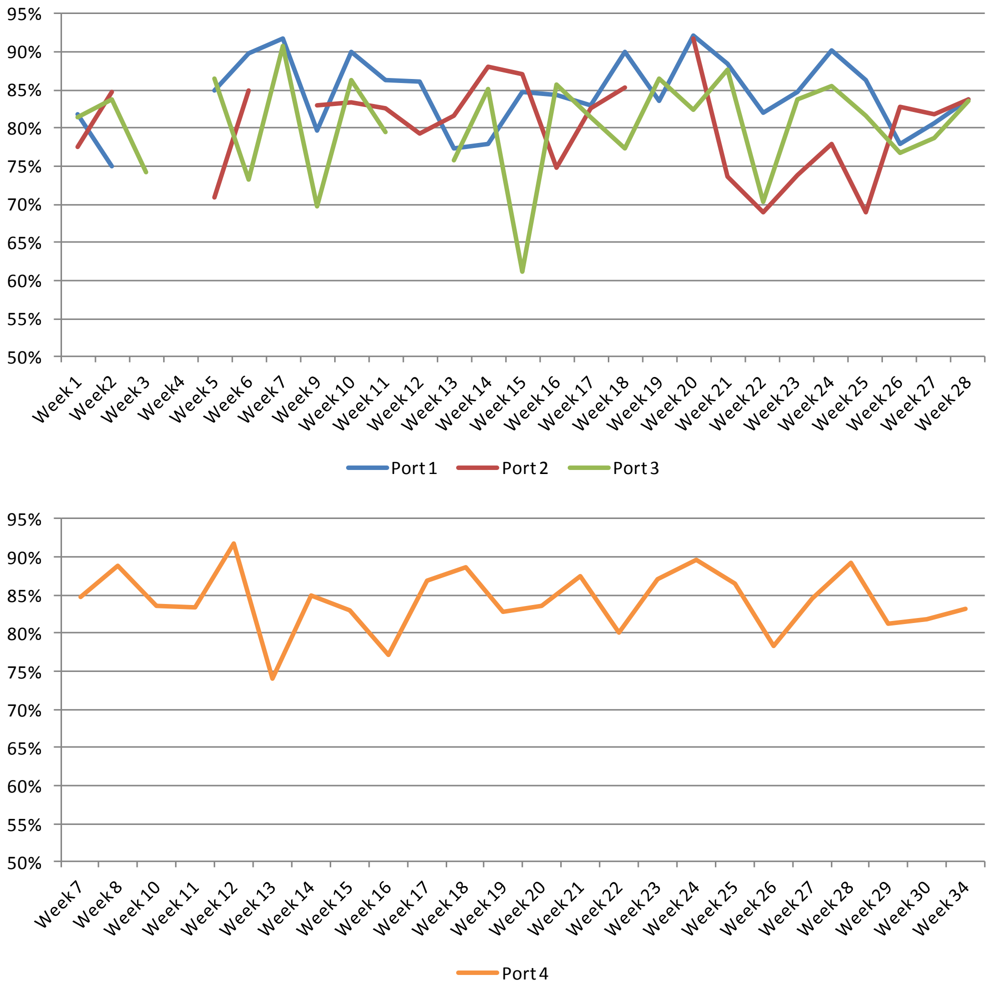

Figure 9.2. Average weekly efficiency score (Φ) per analysed fishing port.

9.4.2 Complementary DEA matrices

The analysis of the efficiency scores obtained in the complementary matrices (Table 9.4), those excluding the inclusion of input 3, does not show significant differences with respect to those obtained in the main DEA matrices. However, in all the ports on the Gulf coast a slight decrease was seen in the average efficiency for all individual vessels. The average scores per port were 2.7% (Port 1), 2.4% (Port 2) and 3.8% (Port 3) lower than the scores obtained when including spotter support. Concerning the standard deviation, it appeared to be slightly higher than in the main DEA matrices for all three ports, as seen in Table 9.4.

Table 9.4. Average efficiency scores (Φ_0) per fishing vessel for the complementary DEA matrices.

Port[1]	**Port 1**		**Port 2**		**Port 3**	
Vessel	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Vessel 1	83.6	±15.4	81.0	±13.8	71.6	±19.8
Vessel 2	75.5	±15.4	73.9	±17.0	77.1	±18.4
Vessel 3	85.4	±13.1	83.9	±16.6	81.9	±17.9
Vessel 4	72.5	±19.4	80.6	±20.8	70.4	±18.6
Vessel 5	84.3	±14.1	74.0	±15.2	72.9	±19.8
Vessel 6	84.7	±14.8	68.3	±20.8	94.1	±13.3
Vessel 7	86.7	±18.1	65.8	±19.7	70.1	±24.6
Vessel 8	78.7	±17.0	95.7	±7.9	74.3	±15.6
Vessel 9	73.8	±15.2	89.1	±12.1	--	--
Vessel 10	92.0	±10.5	67.9	±20.4	--	--
Average	81.7	±15.3	78.0	±16.4	76.6	±18.5

[1] Note that the results for Port 4 were excluded from this table due to the misreporting error for spotter support.

9.5. Discussion

9.5.1. Analysis regarding the existence of the skipper effect in the menhaden fishery

Inefficiencies in the fisheries targeting US menhaden detected through window analysis suggest the existence of a skipper effect in the four evaluated ports. In our hypothesis, we explicitly suggest that in a fleet of these characteristics, where close-to-identical vessels operate with similar patterns, the absence of a skipper effect would be visible in terms of low inefficiency rates in all vessels repeatedly through the assessed period. However, the results obtained show that no vessel attained efficiency (Φ=1) during the entire fishing season. Additionally, remarkably strong variances between vessels were identified, not only on an annual mean basis, as seen in Table 9.3, but also within each week of study. These strong variances between vessels could be attributed to random variation through time, if it were not for the fact that best performing vessels in each port managed to repeatedly perform at high efficiency rates throughout the selected period (see Tables F.1a-F.1d in Appendix I).

Moreover, one could go back to the assumption that there might be some non-quantified technical or operational feature that has been disregarded. However, all vessels assessed showed best performing patterns (Φ=1) in at least one week throughout the season, suggesting that the differences between vessels are due to the fact that some skippers, and by extension crews, are capable of maintaining high performance standards for the entire season, whereas skippers with higher inefficiencies were not able to retain desired performance rates. In fact, this argument is supported when crossing the standard deviation of vessels through time with the average individual vessel efficiency, as can be seen in Figure 9.3. In the three Gulf ports (Ports 1-3) there is a clear tendency that vessels with highest efficiencies show lower variability, while those with less skilfulness presented high standard deviations.

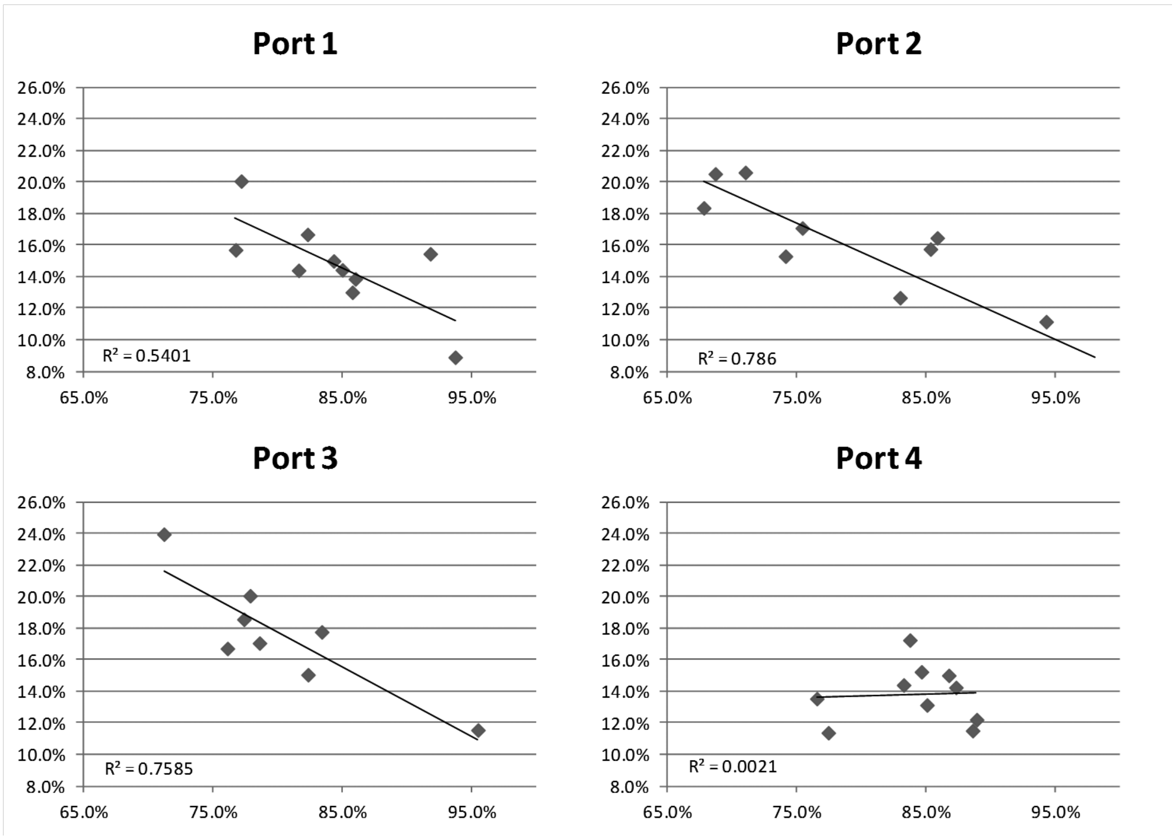

Figure 9.3. Efficiency scores standard deviations versus mean annual efficiency scores per vessel for the main DEA matrices.

The fact that port 4 does not show the same pattern is discussed separately given the systematic misreporting of an operational input in this particular fleet. Additionally, it is important to note that due to this error, the results when comparing the main and the complementary matrices of this fleet are the same, since inputs 2 and 3 are in the same proportion with respect to input 1 and the output. This situation only allows a discussion in terms of assessing the fishing vessels in terms of fuel consumption and number of sets used as compared to the catch.

As mentioned in section 9.4.1, results in this fishery presented different patterns to those in the Gulf coast. For instance, mean efficiency scores for individual vessels showed a lower range of values, although the average efficiency score of the fleet was similar to those of Ports 1-3, as well as lower standard deviations than the main DEA matrices results for the other three ports. This leads us to presume that there also is a skipper effect in the Atlantic menhaden fishery, but it is not manifested in a great variability between vessels through time, suggesting that simply the skippers in this port have similar performance abilities.

When this fleet is compared to the complementary DEA matrices of the other ports, that is, under the same input/output conditions, a shift in the patterns of the other three ports was expected towards those in Port 4. However, this was not the case, as seen in Figure 9.4. Vessels in these ports showed lower efficiency levels than those in Port 4, which could be linked to use of spotters being more crucial in the Gulf coast fishery. A final observation is the fact that the small tendency variations observed in Ports 1-3 for the complementary matrices with respect to the main matrices further supports the idea that skippers in Port 4 simply show comparable operation skills.

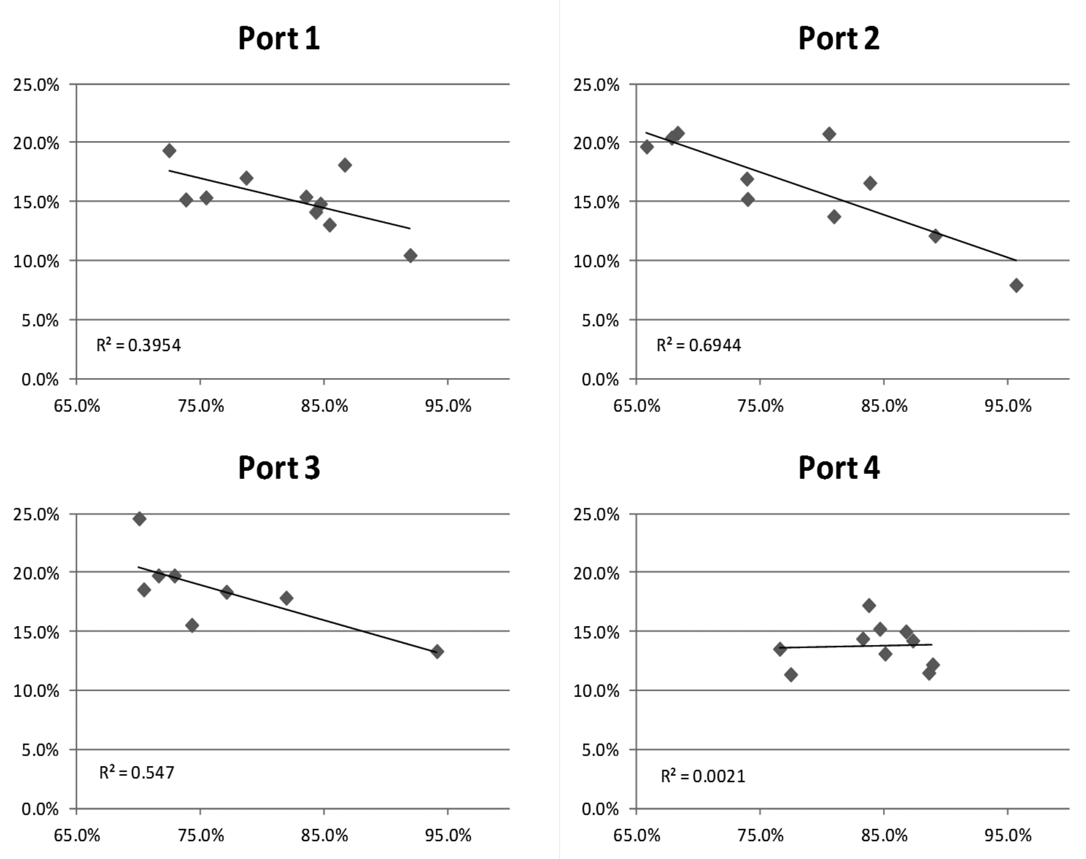

Figure 9.4. Efficiency scores standard deviations versus mean annual efficiency scores per vessel for the complementary DEA matrices.

The latter assumption leads to presume that besides the two notions that have been discussed in literature regarding skipper effect (Russell and Alexander, 1996), an alternative possibility may arise in certain cases. Therefore, on the one hand, the idea proposed by Thorlindsson (1988) stating that only a small elite of skippers outstand from the rest on a regular basis would be in accordance with the situation in Port 3, where one single vessel stood out above the rest. On the other hand, the approach launched by Barth (1966) and Heath (1976), that skippers show a hierarchical but static efficiency with respect to each other, closely reflects the situation observed in Ports 1 and 2. Moreover, an alternative scenario is reflected in Port 4, where the levels of inefficiency between vessels presented very short ranges, but significantly below the efficiency level. However, the existence of this third scenario would have been lost if the collected data had been computed on an annual basis, which reaffirms the difficulty of identifying skipper effect patterns.

Matrices without spotter support for the Gulf menhaden fleets showed lowered efficiency levels and higher standard deviations than the main matrices, but the distribution of the individual vessels with respect to others was more or less constant. This indicates that the use of spotter support seems to improve slightly their performance. Moreover, when the efficiency scores for the main matrices are crossed with the percentage of sets that were performed with spotter support (Figure 9.5) results suggest that those vessels with highest average efficiencies also have a lower dependency on plane spotters in two of the assessed ports. This finding would support the perception people have in the menhaden industry that despite the use of planes for spotting in the fishery, the skills of the skipper have a highly significant impact (Mr. Mike Wilson, VP fleet operations, Omega Protein Inc., 2001, personal communication; Ruttan and Tyedmers, 2007).

More specifically, the spotting of pods of eastern brown pelicans, which feed off menhaden fish in the Gulf of Mexico, has been found to be an interesting alternative to artificial spotting through planes now that these populations are recovering in the area (Hingtgen et al., 1985; Holm et al., 2003). While the use of pelican pods for guidance may not be the only factor that explains why vessels that perform more efficiently tend to have a lower dependency on spotters, it seems plausible that it is a major element in breaking down the sources of variability within vessels. However, and always subject to further research, it also seems credible to assume that skilled skippers will use both natural and artificial spotting techniques depending on their convenience, usually due to a set of environmental and technical circumstances that they will have to scale. In fact, this perspective may explain the absence of a clear relationship between spotter support and efficiency in Port 1.

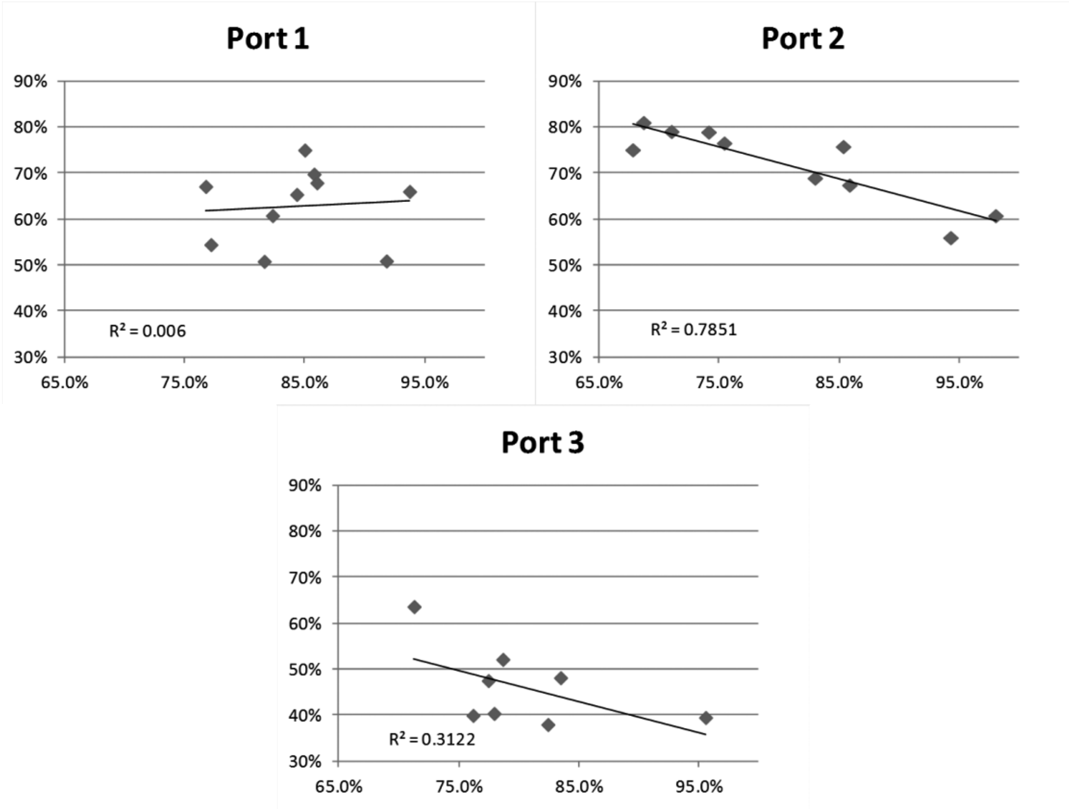

Figure 9.5. Average use of spotter support over the total amount of sets in terms of average efficiency scores (Φ) per vessel.

However, the fact that Port 1 does not show this same pattern is puzzling. Therefore, in this specific port there is a strong evidence for skipper effect, but it does not seem to be affected by the use of spotter planes. A possible explanation for this pattern could be linked to some type of environmental circumstance that affects this vessels in a particular way, making the use of spotters more important in order to attain improved efficiency levels (Ruttan and Tyedmers, 2007).

9.5.2. The role of skipper effect in other fisheries in efficiency and eco-efficiency determination

The potential inefficiencies that may occur in purse seining vessels, as observed in the current study, may not always be attributable to the lack of TE or to misreporting issues. In fact, in the current study these two factors have been reduced to a minimal expression thanks to the specific characteristics of the computed data. However, the existence of a wide variability of inefficiencies in a fleet with these features reveals that current fishing management regimes in North Atlantic and North American fisheries, which attempt to reduce the capacity of fleets in order to increase their efficiency, may be underestimating a whole set of human factors that complement the technical characteristics of fleets.

In other fishing fleets, such as trawlers or long liners, which depend more on stock distribution and abundance in a specific moment to a higher extent than purse seiners, the skipper effect seems less inclined towards causing relevant differences between vessels, given the lower potential for individual skipper tactics to make a difference during operation (Gaertner et al., 1999; Ruttan and Tyedmers, 2007).

The fact that efficiency in fisheries with high data quality (i.e., reducing misreporting to a minimum) may not be explainable in terms of TE or operational efficiency also creates an interesting scenario in the environmental assessment of these fisheries. Quantification of environmental impacts due to inefficiencies in vessels has been computed through LCA+DEA methodology in several fishing fleets (Chapter 8). The target reductions in the environmental profile of fishing vessels calculated in LCA+DEA would maintain their validity as a theoretical baseline, but in some cases, especially when the existence of a strong skipper effect is observed, these best performing targets may be difficult to achieve through resource minimization, unless specific measures are taken to improve the individual skills of low performing skippers and crews.

However, it is also true that in fisheries with heterogeneous characteristics the identification of inefficiencies attributable to skipper skills may be more difficult to detect, complicating the process of inefficiency breakdown in fisheries into its three main components: operational issues, mainly TE, the skipper effect, and misreporting or survey bias in data collection. Interestingly, and adding to this complexity, two opposing theories have been suggested in literature. On the one hand, certain researches argue that identifying skipper success as a key parameter in vessel efficiency may just be due to some sort of unmeasured technical characteristic (Hilborn and Ledbetter, 1985; Pálsson and Durrenberger, 1990). On the other hand, given that the skipper effect is made up of a series of skills that are complex to observe and describe, inefficiencies attributed to other factors such as TE may actually be part of the skipper effect (Russell and Alexander, 1996). For instance, the fact that larger vessels perform at higher levels of efficiency in a certain fishery, may reflect a skipper effect in itself, since the improved skills of the skipper may have provided the reward to steer a larger vessel (Gatewood, 1984; Russell and Alexander, 1996).

9.6. Conclusions

Revisiting the US menhaden fleet in order to analyse the visibility of variable skipper abilities in the efficiency of the vessels has helped confirm previous findings by Ruttan and Tyedmers (2007). In the first place, results reaffirm the existence of a skipper effect in all the analysed ports. Nevertheless, the differing patterns observed with respect to individual vessels in the evaluated ports demonstrated that skipper effect can be attested in different ways. For instance, skippers in the Atlantic fishery appeared to have resembling skills, while skippers in the assessed Gulf ports showed a wider range of abilities.

The confirmed importance of skipper effect in this fishery is expected to be of value for other fisheries and fishing fleets with similar characteristics, especially small pelagic species fisheries, where the instinct and knowledge of identifying shoals is highly relevant. In fact, DEA presents itself as a feasible tool not only to determine the overall efficiency of fishing vessels, but also as a valid tool to identify the specific sources of inefficiencies. Moreover, the results imply that policy-making and management in fisheries should pay closer attention to other issues besides capacity utilization when deploying vessels.

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SECTION IV

DISCARDS IN THE GALICIAN FISHING FLEET AND THEIR IMPLICATION IN LCA

Chapter 10

Estimating global discards and their potential reduction for the Galician fishing fleet (NW Spain)[1]

Summary

This chapter presents the first comprehensive estimation of discard amounts in the Galician fishing fleet, in order to provide an integral view of this increasing environmental problem on a regional scale. Subsequently, a series of improvement actions relating to discard minimization are suggested with the goal of enhancing the performance of the Galician fishing fleet. Discard estimates were constructed individually for the different Galician fisheries by aggregating primary data obtained from a total of 89 fishing vessels and secondary data for those fleets that were not directly sampled. Results showed that roughly 60,250 t of marine organisms were discarded by the Galician fleet in 2008, representing 16.9% of the total capture. Moreover, an important percentage of these discards were linked mainly to trawling vessels and to a lesser extent, to certain long lining fisheries. Therefore, improved management measures in target stocks should take into account the fact that alternative fishing gears other than trawl nets may reduce the amount of discards for certain species. This estimation may improve the assessment of stocks and help to quantify the damage that discards may have on wild ecosystems.

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[1] Vázquez-Rowe, I., Moreira M.T., Feijoo, G., 2011. "Estimating global discards and their potential reduction for the Galician fishing fleet (NW Spain)". *Marine Policy,* 35: 140-147

Index

10.1. Introduction

As mentioned in Chapter 1, EU policymakers are currently focusing on introducing the new CFP by the year 2013, in order to increase efficiency when it comes to ensuring that fishing pressure is not higher than stocks can sustain (European Union, 2006). According to the consultations carried out by the European Commission, there is a wide consensus that the ecological sustainability of fisheries must be one of the main targets of this new framework, in order to guarantee a viable fishing sector, together with economic and social objectives (European Commission, 2010).

In this context, MSY is highlighted as one of the main targets to be implemented by the new CFP. Accordingly, increased efforts must be made to guarantee a detailed stock assessment of the entire ecosystem, since most fishing areas not only present mixed fisheries landings, but also a high number of juveniles or non-marketable species that end up discarded (Catchpole et al., 2005; Kelleher, 2005).

The main reasons that lead fishing vessels to discard part of their catch are multiple. FAO divides these reasons into five main blocks: biological causes, legislative restrictions, market demands, fishing gear and vessel characteristics (Murawski, 1996; Stratoudakis et al., 1998; Tamsett et al., 1999; Kelleher, 2005). According to the latest FAO estimates, discards from 1992 to 2001 reached a total of 7.3 million tonnes annually, 8% of the total catch. The Northeastern Atlantic (FAO Area 27), with 1.33 million tonnes of discards per year, was found to be the region with the highest amount of discards, due mainly to high discard rates in certain EU fisheries (Kelleher, 2005).

Given that Galicia is the Spanish region with the highest number of fishing vessels and highest amount of annual landed fish (Xunta de Galicia, 2009), it is one of the main fishing regions on a European and worldwide scale. Consequently, Galicia may be a strategic area in which to implement schemes leading to increased discard reductions.

Trawlers, which have been highlighted as the vessels with highest discard rates in most fisheries, represent roughly 25% of total landings in Galicia (Alverson et al., 1994; Catchpole et al., 2005; Kelleher, 2005; Xunta de Galicia, 2009). This leads to the assumption that discards in the Galician fleet may represent an important proportion of the catch. Hence, the main objective of this study is to quantify the total discards generated by the Galician fishing fleet on an annual basis.

This analysis is of interest in order to identify possible improvement actions in the Galician fishing performance. Furthermore, primary discard data obtained for this specific study are compared with bibliographical data available. Finally, a series of suggestions to reduce discards through policy making are discussed in this chapter.

10.2. Materials and Methods

10.2.1. Scope of the study and calculation basis

As mentioned above, this study aims at calculating an estimate of the global discards performed by Galician fishing fleets. In accordance with the current distribution of the fleet, a series of vessels were selected to guarantee representativeness of the study, enabling the estimation of discards (absolute value) and discard rate (relative value) for the entire fleet referred to 1 year of activity.

Figure 10.1. Trawling vessels at the port of Celeiro (Galicia, Spain).

Hence, the estimate of discards has been calculated by aggregating primary data obtained through a series of questionnaires filled out by skippers from a wide range of Galician fleets, as seen in Section II of this dissertation, and secondary data obtained from bibliographical sources for those fleets that were not directly sampled. The sampling method, based mainly on questionnaires, was done in a confidential manner to the different skippers by a knowledgeable researcher. However, inexact discard reporting in logbooks and skippers that refused to cover the questionnaire may bias the results in some way (only one skipper refused to participate in the programme). Nevertheless, this sampling method has certain advantages over the use of trained observers. In the first place, it avoids hostile environments out at sea. Secondly, the presence of observers on board may vary the retention rate of the catch on board (Cotter, 2003). Finally, this method appeared to have reduced economic costs, enabling a broad study of the Galician fishing fleet (Lart, 2002). Therefore, the only realistic way to estimate the total discards was carried out by means of collection of samples by fishermen (through the vessels' logbook), referring when necessary to secondary data (Allen et al., 2001). These bibliographical sources are related to previous discard estimates made by FAO and other research groups.

10.2.2. Data acquisition

Discard reports were available for a total of 89 vessels from 6 different fishing fleets, as can be observed in Table 10.1.

Table 10.1. Brief description of the samples of the assessed Galician fishing fleets.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
Sample size	30	24	9	12	5	9
% over total	18.2	23.8	14.3	20.7	8.0	33.3
Year of inventory	2008	2008	2008	2008	2009	2009
Total landings (tonnes)	12,597	16,056	3,769	3,416	1,185	5,000
Target species	Pilchard	Hake	Megrim	Hake	Swordfish	Cephalopods
	H. mackerel	H. mackerel	Anglerfish	Fork beard	Blue shark	Flatfish
	A. mackerel	A. mackerel	Hake	Common ling	Porbeagle	Senegal hake
	--	Blue whiting	--	Atlantic pomfret	Bigeye tuna	--
Main reported discards	Juveniles	Hake juveniles	Pouting	Juveniles	Undersized individuals	H. mackerel
	--	Blue whiting	H. mackerel	Varied species	--	Chub mackerel
	--	Varied species[1]	Undersized individuals	--	--	Pilchard

[1] Varied species: non-commercial fish species, over quota target species or invertebrate organisms.

F1= coastal purse seiners; F2= coastal trawlers; F3= offshore trawlers; F4= offshore long liners (Northern Stock); F5= offshore long liners (Azores); F6= cephalopod trawlers (Mauritanian EEZ); H. mackerel= Atlantic horse mackerel; A. mackerel= Atlantic mackerel

A total of 30 purse seiners and 24 trawlers were assessed in the coastal fleets. Similarly, data regarding offshore fleets were also obtained. In this case, the skippers interviewed belonged to the Northern Stock fleet (12 long liners and 9 trawlers) and to the Azores long lining fleet (5). Finally, 9 vessels belonging to the cephalopod fleet in Mauritania were evaluated within this study. These values represent variable representativeness of the specific fishing fleets, ranging from 8% (Azores long lining fleet) to 33.3% (trawlers in the Mauritanian EEZ). Detailed information relating to the main landed and discarded species by the different fishing fleets is available in Table 10.1.

10.2.3. Assumptions

Recent estimates state that over 50% of world discards are performed by demersal and shrimp trawlers, which only account for 22% of world landings (Fernández et al., 2010; Kelleher, 2005). In this particular case study, three out of four Galician trawling fleets were evaluated. Therefore, it is assumed that assessed fleets guarantee a moderately accurate approach when estimating the discards for the total annual Galician fishing fleet. Furthermore, given the wide range of the study, the potential deviations linked to this assumption are considered low, since most of the fleets that were not directly evaluated have been considered low-discard fleets in previous studies (Alverson et al., 1994; Kelleher, 2005). A series of specific assumptions when calculating the discards of coastal, offshore and open sea fishing are indicated in the results section.

10.3. Results

10.3.1. Coastal fishing fleets

An estimation of the discards performed by the Galician coastal fishing fleets in the year 2008 was made by aggregating the discards of the four fleets that extract in this fishing area. Table 10.2 details the annual discards calculated for the different coastal fishing fleets individually. The first two fleets correspond to the evaluated fleets (coastal demersal trawling and coastal purse seining), whereas the individual discards for the remaining fleets (trolling and artisanal) correspond to rough estimations based on data obtained by the latest discard report from FAO (Kelleher, 2005).

Table 10.2. Total annual landed and discarded catch and discard rates for coastal fishing fleets.

Coastal fishing fleet	Landings (tonnes/year)	Discard rate (%)	Total discards (tonnes/year)
Trawlers	49,601	42.1	36,066
Purse seiners	43,154	3.2	1,408
Trollers	2,026	0.0	--
Artisanal vessels	16,855	3.6	645
Total coastal vessels	111,636	25.5	38,118

The assessed coastal trawlers showed an average and standard error discard rate of 42.1±3.3% by weight, the highest rate within the coastal fleets. This translated into 487±62 tonnes of discard annually for each vessel on average. When the discard rate for the assessed vessels is extrapolated to the entire landings reported by the coastal trawling fleet, a total of 36,066 tonnes of discards is obtained in this fleet. Skippers and fishermen from coastal trawlers reported discarding mainly juvenile hake and hake catches above the specified quota, together with smaller amounts of nonmarketable species and other varied juveniles.

The average and standard error of annual total catch for the coastal purse seiners was 433.6±33.8 tonnes per vessel, of which on average 3.2±0.2% by weight was discarded. Applying this discard rate to the entire landings of this fleet, the total discards sum up to 1408 tonnes. Discards in this fleet are mainly linked to European pilchard, Atlantic horse mackerel and Atlantic mackerel juveniles, low value species such as bogue and highly damaged or above quota individuals.

The trolling fleet was not assessed within this study for two main reasons. In the first place, all trolling vessels contacted reported no discards with this fishing gear. Secondly, all bibliography relating to trolling fisheries agrees that insignificant discards are reported worldwide for this fishing gear (Findlay and Searle, 1998; Sánchez and Olaso, 2004; Kelleher, 2005). Therefore, a discard rate of zero was applied to all the landings performed by this fishing fleet.

Finally, the increased size of the artisanal fleet in Galicia and its heterogeneity made any type of evaluation complicated from an economic point of view (Freire and García-Allut, 2000; Bundy and Pauly, 2001; Kelleher, 2005; Batista et al., 2009). This leads to estimate discards related to small-scale or artisanal fishing fleets on the basis of the most current FAO report (Kelleher, 2005). Hence, an aggregated discard rate of 3.7% was assumed, which translates into 645 tonnes of discards.

The total discards estimated for the whole coastal fishing activity in Galicia were 38,118 tonnes, representing a global discard rate of 25.5%. Tables B.1 and B.2 in Appendix I provide additional information regarding individual vessel discards for the sampled vessels.

10.3.2. Offshore fishing fleets

Table 10.3 presents the total discards for the three offshore fishing fleets. The trawling vessels that were assessed from the Northern Stock (ICES Divisions VIIIabd and VII) discarded on average 321±74 tonnes annually. The 66 vessels from this fleet discarded 13,064 tonnes, representing 43.5±3.5% of captures. Most of this discards corresponded to hake and megrim juveniles, low value species such as horse mackerel and pouting and non-marketable species.

Table 10.3. Total annual landed and discarded catch and discard rates for offshore fishing fleets.

Offshore fishing fleet	Fishing area	Landings (tonnes/year)	Discard rate (%)	Total discards (tonnes/year)
Trawlers	Northern Stock	16,969	43.5	13,064
Long liners	Azores	3,376	8.1	298
Long liners	Northern Stock	18,786	1.7	315
Total offshore vessels	--	39,131	25.9	13,677

Long liners in this same area discarded 1.7±0.2% of their catch (315 tonnes of discard for the entire fleet). Finally, long liners in the Azores (ICES Area X) have an average discard rate of 8.1%. For both long lining fleets, skippers reported discarding exclusively small size target species (e.g. swordfish individuals below 25 kg are banned for landing in the Azores fishery). Table D.1 and G.1 in Appendix I include further details regarding individual sampled vessels. Annual discards sum to a total of 13,677 tonnes, which represents 25.9% of the total catch for the assessed fleets.

10.3.3. Open sea fishing fleets

Table 10.4 presents the total discards generated by open sea fleets. The highest discard rates correspond to the trawling fleets in Mauritania and in NAFO (19.5% and 11.3%, respectively). Purse seining fleets in the different oceans, targeting mainly different tuna varieties, present discard rates that range from 4.1% in the Atlantic Ocean to 5.9% in the Pacific Ocean. Data for all these fleets, except for the Mauritanian trawling fleet, do not correspond to direct analysis, but to the latest discard estimates performed by FAO (Kelleher, 2005). The sum of all the open sea fleets adds up to a total of 8460 tonnes of discards per year.

Table 10.4. Total annual landed and discarded catch and discard rates for open sea fishing fleets.

Offshore fishing fleet	Fishing area	Landings (tonnes/year)	Discard rate (%)	Total discards (tonnes/year)
Tuna purse seiners	South-Atlantic Ocean	38,038	4.1	1,626
Tuna purse seiners	Indian Ocean	70,800	5.0	3,726
Tuna purse seiners	Pacific Ocean	26,068	5.9	1,634
Trawlers	Mauritanian EEZ[1]	1,909	19.5	462
Trawlers	NAFO[2]	7,934	11.3	1,011
Total open sea vessels	--	144,748	5.5	8,460

[1] EEZ= Exclusive Economic Zone.
[2] NAFO= North Atlantic Fisheries Organization.

10.3.4. Galician fishing fleets as a whole

The lump sum of the discards for coastal fishing, offshore fishing and open sea fishing provides the global discarded amount for the entire Galician fishing fleet (Figure 10.2). Thus, 60,255 tonnes per year are attributed to the whole Galician fishing activity. Coastal fishing turned out to be the fishing fleet with the highest number of discards (63.3% of total discards). Conversely, offshore fleets showed a higher average discard rate (25.9%) than coastal fleets (25.5%) and open sea fleets (5.5%). Further analysis on these values is presented in section 10.4.

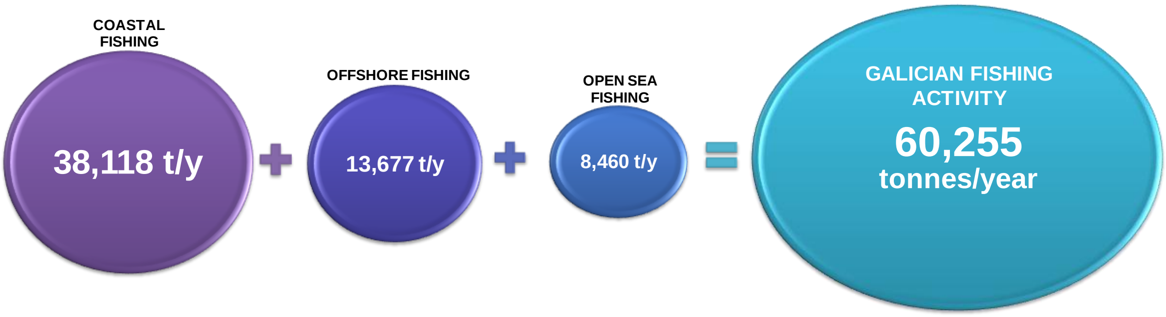

Figure 10.2. Total discards estimated for the Galician fishing fleet (tonnes per year).

10.4. Discussion

10.4.1. Identification of major discards in the Galician fleet

The results obtained in this study confirm a series of patterns regarding discards worldwide. In the first place, the increased discard rates obtained for the three assessed trawling fleets confirm that fishing vessels that use this type of gear are responsible for an important part of discarded material, independently of the fishing zone or other factors (Catchpole et al., 2005; Kelleher, 2005; Fernández et al., 2010). Nevertheless, the data provided by skippers of these three trawling fleets is substantially lower than that of bibliographical data obtained for these fishing fleets in previous years, as can be seen in Table 10.5 (Kelleher, 2005).

Table 10.5. Estimated discard rates from the current study and those from the FAO report 470.

Fishing fleet	Discard rate (%) Kelleher (2005)	Total discards (tonnes/year)	Discard rate (%) Current study	Total discards (tonnes/year)
F1	1.6	702	3.2	1,408
F2	54.0	58,227	42.1	36,066
F3	69.0	37,769	43.5	13,064
F4	8.2	1,678	1.7	315
F5	22.0	952	8.1	298
F6	45.0	1,562	19.5	462
Total	--	100,890	--	51,613

F1= coastal purse seiners; F2= coastal trawlers; F3= offshore trawlers; F4= offshore long liners (Northern Stock); F5= offshore long liners (Azores); F6= cephalopod trawlers (Mauritanian EEZ).

The interpretation of results when comparing the estimated discards obtained in this study and those calculated by Kelleher (2005) must be done with caution because (i) FAO does not provide fleet-specific discard rates for Galicia; (ii) discard rates estimated by FAO correspond to the average rate between 1992 and 2001, whereas the discard data from the assessed fleets are more updated and refer to the year 2008; (iii) the proposed sampling method in this case study is based on fishermen reporting by direct questionnaires and logbooks, while FAO uses a variety of sampling techniques to perform the estimations; (iv) the sample sizes for the assessed fleets are larger and more specific than those reported by FAO thanks to the reduced size of the different Galician fleets. Moreover, taking into account that Alverson et al. (1994) estimated an average of 27 million tonnes of discards worldwide in 1994, and the estimation conducted by Kelleher (2005) ten years later lowered the discards to 7.3 million tonnes annually, it is expected that the results from the current study should also show a further reduction in discards. Some of the reasons for this decline include the increase of gear selectivity, the decrease in fishing effort, the shift to new target species in many fisheries, especially trawling fisheries, or legislative changes in order to introduce former discarded species into the market (Murawski, 1992; Davies et al., 2009).

In this context, the trawling fleet in the Northern Stock was the fleet in which the highest proportion of discards was identified. Nevertheless, the average discard rate (43.5%) is considerably lower than the rate attributed to this fleet in the latest FAO report (69%). The lower discards reported for 2008 may be linked to the fact that higher controls and surveillance have been implemented in the Northern Stock in order to increase the sustainability of some species, such as hake, increase of mesh size and higher temporary fishing bans (Fernández et al., 2010; MARM, 2008). Nevertheless, it would be interesting to compare discard rates of this fleet with similar fleets from France and United Kingdom, in order to assess how quota restrictions (stricter for Spanish vessels) may affect, not only discards themselves, but also their composition.

The coastal trawling fleet also shows reduced proportion of discards in the evaluated sample when compared to FAO projections. In this case, FAO estimated an average discard rate of 54% for demersal trawlers in the Cantabrian Sea. Skippers belonging to this fleet reported discarding great amounts of hake and, to a lesser extent, of Atlantic mackerel due to quota restrictions. However, it is important to note the change that this fleet has undergone in the past few years regarding the target species, shifting landing composition to smaller species and lower down in the trophic chain. Therefore, species such as Atlantic mackerel and horse mackerel, which were discarded by this fleet in the past, have now begun to be target catch (Kelleher, 2005; Davies et al., 2009).

The reported discard rate for cephalopod trawlers in Mauritanian waters was 19.5%, 25 points lower than that reported by FAO for Northwestern Africa. Despite the increased reporting difference, these two values prove that demersal trawling of cephalopods in Mauritania has a lower discard rate than shrimp trawlers: 80% (Kelleher, 2005) and a higher rate than pelagic trawlers in this area: 9.9% (ter Hofstede and Dickey-Collas, 2010).

All other fisheries assessed showed much lower discard rates than demersal trawlers. Nevertheless, as observed for trawling vessels, the discard rate for all these fleets, except for coastal purse seiners, was considerably lower when reported discards by skippers were used. In this way, Northern Stock and Azores long liners show a reduction of 79.3% and 63.2%, respectively, in the annual discard rate. Finally, the reported discard rate for purse seiners (3.2%) is higher than that reported by Kelleher (1.6%).

10.4.2. Contrasting the final values

A series of individual discard rates were obtained for a wide range of fishing fleets in Galicia. Discard rates ranged from insignificant rates (coastal trolling fleet) to 43.5% (offshore trawling fleet) of total catch. According to previous studies relating to discard rates in European fisheries, the results for individual fleets are within usual ranges (Alverson et al., 1994; Catchpole et al., 2005; Kelleher, 2005; Catchpole and Gray, 2010; Fernández et al., 2010). Nevertheless, they show a clear decreasing tendency, linked, as mentioned above, to technological improvements in gear selectivity and to shifting target species (Kelleher, 2005). Moreover, the higher discard values observed for offshore and open sea fleets when compared to similar fleets in coastal areas may be linked to the lower profitability of landing low value species (e.g. horse mackerel) by offshore fleets.

Additionally, the current study not only estimates the discard rates for the individual Galician fishing fleets, but also provides an overall estimation for the entire Galician fleet as a whole. Comparing the total discards estimated for Galicia in 2008 with previous worldwide-level FAO studies (Alverson et al., 1994; Kelleher, 2005) enables a global interpretation of the calculated discard amounts. For instance, the total discards amounts estimated by FAO (Kelleher, 2005) for Area 27 were 1.33 million tonnes. Hence, the entire Galician fishing fleet would represent 4.5% of the discarded amounts linked to Area 27. This is a significant amount considering the difference between regional and continental scale.

10.4.3. Environmental impacts identified through fishery-specific impact assessment

One of the main problems of the current CFP is the myopic view that it has when assessing stocks, usually focusing on individual species rather than on an integrated analysis of the ecosystem.

Furthermore, the final annual quotas for the different species within European waters, though based on scientific reports, are usually amended by EU member states in order to obtain economic and political benefits, resulting usually in higher fishing quotas than recommended by experts (Oceana, 2005; Clover, 2006). Moreover, current Spanish legislation in fishing issues is based mainly on enforcing quota limitations and temporal or permanent fishing bans in the frame of the EU's CFP.

Another increasing problem is the lack of stock assessment when the EU signs fishery agreements with developing countries, such as Mauritania, Guinea or Senegal (Platt-McGinn, 1998). Even though some of these are increasing their management measures, the EU has based these agreements on merely commercial treaties in order to reduce overfishing within European seas and to pursue new fishing possibilities to relocate the great overcapacity that exists in the European fishing fleet (Kazcynski and Fluharty, 2002).

This context leads to a situation in which a high number of political decisions disregard the increased amount of discards that their implementation may generate. Even admitting, as stated in several FAO reports (Alverson et al., 1994; Kelleher, 2005), that there are a series of "good" discards that must be identified (species with high survival rate, mammals, species in danger of extinction, etc.), previous studies highlight the low survival rate of most discards (Evans et al., 1994; Lindeboom and de Groot, 1998; Wileman et al., 1999; Cappell, 2001), including a high rate of juvenile mortality (Kelleher, 2005).

Consequently, authorities must focus efforts on introducing policies that encourage vessels, mainly those with higher discards (e.g. demersal trawlers), to reduce them. In the first place, fixing variable daily quotas for different fishing species, which is implemented mainly to maintain fish auction prices stable throughout the year, increases the amount of discards (Hall et al., 2000). Therefore, an integrated quota in which a maximum total quota can be reached daily, without focusing entirely on the composition of the catch may be an alternative. This would permit skippers to land all marketable fish, without having to discard individuals above quota. Furthermore, once annual quota is covered for a certain species, as occurs frequently, vessels would have to stop targeting and catching this species. This combination may help increase catch quality and value, while reducing discards and fishing effort. Nevertheless, annual quota should also implement integrated mechanisms in order to better manage mixed fisheries.

The case study described in Chapter 3 has shown that along the Galician coast there are a series of fleets targeting the same species, with highly different environmental impacts, not only relating to discards, but also to other issues, such as fuel consumption by vessels (see Chapters 3 and 8). For instance, the coastal trawling and seining fleets target a series of species in common, such as horse mackerel and Atlantic mackerel, with a great difference in environmental impacts, especially discards. Additionally, this situation also occurs in offshore and open sea fisheries, such as the hake fishery in the Northern Stock. In this case, the trawling and long lining fleets share the quota for hake. Therefore, a redefinition of target species by fishing fleet may be an interesting legislative action to enforce discards reductions.

10.4.4. Methodological advances

Even though the estimation of discards in this study attempts to give a global perspective of this environmental impact on fishing stocks, it is important to highlight a series of methodological barriers when evaluating its effects.

In the first place, as already mentioned, other sampling methods may be implemented in order to obtain a more precise vision of catch management. However, these methods will always translate into high economic costs that may not be affordable when evaluating an increased fleet size, as in the proposed case study.

Secondly, the exclusion of offal residues when assessing discards, as defined and recommended by Alverson et al. (1994), highly influences the obtained results. Consequently, it may be interesting to analyse the amounts of offal that are discarded by offshore and open sea fleets (coastal fleets usually land round individuals) when gutting individuals in on board processing activities (Fet et al., 2010).

Thirdly, another important methodological constraint relates to what skippers and fishermen understand by discards. Most of the consulted crews reported including only discards related to fish and mammals, whereas other species, such as invertebrates are usually not considered in the logbooks.

Finally, an environmental assessment of the Galician fishing fleets based exclusively on discards may be misleading, since other environmental impacts may highly determine the global impacts related to a fishing fleet or fishery. In this context, discards have recently started to be included in more comprehensive environmental management studies, such as LCA studies as an additional environmental impact that should be analysed when globally evaluating the environmental burdens linked to any fishery, as seen in Chapters 3-6 (Ziegler et al., 2003; Pelletier et al., 2007).

10.5. Conclusions

Detailed estimations on global discards relating to the Galician fishing fleet are encouraged in order to improve global stock assessments and to quantify the damage that discards may have on wild ecosystems. Nevertheless, as far as we have been able to ascertain, this study constitutes the first integral research relating to global discard rates for the entire Galician fishing fleet. Obtained results prove the leading role of demersal trawlers in discard generation in the Galician fishing fleet, certifying that improved management measures in target stocks must take into account that alternative fishing gears other than trawling nets may reduce the amount of discards for certain species (e.g. hake or horse mackerel).

10.6. References

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Chapter 11

Insights in the inclusion of discards indicators in fisheries LCA[1]

Summary

Specific discard indexes are proposed in this chapter to deepen in the development of fisheries LCA studies. The global discard index (GDI) is intended to be an easily understood index whose use is extendible to any fishery in the world. It is presented as a dynamic index that aims at characterizing and normalizing discard rates between fisheries by direct comparison with the global discard rates reported periodically by FAO. Additionally, a simplified approach excluding characterization is presented for scenarios in which the data quality linked to discard reporting are not as detailed as desired. Finally, two additional indicators, survival rate of discards and slipping, are proposed to improve the reporting and quantification of biomass waste by fishing vessels.

GDI implementation showed remarkable differences in the environmental impacts of several fishing fleets when compared with the obtained results when considering conventional LCA impact categories. Results for conventional impact categories were strongly influenced by the energy use in the fishery, while results obtained for fishery-specific categories presented variable trends due to the dependence on a wider range of factors. More specifically, GDI inclusion not only favoured discard normalization in fisheries LCA, but also allowed direct comparison with worldwide average discard rates on a time scale basis, from a wet weight or a net primary productivity perspective, depending on the selected approach.

The proposed indicators achieved the important objective of integrating discard data as a fishery-specific impact in fishery LCA studies. Furthermore, the proposed methodology aims at increasing the benefits of implementing LCA studies in fisheries assessment. Specific advantages of these indexes include changes in capture and landing composition evaluation, assessing the selectivity of the fishing gears and monitoring the behaviour of a particular fishery in a normalized context respect to other fisheries.

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[1] Vázquez-Rowe, I., Moreira, M.T., Feijoo, G., 2012. "Inclusion of discard assessment indicators in fisheries Life Cycle Assessment studies. Expanding the use of fishery-specific impact categories". *International Journal of Life Cycle Assessment,* accepted for publication.

Index

11.1. Introduction

Seafood LCA studies in recent years have included certain issues regarding biological issues. In this sense, several publications have discussed the inclusion of new impact categories, which include: seabed disturbance (Thrane, 2006; Nilsson and Ziegler, 2007; Ziegler et al., 2003; Ziegler et al., 2009); biotic resource use (BRU), first included in aquaculture studies as NPP (Aubin et al., 2009; Papatryphon et al., 2004; Pelletier et al., 2009), but also implemented by Parker (2011); by-catch of non-target organisms (Ziegler et al., 2003; 2009); assessment of prematurely caught organisms (Emanuelsson, 2008; Ziegler et al., 2009); and discard quantification (Ziegler et al., 2011). However, it is important to remark that these newborn impact categories are yet to be standardized.

This situation shows that seafood LCA is slowly shifting to a more comprehensive framework for the environmental analysis of fisheries in terms of impact categories, in order to provide stakeholders with a more robust assessment to help them make choices (Ford et al., 2012). Yet some of these categories have been limited to reporting inventory data per FU, which hinders the comparability between regions and processes (Milà i Canals et al., 2007). This is the case when reporting discard data. To our knowledge, LCA reports including these data have referred to this impact by accounting the total discard per FU. While discard quantification in fisheries LCA is a positive milestone, a current challenge is to deepen in the specific environmental impacts that discards may generate once discharged from fishing vessels.

Therefore, the ultimate goal of this chapter focuses on the proposal of a new set of potential indexes for use in fisheries LCA, combining the use of midpoint and endpoint level indicators (Bare et al., 2000). Specifically, the global discard index (GDI) is presented as an indicator that attempts to characterize and standardize discards in worldwide fisheries. To achieve this objective, two different approaches are suggested depending on data availability and quality. Additionally, an environmental assessment of a selected group of fishing fleets is developed including GDI and other fishery-specific impact categories.

11.2. Framework

11.2.1. Marine discards: an unresolved environmental problem in world fisheries

Discards, as mentioned in chapter 10, are an increasing matter of concern within the scientific community due to the enormous amounts of fish and other marine organisms that are returned to the ocean dead or damaged, and, therefore, may alter the ecosystem (Stephen and Harris, 2010). According to the latest report published by FAO (Kelleher, 2005), the global marine discard rate in 1992-2003 was 8.0% (7.3 million tonnes per year). Motives for discards can be very varied and may be different from one fishery to another. Most of these reasons, detailed in Table 11.1, are linked to environmental factors, to the gear used by the vessel and to a set of fishermen behavioural patterns, which may be influenced by management and economic issues (Catchpole et al., 2011).

Table 11.1. Reasons for discarding in worldwide fisheries (adapted from Clucas, 1996).

Motive	Explanation
Resource motives	
Incorrect species	Not a target species for the vessel.
Size requirements[1]	Certain individuals may be discarded for multiple reasons.
Sex	Gender may be relevant in processing and marketing.
Damaged fish	Due to mis-handling, predation or gear.
Incompatibility	Could damage other species on board.
Poisonous species	Poisonous or inedible species.
Species spoils fast	This could accelerate spoiling in other species.
Management motives	
Space limitations	Usually temporal and economic scaling gives way to selectivity.
Fishing quotas	Discarding individuals above maximum quota.
Prohibition	Illegal to land a certain species.
Season limitations	Some species are not allowed to be landed in specific times of the year, due to spawning, etc.
Gear limitations	Some species can only be caught with specific fishing gears.
Fishing grounds	Existence of administrative or protected areas where caught fish cannot be landed.
Economic motives	
High grading	Sometimes related to size. Individuals with less chances of been placed in the market will be discarded.

[1] Size requirements, despite having strong marine resource implications, can also be due to management and economic motives.

Moreover, a wide range of studies indicate that high mortality rates can be observed in discarded organisms, especially within fish species (Cappell, 2001; Catchpole et al., 2006). In this context, the direct effect on the marine ecosystems originated by discard mortality has been analysed by a wide range of research studies (Afonso et al., 2011; Benoît et al., 2010; Lindeboom and de Grott, 1999; Mesnil, 1996). In most cases, discard mortality has proven to i) reduce species diversity in fisheries worldwide (Greenstreet et al., 1999); ii) produce considerable variations when analysing the relative abundance of species (Jennings et al., 1999); and iii) modify interactions between species (Christensen et al., 2003). However, it is also important to point out that the fishing mortality of discards has proven to vary depending on the used gear, since they infer different grades of damage on the catch (Lindeboom and de Grott, 1999).

Despite the scientific community agreeing on the fact that removing great quantities of non-desired biomass from world fisheries is unnecessary and in many cases harmful, the consequences of discarding are still unknown to a great extent (Cook, 2001; European Commission, 2004; Kelleher, 2005). Nevertheless, current policies consider that the lack of knowledge relating to discard effects should not delay improvement actions in the fishing sector to reduce the amount of biomass discarded every year (Anon, 1999; Anon, 2002; Catchpole et al., 2005; Catchpole and Gray, 2010; European Commission, 2010).

Despite the fact that discarded marine organisms essentially belong to the same natural resource as the landed fish species, it is important to note that discards are a direct waste disposed off in the fishery, while landed species are transformed into an industrialized product on land. Therefore, the scientific community agrees on affirming that, independently of the catch and quota reductions that may have to be implemented, it is desirable to reduce the amount of discards respect to the total amount of captured fish, preferably improving catch selectivity rather than increasing the optimization of possible discards (Cook, 2001; Kelleher, 2005; Catchpole and Gray, 2010). Hence, the perspective taken in this study, which is in accordance with previous LCA studies, is based on considering discards and landed fish as two separate outputs obtained from the environment (Thrane, 2004; Ziegler et al., 2011).

11.2.2. Specific framework for fisheries in LCA

When an LCI is conducted in LCA for fisheries, an accurate study requires the assessment of a representative number of vessels. Furthermore, to date discards had not been included in many studies given the difficulty to retrieve the data and the lack of a well-established mechanism to include this aspect in LCA (Weidema and Wesnaes, 1996; Reap et al., 2008). Hence, a situation in which discard rates are reported and sample representativeness is guaranteed will permit LCA practitioners to include discard data in their case study.

Additionally, it is important to take into account that discards are not taken into account as a co-product when analysing the environmental burdens linked to the products. Therefore, discards are not computed when allocating impacts to the different products, since they are immediately returned to sea once their inappropriateness for landing is identified. In other words, it would not be desirable to attribute a specific environmental impact for conventional impact categories to discarded fish, since it would only reduce the associated impacts to the landed species, giving a misleading approach regarding the environmental profile of the marketable products.

11.3. Proposed indicators

To date, discard calculation in seafood LCAs was limited to reporting the amount of generated discards per FU (Ziegler et al., 2009). This chapter attempts to develop methodological advances on how LCA studies may integrate discard data as an index rather than a mere value accompanying other impact categories.

A total of three indicators have been proposed as indexes for discarding in fisheries. In the first place, the global discard index (GDI) is presented as a dynamic midpoint indicator to understand the relevance of discarding in a particular fishery (Figure 11.1). Secondly, the survival rate of discards, an endpoint indicator, is discussed with the aim of integrating this factor in the assessment. A third indicator is linked to slipping operations in many purse seining fisheries. Finally, discussion on the potential impact that marine discards have on seabird populations is provided. The selected case study, developed in section 11.4, only includes GDI computation due to data availability limitations. Nevertheless, examples are provided for the other indicators when discussed.

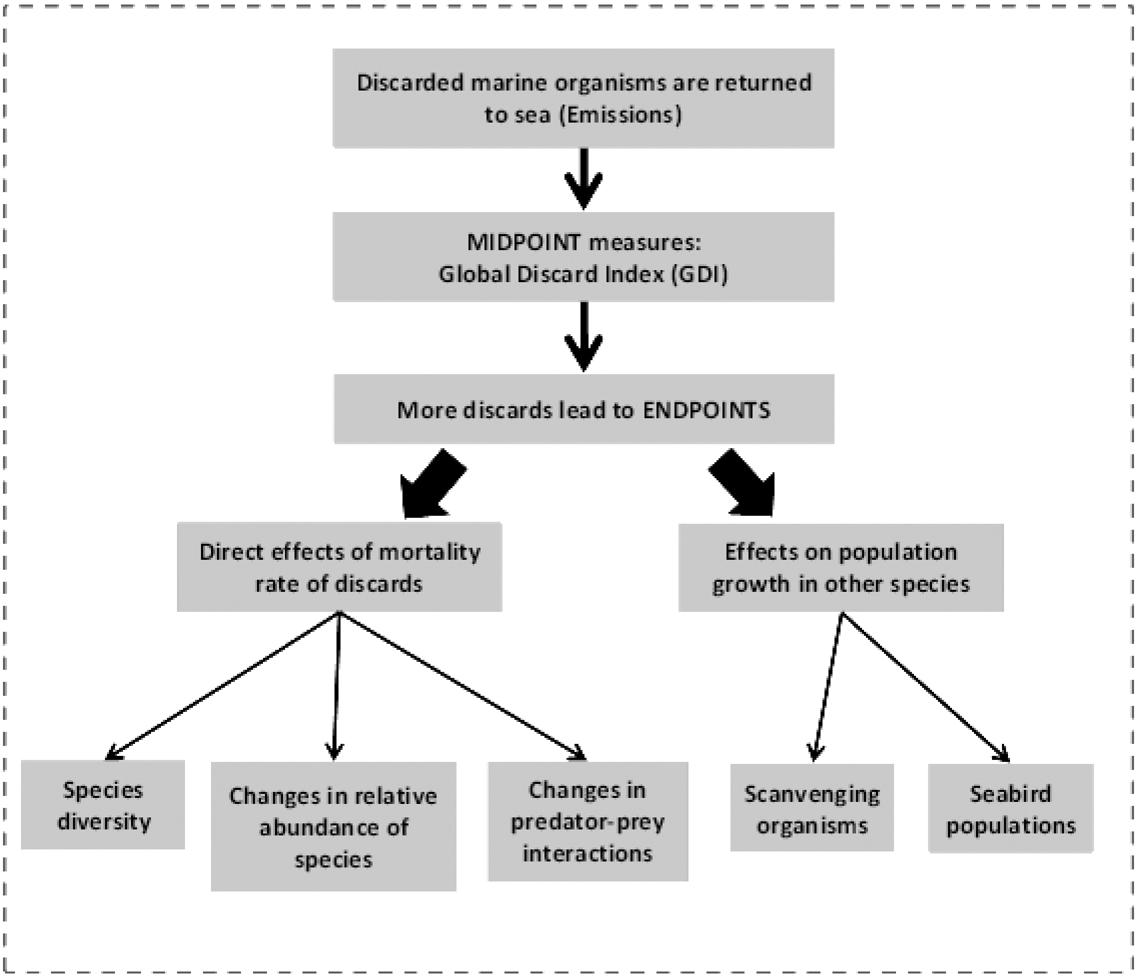

Figure 11.1. Midpoint and endpoint modelling scenarios concerning discards in LCA.

11.3.1. Global discard index (GDI)

Goal and scope

GDI is intended to be a straightforward indicator whose use is extendable to any fishery in the world to introduce discard quantification in fishery LCAs. A general flow diagram, including the relevant system boundaries can be observed in Figure 11.2. The methodology is based on the comparison of the discard rate for a certain fleet with the average worldwide discards considered as a reference value. For this, the latest available global discard rate reported by FAO is used as the reference set since it is considered the most accurate and current value (Kelleher 2005). Nevertheless, this value corresponds to data reported at least 8 years ago, showing that global discard rates are usually available with a significant time delay (Alverson et al. 1994; Kelleher 2005). Moreover, these average values are important reference points for fishery certification programs (Thrane et al. 2009). As summarized in Figure 11.3, the proposed methodology comprises three major stages.

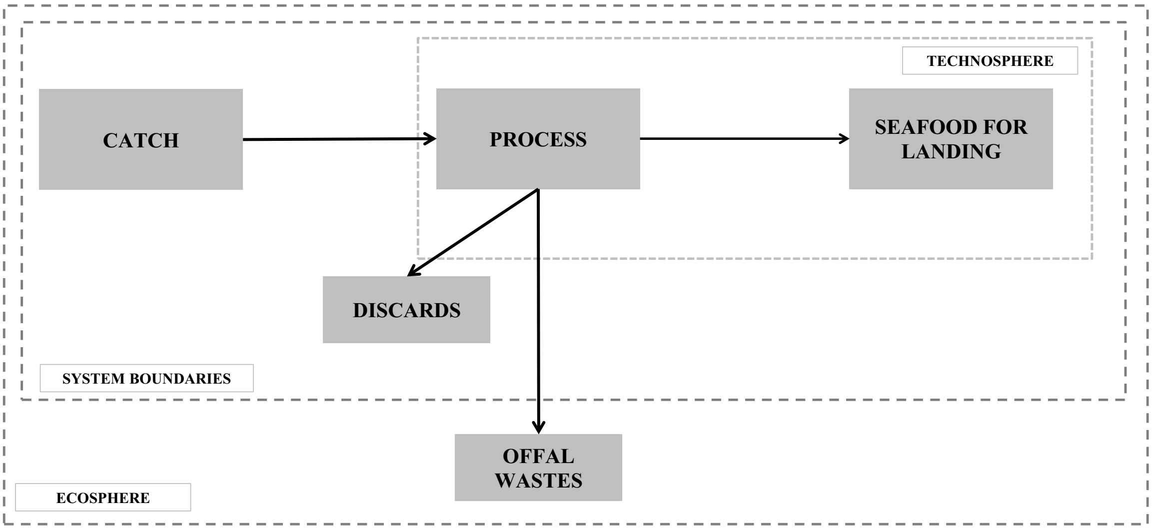

Figure 11.2. Generic unit process for discards in fisheries and system boundaries.

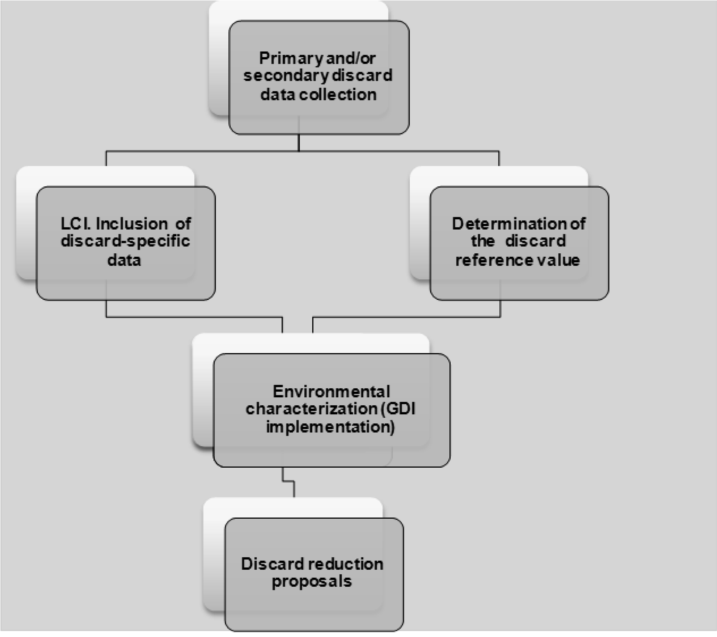

Figure 11.3. Schematic representation of GDI implementation in fishery LCA methodology.

Required inventory data

The first step when using GDI in fishery LCAs is to obtain all the necessary data for LCI computation. Hence, apart from the regular inventory data required to carry out fisheries LCAs, it is important to include discards, catch rate and the landing rate of the captured species, as detailed in Table 11.2. Discard reporting should follow the definition for this term given by FAO Report N° 547 (FAO 1996).

Table 11.2. Required life cycle inventory items for GDI computation.

Inputs from nature		
Items	**Requirements**	**Indicator**
Fish catch from fishery	Fish species disaggregation (mass)	GDI_{BRU}/GDI_{mass}
	Mean trophic level per species	GDI_{BRU}
Outputs to the technosphere		
Items	**Requirements**	**Indicator**
Landed catch	Fish species disaggregation (mass)	GDI_{BRU}/GDI_{mass}
Outputs to nature		
Items	**Requirements**	**Indicator**
Discards	Fish species disaggregation (mass)	GDI_{BRU}/GDI_{mass}
Additional required information		
• Updated global discard rate from a feasible data source.[1]		

GDI= global discard index; BRU= biotic resource use.

[1] The specific data source for this research was FAO (Kelleher, 2005).

Discard reference value and approach selection

Once the LCI is complete, it is necessary to determine the reference value that will be used when implementing GDI. As mentioned above, the recommended reference value is the global discard rate (GDR) estimated by Kelleher (2005) since it is currently the most updated global discard value. Furthermore, the use of two different approaches when using this reference value is proposed.

- Biotic GDI method [$\mathrm{GDI_{BRU}}$]. This approach is based on converting the obtained capture and discard data into BRU values, to report final results in terms of removed carbon that was fixed through photosynthesis. $\mathrm{GDI_{BRU}}$ involves a characterization phase in which the discarded fish are characterized in terms of NPP, as in a regular BRU calculation procedure, prior to normalization at a world scale.

  For $\mathrm{GDI_{BRU}}$ calculation, it is necessary to convert the global discard rate and the global landing rates estimated by Kelleher (2005) into net primary production, as shown in equation 1 (Pauly and Christensen, 1995), where PPR stands for the primary production required and TL for the average trophic level of the selected sample. The selected unit to report PPR calculation was mass of carbon per live weight of fish (g C/kg fish, wet weight).

  $$\mathrm{PPR}=[\mathrm{Catch}/9]\times 10^{(\mathrm{TL}-1)} \qquad \text{eq.[1]}$$

  The MTL selected for landing rates was set at 3.1, as reported by Pauly et al. (1998a). There are certain limitations when using this number, however, since it may not reflect the current state of world fisheries. Moreover, recent studies suggest that the trophic level of marine webs is underreported through current calculation methods based on catches (Branch et al., 2010; Caddy et al., 1998). Regarding the mean trophic level for discards, no specific data on a global scale were retrieved from the literature. Furthermore, despite detailed tables in Kelleher (2005) describing the major discarded fish in globally relevant fisheries, no data linked to actual discard breakdown were available. Therefore, the mean trophic level for discards was also assumed to be 3.1 (Pauly et al., 1998a). Nevertheless, any new data that were available in literature may help improve the accuracy and temporal validity of the assumptions when elaborating the reference values for this methodology.

- Catch GDI method [GDI_{mass}]. The catch GDI approach is based on performing GDI calculations in terms of the total amount of catch (e.g. kg of discard/kg of catch), rather than on the energy transfer efficiency from one trophic level to another (Pauly and Christensen, 1995). This method implies a simplified and direct method of obtaining a normalized value for discarding without undergoing a characterization stage. This approach, while not being very orthodox within LCA methodological standards, is an ideal tool that may be implemented when little data are available (i.e. total discard rate for the specific sample).

GDI calculation. Life cycle impact assessment

The final step consists of the environmental characterization of the selected fishery, vessel or fishing fleet regarding discard rate performance. This stage allows comparison of the environmental impacts of discards for the specific fishery under study with those given as reference values, and, by extension, to any worldwide fishery. The estimation of the GDI, regardless of the selected approach, is conducted through the following equation:

$$GDI=1/[GDR/((DR*FU)/LR)] \qquad \text{eq.[2]}$$

where GDI is the global discard index and GDR is the average discard rate for worldwide fisheries. GDR is reported in terms of total mass per selected FU (i.e. grams of C per FU in the biotic GDI approach, or kilograms of discard in the mass perspective). DR is the discard rate (%) for a particular fishery/vessel., FU is the selected functional unit and LR is the landing rate in a particular fishery/vessel respect to the total capture (%). The selected dimensionless unit created to measure this particular indicator was the *global discard unit* (gdu).

Regarding the FU entered in the equation, it is important to highlight that it needs to be converted into the specific mass units that are been used depending on the chosen GDI approach. In other words, if the selected FU is monetary, it would have to be converted to the equivalent values for PPR in the case of biotic GGDI or into the equivalent mass weight for GDI_{mass}.

Additionally, it is required to insert the GDR value in the same units as the one´s selected for the converted FU.

This equation represents the inverse value of the ratio between the worldwide average discard rate and the average discard rate of a given fishery. Its application leads to an index of positive values that can classify fisheries according to three different groups: i) GDI<1, in which the discard rate for a given fishery is lower than average worldwide discards; ii) GDI=1, in which the discard rate for a selected fishery is equal to that of average worldwide discards, and iii) GDI>1, in which the discard rate for a given fishery is greater than worldwide average values. In this framework, Figure 11.4 shows a timeline representation for a given fishery provided that the reference value is constant for each of the three scenarios described above.

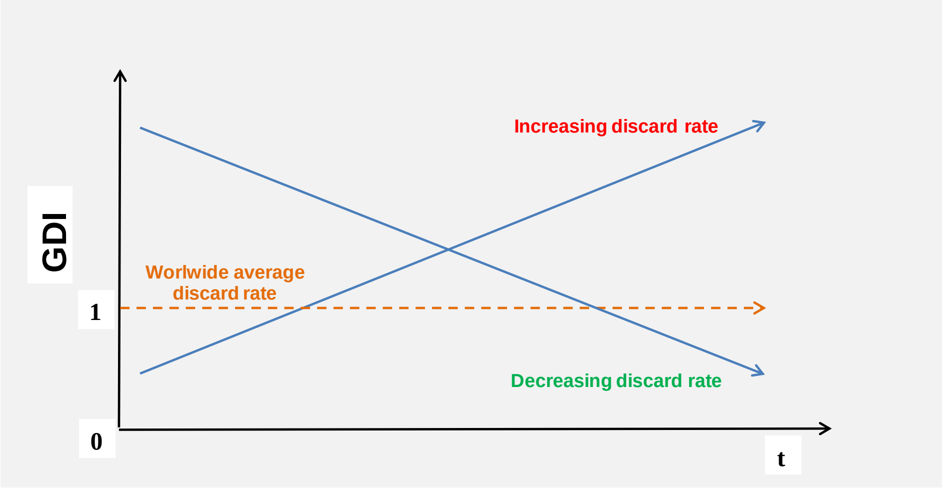

Figure 11.4. Scenario representation for a given fishery at constant reference value.

Result interpretation

The classification of fisheries based on their discard performance with respect to current (or available) world trends is essentially valid for both GDI methods. However, it is important to highlight that while catch GDI presents a linear configuration based directly on the amounts of catch and discard, biotic GDI presents a more complex scenario. In fact, catch GDI will always show a decline in its value for a fishery that is reducing its discards respect to a fixed reference value. On the contrary, biotic GDI variations with respect to a fixed reference value within a fishery do not only reflect discard reductions or increments, but may also show variations in the discard composition. For example, if a fishery were to show a decreasing catch GDI, whereas the biotic GDI is increasing, this situation would translate into more individuals with a higher trophic level being discarded. This particular example may be observed, for instance, in shrimp trawling fisheries, where the target species (shrimps) will probably have a lower trophic level than many discarded individuals.

While harmonization of the proposed impact category with existing categories appears complex due to the specificity of discards in marine ecosystems, its integration in environmental quality monitoring through damage assessment seems a feasible future perspective. In fact, another approach may entail the construction of a new damage assessment category for marine ecosystems, by integrating a set of fishery-specific impacts. While the latter alternative may imply a skewed analysis of the fishing industry with respect to other industries in life cycle thinking, it may be an attractive option for LCA consideration in fisheries management and eco-labelling schemes (Jolliet et al., 2004).

Recommendations

The reference value adopted for GDI is based on the fact that discard reports elaborated by FAO constitute the broadest and most up to date global studies on this particular impact in world oceans. Nevertheless, discard reporting still lacks transparency and accountability, since discard monitoring is still highly rudimentary. Furthermore, it is costly to improve and to standardize sampling methods worldwide (Lart, 2002; Walsh et al., 2002; Wetherall, 2003). Hence, the use of this specific reference value for GDI implies that future studies may improve this reference value and, therefore, the accuracy of the results.

An increase in the thoroughness of the inventory inputs relating to discards, including the detailed breakdown of the discarded catch by species, will benefit the approach that can be implemented for the proposed methodology, as well as the reporting of other fishery-specific impact categories. For instance, the inclusion of discards and other underlying fish consumptions that may occur during fish extraction, such as bait, when analysing the environmental profile of a particular seafood product would improve the quality of the results for this specific category, since the entire removal of biomass from the ocean for fish extraction would be computed.

11.3.2. Additional discard indicators

Survival rate of discards

The survival of discarded organisms is essential to understand their potential ecological impact (Kelleher, 2005), since it can help understand population dynamics and when it comes to implementing technological improvements in fishing gears to reduce mortality. Despite their being broad bibliography on survival rates in fisheries worldwide (Chen and Gordon, 1997; Revill et al., 2005), most studies have been linked to trawling fisheries, given the strong amount of discards that they generate. Furthermore, previous studies suggest that there can be high variance in the mortality of discards, not only from a fishing gear or fishery perspective (Allen et al., 2001; Rodríguez-Cabello, 2001), but also between species (Kaiser and Spencer, 1995; Revill et al., 2005), as can be observed in Table 11.3. For instance, the high survival rate observed for lesser-spotted dogfish (*Scyliorhinus canicula*) with respect to other discarded organisms in trawling hauls is thought to explain the strong proliferation of this species in intensive fishing zones (Walker and Hislop, 1998; Revill et al., 2005).

Table 11.3. Survival rate range of discards in selected literuature publications.

Fishery	Species	Survival rate	Reference
Irish Sea (trawling)	Common dab	24%	Kaiser and Spencer (1995)
Irish Sea (trawling)	Plaice	39%	Kaiser and Spencer (1995)
Irish Sea (trawling)	Rays	59%	Kaiser and Spencer (1995)
North Pacific (trawling)	Pacific halibut	26-97%	Kaimmer and Trumble (1998)
Great Barrier Reef (trawling)	Varied fish and cephalopods	2%	Hill and Wassenberg (2000)
Cantabrian Sea (trawling)	Lesser-spotted dogfish	78%	Rodríguez-Cabello (2001)
NE Gulf of Mexico (hook and line)	Atlantic sharpnose shark	90%	Gurshin and Szedlmayer (2004)
Western English Channel (trawling)	Lesser-spotted dogfish	98%	Revill et al. (2005)
New South Wales (trawling)	Southern herring	0-10%	Broadhurst (2008)
New South Wales (gillnet)	Black sole	73-91%	Broadhurst (2008)

Therefore, the inclusion of an overall survival rate of discards linked to the landing of a specific species or vessel catch as an endpoint indicator in seafood LCA studies may contribute to contextualize the impact of discards in a specific fishery. High survival rates in a given fishery may suggest reduced concerns regarding the effects of returning the biomass back to sea. In fact, this indicator could be of special interest when eco-labeling a fishery, since some eco-labeling schemes base their assessment on maximum discards rates (Friend of the Sea, 2011). Hence, the use of this indicator would help discriminate between "good" and "bad" discards in terms of the reported mortality/survival rates. Nevertheless, the applicability of this indicator, in the same way as other endpoint modelling indexes, is subject to data unlikely to be available for complex multi-species fisheries.

Slipping

Slipping consists of a fishing operation, usually performed in purse seiners, in which part of the catch is freed before drawn aboard (Stratoudakis and Marçalo, 2002). The main reason for slipping is linked to size requirements, inadequate characteristics of the individuals or high grading (Stratoudakis and Marçalo, 2002; Borges et al., 2008). From a technical perspective, slipping is not computed as a discard. Moreover, given the lack of a thorough selection on board, it is difficult to quantify its extent in terms of live mass weight, catch composition and mortality of the released organism due to net injury or crowding (Huse and Vold, 2010).

Nevertheless, according to previous studies, small-pelagic species have shown to be strongly affected by gear related injuries, cutting down their chances of survival once slipped (Huse and Vold, 2010). Hence, reporting the existence of slipping activities in a specific fishery, as well as the observed or expected[2] mortality/survival rate will assist when evaluating the total biomass that is removed from its natural environment. In fact, reporting of this specific impact may add valuable information for fishery certification schemes.

Effect of discards on seabird communities

A broad range of articles have analysed and discussed the effect that discards and offal have on seabird communities (Garthe et al., 1996; Oro and Furness, 2002; Furness et al., 1992). Moreover, it is important to note that offal material and/or wastes derived from slipping also influence bird populations. In fact, some reports suggest proliferation of different bird species (scavengers, predators, etc) depending on the proportions of offal wastes and discards (Furness, 2003).

Evaluating the impact due to variation in fish biomass waste has shown to be a complicated procedure, given the difficulty to discriminate between the effects of waste availability in the sea and other ecological processes affecting seabird ecosystems (Votier et al., 2004). Nevertheless, integrated studies evaluating the influence ocean and sea bird ecosystems exert on each other suggest that abrupt cuts in discarding will cause important changes in seabird compositions, without guaranteeing that these shifts will translate into pre-industrial fishing seabird ecosystem structures (Regehr and Montevecchi, 1997; Heubeck et al., 1999). While this specific impact linked to discarding and other forms of biomass waste at sea due to fishing is not quantified or evaluated in the present study, it is important to take into account that discard management from a life cycle perspective should take into consideration bird population dynamics as indicators of the health of a particular ecosystem.

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[2] The expected limitations to obtain primary data for slipping would probably derive in using bibliographical data for mortality/survival rates.

11.4. Application of the proposed GDI indicator to selected fisheries

11.4.1. Case study: functional unit, system boundaries and data acquisition

A series of examples were proposed based on discard rates reported in the fishing fleets analysed in Chapters 3, 5 and 6. Therefore, this study aimed at quantifying the environmental impact associated with fish landing and discarding in Galician fisheries in recent years. The FU considered was 1 tonne of landed fish in all cases. The rationale behind this FU choice was based on the fact that discards and other fishery-specific impacts are based more on the landings (and catch) of a particular fishery rather than on the landings of a particular species, although it is also true that many vessels and fishing gears have varying discard rates depending on the targeted species, season or area they are fishing in. Nevertheless, an FU referred to one specific species would prevent the assessment from getting a realistic perception of the fisheries' performance.

The system under study involved exclusively the different operational stages of the fish extraction phase performed by vessels in the selected fisheries. Data related to vessel operations such as catch and landing rate or total discards performed were taken into account to perform the inventory. Plant materials or on board post-harvest waste, such as offal, were not included within the discarded material, and were therefore disregarded (FAO, 1996). The product was followed from the fishery until landing for sale, constituting a "cradle to gate" analysis (Guinée et al., 2001).

Inventory data for the six assessed fisheries were obtained through questionnaires filled out by skippers as reported in previous chapters. The selected case studies included two relevant coastal fishing fleets from Galicia (trawlers and purse seiners), three Galician offshore fleets extracting at the Northern Stock (trawlers and long liners) and Azores (long liners) fisheries and one trawling fleet working in Mauritanian waters (Table 11.4).

Table 11.4. Selected Galician fishing fleet samples for the case study.

	F1	F2	F3	F4	F5	F6
Sample size	30	24	9	12	9	5
Percentage over total (%)	18.2	23.8	14.3	20.7	33.33	6.4
Year of inventory	2008	2008	2008	2008	2009	2009
Total landings (tonnes)	12,597	16,056	3,769	3,416	5,000	668
Total captures (tonnes)	12,998	27,750	6,657	3,473	6,213	727
Reported discards (kg/FU)	32.6	728	766	16.8	243	88.4

F1 = coastal purse seining; F2 = coastal trawling; F3 = offshore trawling; F4 = offshore long lining (Northern Stock); F5 = trawling (Mauritania); F6= offshore long lining Azores.

Data quality for the coastal purse seiners and coastal and offshore trawlers, as well as for the trawling fleet in Mauritania allowed computation of GDI_{BRU}, since detailed discard composition breakdowns were available for the mentioned fleets. The GDI for the other two fleets included in the study were only computed in terms of GDI_{mass}, since their detailed discard composition was unknown.

11.4.2. Justification of the case study

The introduction of GDI in fishery LCA studies is presented with the aim of providing a useful methodological innovation in order to report fishery-specific impacts in this type of assessment studies. In these cases, regular LCA impact categories are not sufficient to provide a complete and deep assessment of the environmental performance of fisheries.

Therefore, two additional fishery-specific impact categories – SIP and BRU –- were included in this case study, which will allow broadening the range of environmental assessment of the selected fisheries, increasing its relevance in fisheries management (Pelletier et al., 2007). Unfortunately, other innovative impact categories in fisheries LCA, such as prematurely caught organisms (Emanuelsson, 2008; Ziegler et al., 2009), were not included in the case study due to data limitations.

11.4.3. Methodology application

The fishery-specific impact categories and indicators included in the case study were: the two proposed approaches for GDI, BRU, as proposed by Papatryphon et al. (2004), in order to quantify biotic resource use, and SIP (Ziegler et al., 2003). BRU calculation followed the formula provided by Pauly and Christensen (1995). Values for each of the assessed fisheries are based on the trophic levels of the different species that make up the catch composition, including discards, as seen in Table 11.5 (Pauly et al., 1998a). Additionally, in order to calculate the biotic GDI index (GDI_{BRU}), a worldwide MTL was calculated for discards based on the available data from Kelleher (2005). MTLs of the different species were obtained from *Fishbase* (Froese and Pauly, 2008). The MTL for discards with known compositions can be observed in Table 11.6, while the MTL for discards with unknown composition were assumed to be 3.1 (Pauly et al., 1998a).

Table 11.5. Catch composition for the selected fishing fleets and trophic level of the species.

Species	Scientific name	TL	Catch (%)
F1= coastal purse seining			
Atlantic mackerel	*Scomber scombrus*	3.65	26.79
Horse mackerel	*Trachurus trachurus*	3.64	23.30
European pilchard	*Sardina pilchardus*	2.61	46.85
Discards	--	3.14	3.16
Total	--		100.00
F2= coastal trawling			
Atlantic mackerel	*Scomber scombrus*	3.65	12.27
Horse mackerel	*Trachurus trachurus*	3.64	10.25
Blue whiting	*Micromesistius poutassou*	4.01	25.10
European hake	*Merluccius merluccius*	4.48	10.24
Discards	--	3.55	42.14
Total	--		100.00
F3= offshore trawling (Northern Stock)			
Anglerfish	*Lophius budegassa*	4.49	17.55
European hake	*Merluccius merluccius*	4.48	8.57
Megrim	*Lepidorhombus spp*	3.69	25.95
Norway lobster	*Nephrops norvegicus*	2.60	0.39
Other species	--	3.00	4.17
Discards	--	3.67	43.38
Total	--		100.00
F4= offshore long lining (Northern stock)			
Atlantic pomfret	*Brama brama*	4.08	16.07
Common ling	*Molva molva*	4.25	9.61
Conger eel	*Conger conger*	4.29	1.79
European hake	*Merluccius merluccius*	4.48	59.68
Fork beard	*Phycis spp.*	3.73	5.75
Rock fish	*Helicolenus spp.*	3.81	5.46
Discards	--	N/A	1.65
Total	--		100.00
F5= deep-sea trawling			
Octopus	*Octopus vulgaris*	4.10	63.32
Sepia	*Sepia officinalis*	3.60	9.50
European squid	*Loligo vulgaris*	3.20	9.17
Sole	*Solea solea*	3.13	5.42
Sand sole	*Pegusa lascaris*	3.19	2.53
Senegal hake	*Merluccius senegalensis*	4.50	7.47
Caramote prawn	*Penaeus kerathurus*	2.50	2.59
Discards	--	3.38	19.53
Total	--		100.00
F6= Azores long lining fleet			
Swordfish	*Xiphias gladius*	4.49	31.64
Porbeagle	*Lamna nasus*	4.24	51.24
Blue shark	*Prionace glauca*	4.24	8.25
Bigeye tuna	*Thunnus obesus*	4.49	0.75
Discards	--	N/A	8.12
Total	--		100.00

TL= trophic level.

Table 11.6. Discard composition for the selected fishing fleets and trophic level of the species.

Species	Scientific name	TL	Discards (%)
F1= coastal purse seining¹			
Atlantic mackerel	*Scomber scombrus*	3.65	27.64
Horse mackerel	*Trachurus trachurus*	3.64	24.04
European	*Sardina pilchardus*	2.61	48.33
Total discards	---	3.14	100.00
F2= coastal trawling²			
Atlantic mackerel	*Scomber scombrus*	3.65	7.15
Horse mackerel	*Trachurus trachurus*	3.64	32.54
European hake	*Merluccius merluccius*	4.48	2.18
Blue whiting	*Micromesistimius poutassou*	4.01	8.45
Freckled catshark	*Scyliorhinus spp.*	3.92	8.01
Boarfish	*Capros aper*	3.14	1.46
Haddock	*Melanogrammus aeglefinus*	4.09	1.25
Streaked gurnard	*Trigloporus lastoviza*	3.42	1.97
Invertebrates	---	2.50	15.53
Other¹	---	3.75	21.46
Total discards	---	3.55	100.00
F3= offshore trawling³			
Horse mackerel	*Trachurus trachurus*	3.64	35.00
Pouting	*Trisopterus luscus*	3.73	25.00
Undersized individuals	---	3.99	25.00
Other individuals	---	3.1	15.00
Total discards	---	3.67	100.00
F5= deep-sea trawling³			
Sardine	*Sardina pilchardus*	2.61	10.00
Cunene horse mackerel	*Trachurus trecae*	3.49	35.00
Chub mackerel	*Scomber japonicus*	3.65	15.00
Other¹	---	3.38	40.00
Total discards	---	3.38	100.00

TL= trophic level.

[1] Data corresponding to the purse seining fleet are based on skippers reporting the discard of caught species' juveniles. Therefore, we assumed that these species were discarded in the same proportion as their catch.

[2] Discard data for the coastal trawling fleet correspond to the average discards composition reported by the Galician coastal trawling fleet.

[3] Data for offshore trawlers in the Northern Stock and deep-sea trawlers in Mauritanian waters were based on rough estimates elaborated by skippers from the assessed sample.

11.4.4. Brief discussion of the case study

Table 11.7 shows the environmental performance for each of the selected impact categories in the different fisheries. As observed, fishery-specific impact categories did not show linear correlation with respect to fuel intensity in fisheries, which is the main driving force for conventional impact categories, as discussed in section II of this thesis. For instance, the SIP for purse seining and long lining fleets was identified as zero, while the values for trawling fleets varied from the coastal trawling fishery (0.68 km^2/FU) to the offshore trawling fleet (4.81 km^2/FU). However, it is important to note that there is a certain correlation between the fishing effort of the trawlers and their potential effect on the seafloor.

Table 11.7. Characterization values associated with the selected fisheries per FU.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
Fishery-specific impact categories						
GDI$_{mass}$ (gdu)	0.38	8.36	8.86	0.19	2.79	1.02
GDI$_{BRU}$ (gdu)	0.41	23.61	32.74	N/A	5.32	N/A
BRU (gCkg^{-1} fish)	15,838[1]	127,740[1]	121,573[1]	247,681[1,2]	96,784[1]	265,734[1,2]
SIP (km^2)	0	0.68	4.81	0	1.95	0

[1] BRU results for selected fleets include the BRU of the discards that correspond to 1 t of landed fish.

[2] BRU results for F4 and F6 include the NPP relative to the bait used for fishing. However, it does not include potential discards that may have occurred when fishing for the bait.

GDI$_{mass}$= Global Discard Index, based on live weight catch; GDI$_{BRU}$= Global Discard Index, based on net primary productivity; BRU= Biotic Resource Use; SIP Seafloor Impact Potential; gdu= global discard unit; F1= coastal purse seining; F2 = coastal trawling; F3 = offshore trawling; F4 = offshore long lining (Northern Stock); F5 = deep-sea trawling; F6= Azores long lining fleet.

The BRU values obtained for the different fisheries were dependent on the catch profile, as well as on the composition of their discards and, when applicable, the use of bait. Therefore, the coastal purse seining fleet, that targets small pelagic fish, and the Mauritanian trawling fleet, that targets cephalopods, showed the lowest values, since they catch species that are low down in the trophic chain (Pauly et al., 1998a). Moreover, their discards also corresponded to species with low MTL. On the contrary, the offshore long lining fleets were those with the highest BRU values due to the high MTL of the target species, the high amount of bait used per FU and, to a lesser extent, due to low discarding in these fleets, discards themselves.

Regarding the GDI$_{mass}$ approach, the highest values, as observed in Figure 11.5, were identified for the coastal and offshore trawling fisheries (8.86 and 8.36 gdu, respectively), while the best performance regarding discards was that of offshore long liners in the Northern Stock (0.19

gdu). The coastal purse seining fleet also showed a lower discard rate than average (0.38 gdu). Finally, the Azores long lining fleet presented discard values close to the global average (1.02 gdu).

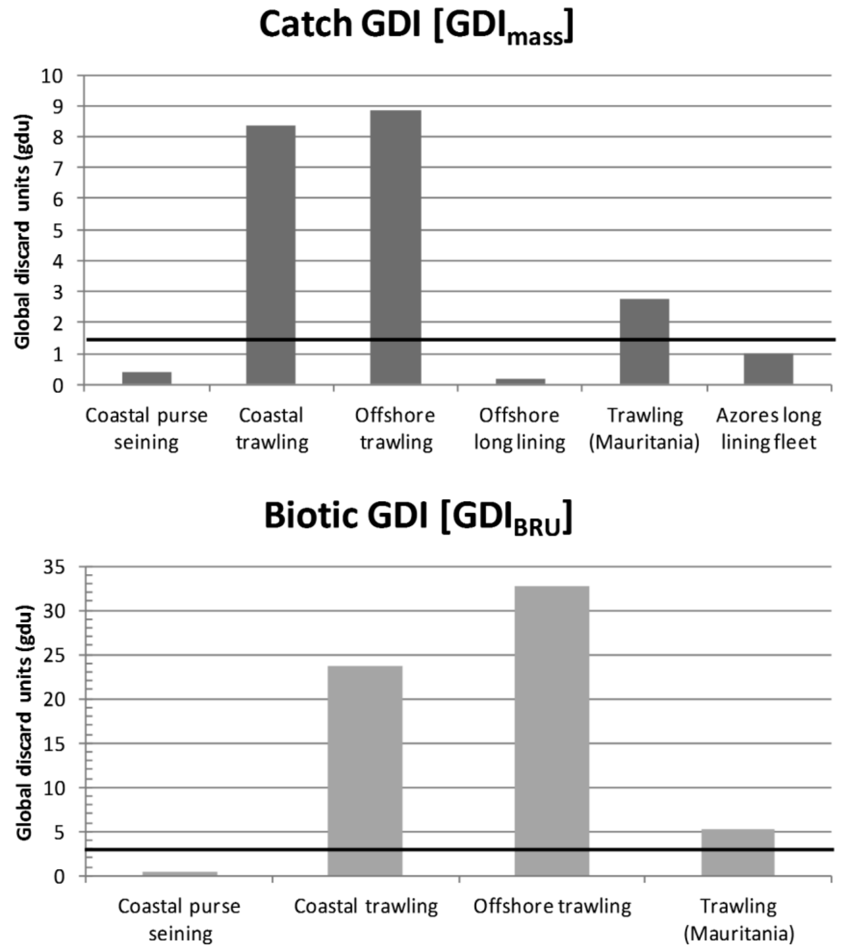

Figure 11.5. GDI results for the selected fishing fleets. Black horizontal line indicates GDI=1, which represents worldwide GDI mean.

Finally, the obtained results for the GDI_{BRU} methodology were identified for those fleets were discard breakdown composition was available. The value for coastal purse seining was 0.41 gdu, a value very close to that observed in the catch GDI approach, due to the similar MTL of this fleets' catches respect to the values assumed at a worldwide scale. The values for the three evaluated trawling fishing fleets showed a higher value respect to catch GDI, due to the high MTL of the discards respect to the worldwide average (Figure 11.5).

Results reflect how when discards and the other fishery-specific categories are compared between fisheries a clear pattern cannot be assumed, showing that multiple factors can affect a fishery when it is analysed from an integral perspective. For instance, GDI does not necessarily increase with increasing energy use in a particular fishery, BRU depends mainly on the nature of the species being captured and used as bait, and SIP is an impact category that refers mainly to the amount of seafloor dragged per FU by trawlers, while the other gears assessed in this chapter contribute zero to this impact category.

Previous studies have already highlighted bottom trawling as being responsible for 50% of worldwide discards, while only landing 22% of catches (Kelleher, 2005). Nevertheless, this increased discard rate that is common for a great majority of trawling fisheries cannot be linked directly to the increased energy use of these fleets, but must be understood in the specific context of each fishery. Hence, despite the fact that an elevated energy use usually implies long dragging hours that may increase discards, compared to shorter gear operations (e.g. purse seining), there are other, more significant aspects that may influence high discard rates, such as the gear used itself, the targeted species, the overexploitation of the fishery or the variety of hydrographical factors.

Additionally, it is important to highlight the pyramidal structure of marine ecosystems. Therefore, the NPP that generates in the lower level of the trophic chain tends to move upwards, with a consequent loss of a high percentage of the productivity due to growth or spawning of marine organisms (Villasante, 2009). The use of the biotic GDI approach, which is recommended whenever quality data are available, allows the inclusion of discard reporting in terms of net productivity appropriation from the sea through fishing activities that is not destined to human/industrial consumption, but is returned, usually with an excessively high mortality rate, to the sea (Cappell, 2001).

Hence, the proposed GDI category for this case study was implemented in order to include a feasible and universal discard indicator for fishing fleets. Moreover, it provides a dynamic value easily comparable between fisheries, facilitating the understanding of discard evolution through time and the proposal of specific discard mitigation management policies (Levasseur et al., 2010).

The implementation of this index, therefore, will be useful to assess the effects of the increased use of the catch, evaluate if there are any improvements in the selectivity of the fishing gear and detect changes in catch composition over time.

11.4.5. Recommendations and advantages of the methodology

Currently, fishery LCAs still present an important number of unresolved challenges. This particular study attempts to provide contributions to partly resolve methodology gaps relating to fishery-specific impacts. In particular, GDI is presented as a normalized midpoint index aiming at providing an additional criterion for eco-efficiency based on discard quantification. It also guarantees worldwide applicability, despite the fact that discards, in the same way as other fishery-specific issues, do not describe fisheries homogeneously at a world scale (Byrd et al., 2011; Hall et al., 2000; Johnsen and Eliasen, 2011). However, the fact that it constitutes a midpoint indicator may reduce its relevance in terms of decision support (Bare et al., 2000).

Another relevant characteristic of GDI is the fact that it is a flexible index. Given that its calculation involves direct comparison with average discards worldwide implies that a global reduction of discards will translate into a worse GDI value for a particular fishery, provided that the discard rate for this fishery does not decrease and assuming, in the case of biotic GDI, that there are no variations in the mean trophic level for discarded biota. This advantage may translate into an important starting point for fisheries management when it comes to analysing how discard reduction policies applied elsewhere may be used in a particular fishery.

The inclusion of GDI as a regular indicator included in fishery LCAs will also enhance the reporting of discards in this type of assessments. Therefore, this implementation will not only increase the availability of results relating to discards in worldwide fisheries, but will also increase the reporting of discards in fisheries with suspected low discards. This is an important point, since low discarding fisheries are not necessarily linked to lower impacts on the ecosystem (Kelleher, 2005; Zhou et al., 2010). Furthermore, GDI may also help to have more updated data regarding discards and provide a series of reference values for fisheries that have not been assessed in the past. It also provides increased feasibility when reporting discards, avoiding this concept to be used interchangeably or as an equivalent term to by-catch, as occurs in many scientific publications

(Kelleher, 2005), making it difficult to determine whether the values presented refer to landings or to total capture.

Finally, discard reporting has shown to be highly variable from one year to another, despite an unquestionable discard reduction trend through time in many fisheries (Catchpole et al., 2011; Kelleher, 2005). Therefore, an ideal analysis should be based on adequate chronological series. However, currently most fishery LCA studies, including the one presented in this case study, fail to analyse discards and other fishery aspects, such as stock assessment or fishing effort, on a prolonged temporal scale, due mainly to difficulty in achieving wide inventories for a great number of years (see Chapter 4). Nevertheless, the use of GDI enables LCA practitioners to obtain an index value based on a previous reference value.

11.4.6. Limitations of the methodology

While the computation of GDI_{mass} is considered a preliminary approach, useful when data quality is low, the main limitations linked to the implementation of GDI_{BRU} are associated with the calculation of the average MTL for individual species, as well as at a global scale. Despite taking into account a total of 220 different species groups of invertebrates and fish, based on FAO landing statistics, MTL values do not discriminate between increasing MTL of individuals as they age. This specific characteristic of marine species has not been addressed in depth in the available literature, so MTL values in this case study refer to average trophic levels per species (Caddy et al., 1998; Pauly et al., 1998b; Pauly and Palomares, 2005). Moreover, the values reported by Pauly and Christensen (1995) do not account for illegal, unregulated and unreported (IUU) fishing. Therefore, it is expected, for example, that in fisheries with important discard amounts regulated with thorough minimum size requirements, the MTL of the discards may be overestimated due to the lower value expected in the younger, undersized individuals that are been discarded.

11.5. Perspectives and conclusions

The methodology presented in this study achieved the important objective of integrating discard data as a fishery-specific impact in LCA studies. The application of GDI, as well as the other two suggested indicators may not succeed at determining the specific impacts that discards are potentially creating over a specific ecosystem in a given fishery, since discard patterns depend on a wide range of variables (stock abundance and distribution, fishery policy, landing restrictions, fishermen behaviour, etc). Nevertheless, they constitute a useful starting point to identify tendencies in discard and discard management in worldwide fisheries, thanks to its dynamic characteristics.

In fact, to date, conventional impact categories used in LCA studies have focused on the environmental impacts that originate from the wide range of fishery-linked industrial activities. However, the driving force of most of these is linked to energy use. Therefore, the proposed methodology, in the same way as other previously recommended biological impact categories (i.e. BRU or SIP), aims at increasing the usefulness of fisheries LCA as a management tool by adding a fishery-specific perspective to the assessment. Accordingly, the specific indicators for discards will generally prove feasible in fisheries LCA research and can be understood as a regular procedure to follow in fishery assessment.

Nevertheless, future research will have to determine how midpoint indicators proposed for fishing systems are integrated consistently for damage assessment in LCA. One possible approach may consider the construction of a new damage category for fishery-specific impacts, which may trigger the usefulness of LCA in fisheries management. An opposing perspective, however, would consider their integration in currently existing damage categories, in order to avoid comparability gaps in LCA interpretation.

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SECTION V

CARBON FOOTPRINTING IN THE GALICIAN FISHING SECTOR

Chapter 12

Estimating the carbon footprint in Galician fishing fleets and aquaculture[1,2]

Summary

The food production system as a whole is recognized as one of the major contributors to environmental impacts at a global scale. In this sense, food production, processing, transport and consumption account for a relevant portion of the GHG emissions associated with any country. In this context, there is an increasing market demand for climate-relevant information regarding the global warming impact of consumer food products throughout the supply chains. This chapter deals with the assessment of the carbon footprint of seafood products in Galicia as a key subgroup in the food sector. The analysis is based on a representative set of species within the Galician fishing sector, including species obtained from coastal fishing (e.g. horse mackerel, Atlantic mackerel, European pilchard and blue whiting), offshore fishing (e.g. European hake, megrim and anglerfish), deep-sea fishing (skipjack and yellowfin tuna), extensive aquaculture (mussels) and intensive aquaculture (turbot).

The CFs associated with the production-related activities of each selected species were quantified following a business-to-business approach on the basis of 1 year of fishing activity. These individual CFs were used to calculate the CF for each of the different Galician fisheries and culture activities. Finally, the lump sum of the CFs for coastal, offshore and deep-sea fishing and extensive and intensive aquaculture brought about the CF of the Galician fishing activity (i.e., capture and culture). A benchmark for measuring and communicating emission reductions was then provided, and opportunities to reduce the GHG emissions associated with the Galician fishing activity could be prioritized.

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[1] Iribarren, D., Vázquez-Rowe, I., Hospido, A., Moreira, M.T., Feijoo, G. (2010). "Estimation of the carbon footprint of the Galician fishing activity (NW Spain)". *Science of the Total Environment,* 408: 5284-5294

[2] Iribarren, D., Vázquez-Rowe, I., Hospido, A., Moreira, M.T., Feijoo, G. (2011). "Updating the carbon footprint of the Galician fishing activity (NW Spain)". *Science of the Total Environment,* 409: 1609-1611

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12.1. Introduction

Food production systems as a whole constitute one of the major contributors to environmental impacts, since they are great consumers of both energy and natural resources (Edwards-Jones et al., 2008; Foster et al., 2006). This fact, together with current consumption patterns, has motivated an increasing interest to report the environmental performance of food products. In this sense, it is generally accepted that food production, processing, transport and consumption account for a relevant portion of the environmental GHG emissions associated with any country (Garnett, 2008). This chapter deals with the assessment of the carbon footprint for seafood products as a key subgroup of the food sector. In particular, the estimation of a value for the global warming impact of the Galician fishing activity is discussed.

12.1.1. Environmental issues within the fishing sector

Fishing activities are usually divided into two main blocks: commercial fishing and aquaculture. Commercial fishing comprises coastal, offshore and deep-sea fisheries of fish, cephalopod, crustacean and other marine organism landings. On the other hand, aquaculture encompasses two farming subsectors: extensive aquaculture and marine intensive aquaculture.

General environmental concerns regarding commercial fishing focus on direct impacts to targeted species (Pauly et al., 2002), by-catch (Glass, 2000), benthic communities alteration (Johnson, 2002), and trophic dynamics modifications (Jackson et al., 2001). On the other hand, aquaculture practices also entail environmental concerns such as eutrophication, benthic deterioration, disease transmission, and other issues linked to the use of feed and pharmaceuticals (Folke et al., 1992; Hastein, 1995; Naylor and Burke, 2005).

These general concerns do not cover all aspects related to the environmental performance of fishing activities. In this context, LCA has shown to be a suitable methodology to undertake the environmental assessment of seafood products according to a life-cycle approach, as seen throughout previous chapters of this dissertation. In fact, the global warming impact category has arisen as one of the most common categories assessed. However, current trends in the communication of climate change question the convenience of using LCA standards to perform the calculation of product carbon footprints (SETAC, 2008). This particular study gives insights on the estimation of carbon footprints for seafood products by proposing a case study of Galician fishing activity.

12.1.2. Introduction to Carbon Footprinting

Carbon Footprint (CF) calculation consists of the estimate of the overall amount of GHG emissions associated with a product along its supply chain (EPLCA, 2007). Therefore, the CF of a specific product refers to its GHG emissions across its life cycle, from raw materials through production, distribution, consumer use and disposal (Carbon Trust et al., 2008).

Among the standardized methods developed to complement LCA standards (Finkbeiner, 2009), the Publicly Available Specification (PAS2050:2008) is highlighted as it is receiving increasing acceptance (BSI, 2008). PAS 2050:2008 was published by the BSI, the Carbon Trust and the Department for Environment, Food and Rural Affairs of the United Kingdom (Defra) in 2008. It specifies requirements for the assessment of the life cycle GHG emissions of goods and services based on key life cycle techniques and principles (Sinden, 2009).

Three driving forces can be distinguished when explaining the increasing market demand for product CFs. First, the participation of retailers is stressed (Clift et al., 2005). In particular, retailers have arisen as deciding actors for the expansion in the use of CFs in the UK. This has been possible thanks to the involvement of high-profile retailers such as Tesco. Governments arise as a second driving force for CF. For example, expected introduction of mandatory carbon footprinting is behind the wide expansion of this tool in France (Karst, 2009; McLeod and Audran, 2009). Finally, recent consumers' awareness on the global environmental challenges significantly leads to promote CF as a measure towards sustainable economy.

Direct applications of carbon footprinting for companies include: internal assessment of product life cycle GHG emissions and subsequent reduction; incorporation of emissions impact into decision making; support for corporate responsibility reporting; identification of cost savings opportunities; benchmarking for measuring and communicating emission reductions; and support for comparison of product-level GHG emissions (Carbon Trust et al., 2008). Furthermore, companies may decide to communicate the CF of any of their products in order to gain market access and competitiveness (Carbon Trust, 2008a).

Since the fishing sector usually plays an important role within the food sector of any country, and given the relevance of the GHG emissions coming from the latter, this chapter discusses the calculation of CFs for seafood products on the basis of the Galician case study.

12.2. Case study: Galician fishing activity

Fishing in Galicia constitutes a key economic sector, providing 10% of the regional GDP (Sainz et al., 2008). Figure 12.1 presents the distribution of the Galician fishing activity, in terms of both production and economic turnover, according to available official data (ANFACO, 2009; FAO, 2009; Xunta de Galicia, 2009). As shown, commercial fishing covers 60% of the regional fishing production rate and 75% of the economic turnover (reference year: 2008). The role played by aquaculture should not be disregarded as it provides 40% of the total production and 25% of the total economic turnover (IPAC, 2009; Xunta de Galicia, 2009).

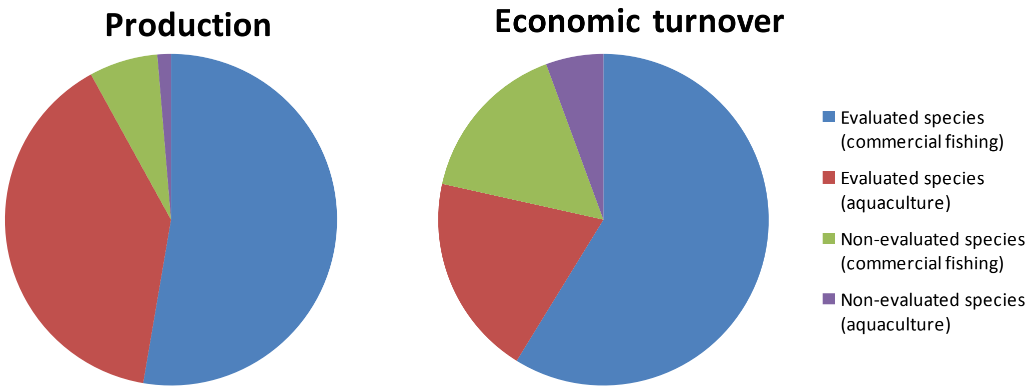


Figure 12.1. Statistical representation of the Galician fishing activity.

Demersal species (e.g. hake, megrim, anglerfish, Atlantic pomfret and conger eel), which are captured mainly by trawling and long lining fishing gears, account for about 25% of the targeted species linked to commercial fishing, as well as for more than 50% of the economic turnover. Pelagic species, such as European pilchard, Atlantic mackerel or tuna, are the other main target group, accounting for roughly 75% of the capture performed and 45% of the economic turnover.

Regarding aquaculture, mussels cultured in traditional rafts based on extensive farming practices prevail for both production (more than 90% of the total for aquaculture) and economic turnover (50% of the total value for aquaculture). Moreover, turbot from intensive farming entails over 95% of total production associated with marine intensive aquaculture. While turbot provides just 3% of the total aquaculture production, this species contributes to over 25% of the economic turnover.

The case study presented in this chapter aims to perform the CF of a selection of species targeted by the Galician fishing activity. According to the current distribution of the Galician fishing activity, a set of species was defined in such a way that representativeness was guaranteed, enabling the subsequent estimation of a global carbon footprint for the entire Galician fishing activity.

The most relevant coastal fishing species evaluated were: horse mackerel (trawling and purse seining), Atlantic mackerel (trawling and purse seining), blue whiting (trawling), hake (trawling), European pilchard (purse seining) and chub mackerel (purse seining). Concerning offshore fishing, the species evaluated included: hake (long lining and trawling); megrim, anglerfish and Norway lobster (trawling); conger eel, Atlantic pomfret, common ling, rock fish, fork beard and splendid alfonsino (long lining). These species are the main species targeted by fishing vessels in the Northern Stock (ICES Divisions VIIIabd and VII). Other assessed species were porbeagle, mako shark, bigeye tuna, blue shark and swordfish (long lining in the Azores-ICES Divisions X a1 and a2). Regarding deep-sea fishing, skipjack and yellowfin tuna (purse seining in the Indian, Atlantic and Pacific Oceans) were the species subject to assessment.

Mussels cultured in traditional rafts were evaluated as the main representative of the extensive aquaculture practices in Galicia. Finally, turbot was the species evaluated for the study of marine intensive aquaculture in Galicia.

Figure 12.2 shows the representativeness of the whole selection of species according to their contribution to the total production and economic turnover (reference year: 2008). The thoroughness of the sample is proved since 92% of the total production of the Galician fishing activity as well as 79% of its economic turnover was covered.

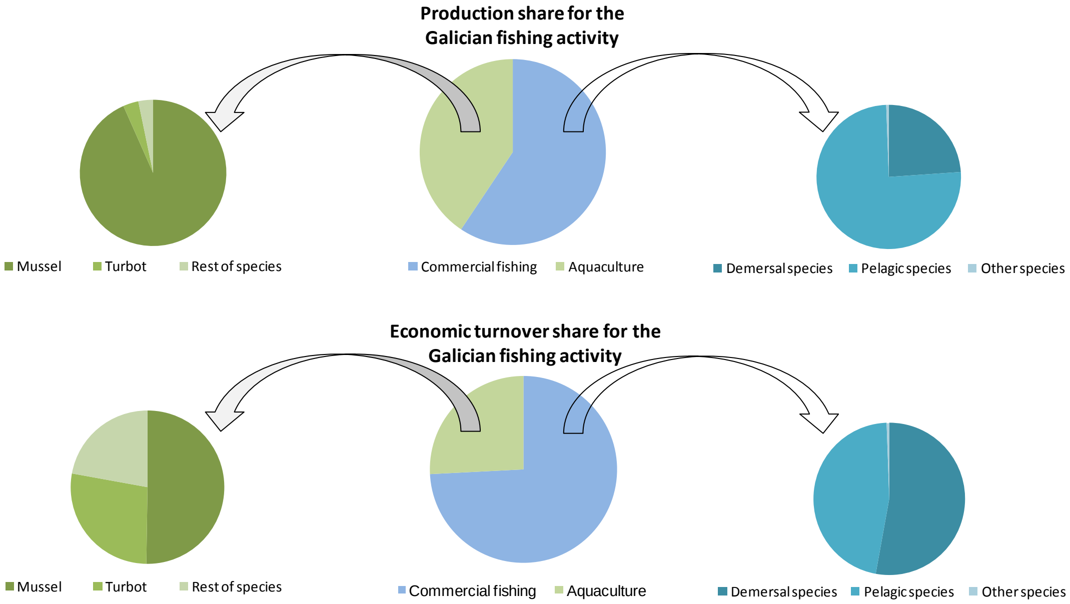


Figure 12.2. Sample representativeness in terms of production and economic turnover (%).

12.3. Framework

The goal of this study is to quantify the CF of a representative set of species within the Galician fishing sector that can allow the estimation of the CF of the whole Galician fishing activity.

12.3.1. Scope of the study and calculation basis

Two different approaches are usually distinguished for the assessment of life cycle GHG emissions of products. On the one hand, a business-to-consumer (B2C) assessment involves a cradle-to-grave approach as it embraces the emissions arising from the full life cycle of the product. On the other hand, a business-to-business (B2B) assessment corresponds with a cradle-to-gate approach that includes all upstream emissions and stops at the point where the product is delivered to a new organization (Carbon Trust et al., 2008).

Taking into account that multiple species (with diverse downstream processes, i.e. different ways of processing and consumption) undergo thorough evaluation, a B2B approach is more appropriate for this case study. Results from this research are expected to be useful to undertake future CF studies that address the B2C assessment of specific seafood products.

Therefore, for the CF of commercial fishing and extensive aquaculture species, only the GHG emissions from capture/culture to landing in Galician ports were included. Similarly, for the CF of the marine intensive aquaculture, the GHG emissions arising from the production of farmed turbot were assessed up to the supply of commercial adult turbot for transport to retailers. In all cases, the CF was referred to 1 year of activity in order to finally infer the annual CF associated with the whole Galician fishing activity.

12.3.2. Data acquisition

Inventory data for the assessed coastal species were obtained through a series of questionnaires filled out by skippers from a wide range of Galician fleets, as described in Chapter 3. In particular, the assessed fleets included 30 coastal purse seiners and 24 coastal trawlers. Questionnaires comprised a wide range of operational aspects such as the annual consumption of diesel, oil and antifouling paint, as seen in Section II of this dissertation.

Similarly, data regarding the offshore species were also obtained through analogous questionnaires, described in previous chapters of this dissertation. In this case, the interviewed skippers belonged to the Northern Stock fleet (12 long liners and 9 trawlers) and to the Azores long lining fleet (5).

Inventory data for the Galician deep-sea fishing were obtained from a total of 9 purse seiners that land their tuna catches in Galician ports. Three of these vessels operate in the Atlantic Ocean, three in the Indian Ocean, and the remaining three vessels catch in the Pacific Ocean (Hospido and Tyedmers, 2005).

Inventory data regarding cooling agent leakage were not available through direct contact with skippers, but were obtained from two major cooling agent retailing companies in Galicia (J.M. Juncal from Frimarte and Vigo Headquarters of Kinarca, June 2010, personal communications). Consulted technicians agreed that a vast majority of fishing vessels based in Galician ports were by late 2009 still using R22, an HCFC with high ozone depletion and global warming potentials (GWP: 1810 relative to CO_2 according to IPCC, 2007).

Main data for mussel culture in traditional rafts were obtained from skippers of 22 auxiliary vessels in charge of 80 rafts (Iribarren et al. 2010a, 2011a), while inventory data for marine intensive aquaculture were mainly taken from the environmental statements of several Galician plants belonging to worldwide leading companies in the aquaculture sector (Iribarren et al. 2011b).

Besides primary activity data, CF studies also require secondary data, which are those obtained from sources other than direct measurement of the processes included in the life cycle of the product (BSI, 2008). In this sense, the ecoinvent® database was used as preferred database as it is nowadays the most complete and updated (Frischknecht et al., 2007a).

12.3.3. Assumptions

Capital goods were excluded from the assessment in accordance with PAS 2050 guidelines (BSI, 2008). Nevertheless, this methodological decision is discussed in section 12.5.3 for some species in order to show its relevance when performing seafood CF. Note that the term 'capital goods' refers to goods such as machinery, equipment and buildings, used in the life cycle of products. In particular, the construction of vessels, engines, buildings and similar goods was excluded.

Allocation was necessary when assessing fisheries that target more than one species. Following PAS 2050:2008 criteria, economic allocation was considered when dealing with species from coastal trawling, coastal purse seining, offshore trawling, and offshore long lining. The relevance of this methodological decision was numerically discussed in section 12.5.3.

It is assumed that the evaluated species guarantee an accurate approach when estimating the CF for the total annual Galician fishing activity. According to the percentages shown in Figure 12.2, and given the wide range of the study, the potential deviations linked to this assumption were considered low. Specific assumptions when calculating the CFs of the considered subsectors are stated in section 12.4. In accordance with PAS 2050 guidelines, the values of global warming potentials (GWP100) to transform GHG emissions in kg of CO_2eq are based on the latest ones available from the Intergovernmental Panel on Climate Change (IPCC, 2007).

12.3.4. Main inventory data

Table 12.1 exemplifies the main input/output inventory data for some of the selected species. Diesel, antifouling paint and annual leakage for R22 stand out as the main quantitative inputs. On the other hand, catch rates and emissions to air that arise from diesel combustion are the main outputs. Data are here referred to 1 tonne of landed species in order to facilitate reading. Additionally, Table 12.2 summarizes the main inventory data for turbot aquaculture in Galicia.

The reported average annual leakage for R22 in coastal trawlers was 150 kg per vessel, while the corresponding leakage for coastal purse seiners was of nearly 10 kg. The reported average leakage for offshore vessels was 200 kg per vessel and year. Finally, deep-sea purse seiners leaked on average 500 kg/y of R22. Moreover, these values are in a similar range to those reported by Winther et al. (2009).

Table 12.1. Summary of inventory data for some of the species selected (data per tonne of landed catch).

		Sp 1	**Sp 2**	**Sp 3**	**Sp 4**	**Sp 5**	**Sp 6**
Inputs from the technosphere	Units						
Diesel	kg	1550.5	315.9	175.5	2547.0	313.0	13.5
Net use	kg	N/Ap	1.53	10.12	8.78	N/Av	N/Ap
Antifouling	kg	2.23	0.41	0.36	2.12	0.16	0.17
Outputs: products	Units						
Production rate	t	1.00	1.00	1.00	1.00	1.00	1.00
Outputs: emissions to air	Units						
CO_2	kg	4916.1	1001.5	555.4	8038.0	990.6	42.70
SO_2	kg	15.51	3.16	1.75	25.47	3.13	0.13
VOC	g	3.72	0.76	0.42	6.11	0.75	0.03
NO_x	kg	111.6	22.75	12.6	183.4	22.53	0.97
CO	kg	11.47	2.34	1.30	18.85	2.32	0.10
R22	g	834.0	143.0	23.0	577.0	51.0	N/Ap

Sp 1= European hake (offshore long lining); Sp 2= Atlantic horse mackerel (coastal trawling); Sp 3= European pilchard (coastal purse seining); Sp 4= Anglerfish (offshore trawling); Sp 5= Tuna (deep-sea purse seining; Indian Ocean); Sp 6= Mussels (extensive aquaculture); N/Ap= not applicable; N/Av= not available.

Table 12.2. Summary of inventory data for turbot aquaculture in Galicia.

Inputs from the technosphere	Units	Amount	Outputs	Units	Amount
Liquid oxygen	t	3.48	Products		
Feed	t	1.55	Production rate	t	1.00
Diesel	t	0.86	Emissions to air:		
Electricity	MW/h	20.04	CO_2	t	5.99
			SO_2	kg	3.95
			NO_x	kg	5.33
			CO	kg	0.77

12.4. Results

12.4.1. Coastal fishing species

With the aim of estimating the annual CF of the Galician fishing activity, the CF of each of the selected species was performed. Coastal fishing species were the first species evaluated. Table 12.3 gathers the annual CFs for the coastal fishing species caught in Galicia. The first eight inputs involve the species evaluated, whereas the remaining inputs correspond to rough CFs estimated on the basis of the fishing gear. Tables H.1 and H.2 in the Appendix provide further carbon footprinting information concerning these other species. SimaPro 7 was the software used for the computation of the CFs (Goedkoop et al., 2010). The CF estimated for the whole coastal fishing activity in Galicia was 188,328 tonnes CO_2 eq.

Table 12.3. Carbon footprint calculation for the annual coastal fishing activity in Galicia.

Coastal fishing species	Scientific name	Fishing gear	Catch rate (t/y)	Carbon footprint (t CO_2eq/t)	Carbon footprint (t CO_2eq/y)
European pilchard	*Sardina pilchardus*	Seining	15,021	0.78	11,717
Atlantic horse mackerel	*Trachurus trachurus*	Trawling	12,898	1.44	18,574
Atlantic horse mackerel	*Trachurus trachurus*	Seining	11,246	0.98	11,021
Atlantic mackerel	*Scomber scombrus*	Trawling	9,795	0.88	8,620
Atlantic mackerel	*Scomber scombrus*	Seining	6,284	0.61	3,833
European hake	*Merluccius merluccius*	Trawling	11,094	6.46	71,670
Blue whiting	*Micromestimius poutassou*	Trawling	12,838	1.54	19,771
Chub mackerel	*Scomber japonicus*	Seining	8,811	0.78	6,881
Other species	-	Trawling	2,975	2.26	6,709
Other species	-	Seining	1,791	0.78	1,399
Other species	-	Other[1]	18,881	1.49	28,133
Total	-	-	111,636	-	188,328

[1]Other gears include trolling and artisanal vessels.

12.4.2. Offshore fishing species

Table 12.4 shows the CFs for offshore species. *Other species* include species, as shown in Table H.3 in Appendix I, whose CF was estimated based on gear and fishing area. An annual CF of 338,468 tonnes CO_2 eq. was estimated for the offshore fishing activity.

Table 12.4. Carbon footprint calculation for the annual offshore fishing activity in Galicia.

Offshore fishing species	**Scientific name**	**Fishing gear**	**Fishing area**	**Catch rate (t/y)**	**Carbon footprint (t CO_2eq/t)**	**Carbon footprint (t CO_2eq/y)**
European hake	*Merluccius merluccius*	Long lining	Northern Stock	9,770	7.21	70,442
European hake	*Merluccius merluccius*	Long lining	Northern Stock	5,555	6.96	38,664
Megrim	*Lepidorhombus spp.*	Trawling	Northern Stock	6,437	8.41	54,317
Anglerfish	*Lophius budegassa*	Trawling	Northern Stock	4,281	10.43	44,657
Norway lobster	*Nephrops norvegicus*	Trawling	Northern Stock	694.5	28.30	19,655
Conger eel	*Conger conger*	Long lining	Northern Stock	2,050	3.88	7,954
Atlantic pomfret	*Brama brama*	Long lining	Northern Stock	3,583	3.49	12,506
Common ling	*Molva molva*	Long loning	Northern Stock	778	3.13	2,436
Rock fish	*Helicolenus dactylopterus*	Long lining	Trawling	1,182	6.94	8,200
Fork beard	*Phycis spp.*	Long lining	Northern Stock	1,342	6.25	8,389
Bigeye tuna	*Thunnus obesus*	Long lining	Azores	126.7	20.45	2,590
Splendid alfonsino	*Beryx splendens*	Long lining	Northern Stock	80.3	3.49	280
Mako shark	*Isurus oxyrinchus*	Long lining	Azores	181.3	9.02	1,636
Porbeagle	*Lamna nasus*	Long lining	Azores	479.6	14.24	4,326
Swordfish	*Xiphias gladius*	Long lining	Azores	782.3	3.37	11,140
Blue shark	*Prionace glauca*	Long lining	Azores	1,807	6.39	6,081
Common cuttlefish	*Sepia officinalis*	Trawling	Mauritania	166.8	7.35	1,066
Common octopus	*Octopus vulgaris*	Trawling	Mauritania	810.0	6.91	5,953
Lesser-flying squid	*Todaropsis eblanae*	Trawling	Mauritania	932.3	4.00	6,442
Other species	-	Varied	Varied	7,934	-	31,735
Total	-	-	-	48,973	-	338,468

12.4.3. Open sea fishing species

Table 12.5 presents the CF of tuna based on the ocean basin where capture took place. The sum of the three CFs for tuna adds up to 207,019 tonnes CO_2 eq. per year. This value is assumed to represent the CF of annual open sea fishing activities, given that the Galician tuna processors are the final destination of all the tuna captured by the Spanish fleet.

Table 12.5. Carbon footprint calculation for the annual deep-sea fishing activity in Galicia.

Offshore fishing species	Fishing gear	Ocean	Catch rate (t/y)	Carbon footprint (t CO_2e/t)	Carbon footprint (t CO_2e/y)
Tuna	Seining	Atlantic	38,038	1.56	59,339
Tuna	Seining	Indian	70,800	1.39	98,412
Tuna	Seining	Pacific	26,068	1.89	49,268
Total	-	-	134,906	-	207,019

12.4.4. Mussels from extensive aquaculture

A calculated value of $8.31 \cdot 10^{-2}$ tonnes CO_2 eq. per tonne of farmed mussels together with an annual production of mussels cultured in Galicia of 188,818 tonnes (Xunta de Galicia, 2009), leads to an annual CF for mussel production of 15,691 tonnes CO_2 eq. As mussels cultured in traditional rafts involve practically all the production of the Galician extensive aquaculture, the CF of the annual extensive aquaculture activity in Galicia can be calculated through the use of a scaling factor that considers the ratio total extensive aquaculture production to total mussel production. Since the production rate of extensive aquaculture species in Galicia is 195,103 tonnes per year (Xunta de Galicia, 2009), the scaling factor is 1.03, and the CF of the extensive aquaculture activity in Galicia is 16,213 tonnes CO_2 eq. per year.

12.4.5. Turbot from marine intensive aquaculture

A value of 19.40 tonnes CO_2 eq. was found per tonne of farmed turbot, whose annual production is 6863 tonnes (Xunta de Galicia, 2009). Therefore, 133,144 tonnes CO_2 eq. per year are associated with turbot farming in Galicia. Since turbot represents more than 95% of the total production of the Galician marine intensive aquaculture, a scaling factor of total marine intensive aquaculture production to total farmed turbot production can be used in order to estimate the CF of the entire sector. Since the regional production rate of marine intensive aquaculture species is 7144 tonnes per year (Xunta de Galicia, 2009), the scaling factor is 1.04, and the annual CF of the Galician marine intensive aquaculture activity results in 138,592 tonnes CO_2 eq.

12.4.6. Galician fishing activity as a whole

The lump sum of the CFs for the five subsectors included in this study provides the CF of Galician fishing activities (Figure 12.3). Thus, 888,620 tonnes CO_2 eq. per year are attributed to the whole Galician fishing activity. Offshore fishing arose as the main branch contributing to the global CF, clearly ahead of deep-sea fishing. Marine intensive aquaculture and coastal fishing showed similar contributions to the final value, while extensive aquaculture was found to be the least contributing branch. Further details on the contributions to global warming are discussed in Section 12.5.1.

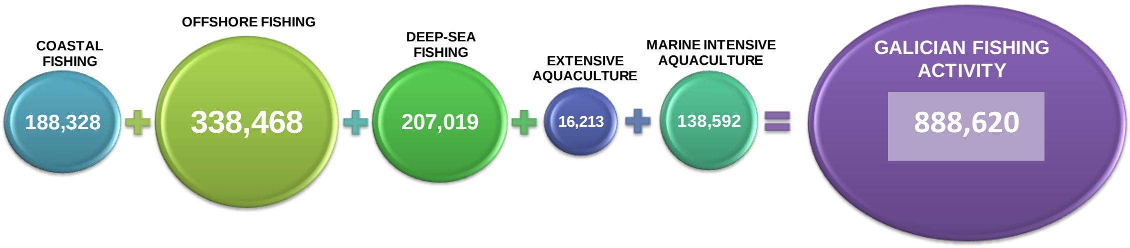


Figure 12.3. Estimation of the annual carbon footprint of the whole Galician fishing activity (tonnes CO_2 eq./year).

12.5. Discussion

12.5.1. Identification of climate change hot spots

CF involves a number of interesting applications and provides chain transparency and accountability for seafood (Iles, 2007; Ayer et al., 2009). For instance, the value of the individual CFs as well as the global CF of the Galician fishing activity is highly useful for benchmarking purposes. In particular, a benchmark for quantifying and communicating emission reductions is provided for the whole Galician fishing activity.

In Figure 12.4, the contribution of each of the commercial fishing and aquaculture subsectors to the global warming impact of Galician fishing activities is shown. As observed, coastal and deep-sea fishing contribute to the global CF in direct accordance with their contributions to the total catch rate and economic turnover of the Galician fishing activity. Furthermore, while extensive aquaculture entails a low contribution to the total CF (especially if compared to its total catch rate and economic turnover), marine intensive aquaculture shows an opposite behaviour. Finally, offshore fishing presents a CF contribution higher than that expected on the basis of its catch rate and economic turnover shares.

Prioritization of opportunities to reduce GHG emissions lead to focus efforts mainly on offshore fishing and marine intensive aquaculture. This remark could seem incongruous with the study provided in Chapter 8 on the comparative eco-efficiency in fisheries which conclude that offshore fleets are better optimized than coastal and extensive aquaculture fleets. However, in the current study, a global (sectorial) perspective is adopted without establishing any comparison at intra-fleet scale. Therefore, discussion just focuses on a comparison based on an inter-subsector scale, i.e. comparing the final CFs of each fishing subsector. This means that environmental improvements in offshore fishing will probably involve the most time- and cost-demanding measures within the Galician fishing activity as offshore operation is carried out in a comparatively efficient manner but, even so, the resulting potential impacts are excessive.

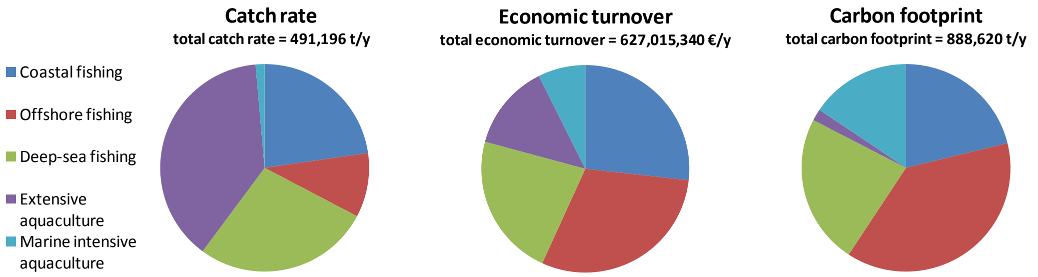


Figure 12.4. Distribution of total catch rate, economic turnover and carbon footprint among Galician fishing activities.

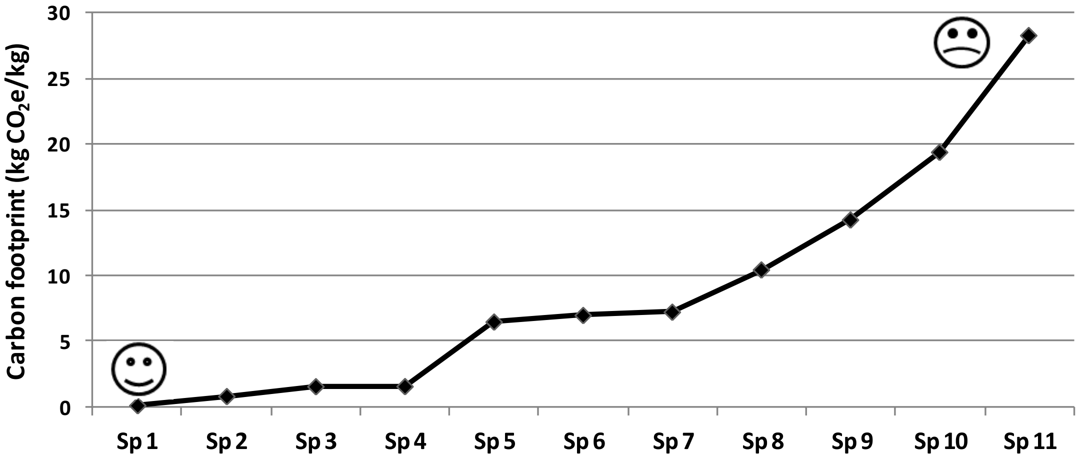
Furthermore, specific CF studies for individual species from commercial fishing and extensive aquaculture suggest that, as expected, diesel production and use constitutes the main source of global warming (Ziegler et al., 2003; Iribarren et al., 2010b). Consequently, improvement potentials for these fishing subsectors should focus on fuel demand minimization, e.g. use of fuels with higher energy efficiency and sustainable planning of vessel routes (Schau et al., 2009; Torres et al., 2010). On the contrary, when dealing with climate change mitigation for intensive aquaculture practices, improvement potentials should be centred on the minimization of the electricity demand for the operation at aquaculture plants.

Additionally, cooling agents proved to play a relevant role regarding their contribution to the CF of fishing activities. In this respect, GHG emissions from cooling agent leakage brought about an overall increase of 13% when comparing the final global carbon footprint for the Galician fishing activity with previous calculations that did not include these emissions. Further efforts, however, should be made in order to provide robust data regarding this type of emissions. Moreover, it is important to take into account that the gradual shift to new types of cooling agents, which should be completed by January 1st 2015, when the use of HCFCs such as R22 will be completely forbidden, may generate considerable changes in the contribution of refrigerant compounds to the global GHG emissions of European fishing fleets (European Commission, 2010).

Finally, a general strength of the wide use of CF lies in the spread of life-cycle thinking (Weidema et al., 2008). In this context, carbon footprinting promotes the idea that environmental protection demands a system approach to consider the whole life cycle of a product/activity, rather than a simplistic perspective merely focused on the control of emission sources (end-of-pipe technologies). Thus, a responsible use of CF would stimulate the establishment of a more thorough framework for the environmental assessment of products. Furthermore, CF-based policies could be made to promote the future development of a more comprehensive policy framework for the environmental assessment of products based on their life cycle.

12.5.2. Contrasting the final values

Individual CFs were obtained for a wide range of aquatic species. These results ranged from 0.08 (farmed mussels) to 28.30 (Norway lobster) kg CO_2 eq/kg of target species. According to previous studies on food carbon footprinting (Carbon Trust 2008b; Winther et al., 2009; CF-Thailand 2010), the calculated carbon footprints are comprised within the common range for food products. As observed in Figure 12.5, species from extensive aquaculture, coastal fishing and open sea fishing entailed CFs below 6.5 kg CO_2 eq/kg, while offshore species accounted for higher values. The higher values achieved by species linked to offshore fishing when compared to open sea species is due mainly to the fishing gear used. Open sea fishing in Galicia is mainly linked to purse seining vessels, whereas trawlers and long liners, in which fuel consumption levels are substantially higher than in seiners, are predominant in the offshore fleet (Ziegler et al., 2003; Thrane, 2004; Ziegler and Valentinsson, 2008; Schau et al., 2009). The CF for turbot was among the highest values since this species is farmed according to intensive aquaculture practices with high energy demand. Finally, the highest CF was associated with Norway lobster, which is partly due to the choice of economic allocation as this species presents a high price.



Sp 1 = mussel (extensive aquaculture), Sp 2 = European pilchard (coastal purse seining); Sp3 = tuna (average; deep-sea purse seining); Sp 4 = blue whiting (coastal trawling); Sp 5 = hake (coastal trawling); Sp 6 = hake (offshore trawling); Sp 7 = hake (offshore long lining); Sp 8 = swordfish (offshore long lining); Sp 9 = anglerfish (offshore trawling); Sp 10 = turbot (marine intensive aquaculture); Sp 11 = Norway lobster (offshore trawling)

Figure 12.5. Ranking the carbon footprint of a selection of species within the Galician fishing activity.

Moreover, this case study goes beyond a product-level research as it also estimates the CF of the Galician fishing activity as a whole. The comparison of this value with climate change results reported by previous sector-, region- or country-level studies would facilitate the interpretation of the global CF computed. For instance, the Spanish Ministry for Environment, Rural and Sea Affairs reported a value of 29.74 Mt CO_2 eq. for the Galician GHG emissions in 2008 (MARM, 2010; Verdegaia, 2010) and a value of 405 Mt CO_2 eq. for the Spanish GHG emissions in 2008 (MARM, 2010). Therefore, Galician fishing activities would entail 3% of total GHG emissions on a regional scale and 0.2% of emissions on a national scale. Additionally, the estimate for the carbon footprint of the total UK food system is 121 Mt CO_2e/y (Choudrie et al., 2008; Garnett, 2008). The whole Galician fishing activity would be equivalent to 0.6% of the GHG emissions linked to the UK food system. Even though these percentages are low, they stress the relevance of the Galician fishing activity in terms of GHG emissions since great scale differences arise when regional activity is compared to broader studies at country level.

12.5.3. Methodological choices affecting CF calculations

Despite the interesting potentials of CF, this tool is not lacking in methodological barriers. In fact, CFs are presented as sole figures. Therefore, caution is needed when reporting this type of results as assumptions and methodological choices can highly determine the final value.

The exclusion of capital goods is among the most relevant decisions that may influence the CF results (Iribarren et al. 2010a). Actually, draft versions of PAS 2050 included emissions related to capital goods (Sinden, 2009), and the current version excludes them but leaves the analysis of inclusion for future revisions of the specification (BSI 2008). Thus, previous studies on both LCA (Frischknecht et al., 2007b; Iribarren et al. 2011b) and CF (Iribarren et al. 2010a) suggest that future CF standards should include capital goods – even based on secondary data – for the calculation of carbon footprints, especially for the assessment of agricultural products and seafood from extensive aquaculture practices[3]. In order to evaluate the influence of capital goods in the case study of the Galician fishing activity, carbon footprints of some selected species were calculated including the GHG emissions linked to capital goods. Increases in carbon footprint were always below 2%, except for farmed mussels, whose carbon footprint highly depends on capital goods. Consequently, the influence of capital goods is considered negligible for species from commercial fishing and

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[3] PAS 2060, which was published shortly before the finalisation of this dissertation, includes the possibility of performing CFs including capital goods.

intensive aquaculture, but requires further attention when assessing species from extensive aquaculture.

Another decision that may entail relevant changes in CF results refers to allocation procedures. In this case study, economic allocation was chosen for the species landed by fleets extracting in multi-species fisheries, such as coastal trawling and purse seining, as well as offshore trawling and long lining. Table 12.6 reveals the role of allocation decisions by calculating the carbon footprints of a series of selected species if mass allocation were to be followed. As shown, this methodological choice usually involves significant changes in the final result. However, it is important to highlight that these changes in the individual CFs of the different species belonging to multi-species fisheries do not affect the global carbon footprint value obtained for the entire fishing activity. Instead, the global value's uncertainty is mainly affected by the non-assessed captures (only 8% of the total production).

Table 12.6. Measure of the change in the carbon footprint for a selection of species when using mass allocation.

Species	Regular CF (t CO2eq/t seafood)	CF using mass allocation (t CO2eq/t seafood)	Change
Horse mackerel from coastal trawling	1.44	2.54	+56.69%
European pilchard from coastal seining	0.78	0.82	+5.13%
Anglerfish from offshore trawling	10.43	9.27	-11.12%
European hake from offshore long lining	7.21	5.87	-18.59%

12.6. Conclusions

CF has proved to be a useful tool for the assessment of the life cycle GHG emissions associated with the Galician fishing activity. Thus, through the calculation of the individual CFs for a selection of species, the CF of the whole Galician fishing activity was estimated as a lump sum of the CFs attributed to commercial fishing (distinguishing coastal, offshore and deep-sea fishing) and aquaculture (extensive farming and marine intensive aquaculture). The methodological steps for this bottom-up approach can be generally applied for the CF of other sectors, not being limited to the fishing production sector.

An extended collection of climate change information regarding seafood was supplied. Beyond the regional interest of the CF results for the Galician fishing activity, this document provides reference values to be compared to similar results from future studies as well as to undertake complementary GHG assessments focused on the whole seafood supply chain. In fact, both LCA seafood community and seafood trade actors (e.g. fish processors) may benefit from the multiple values computed throughout the research.

CF arose as a potential support tool for decision making within the fishing sector, conducting to the identification of opportunities for climate change mitigation. Offshore fishing and marine intensive aquaculture were found to be the subsectors where improvement actions are primarily encouraged. While efforts in the abatement of GHG emissions for commercial fishing and extensive aquaculture species should be centred on the minimization of the vessel's demand for fuel, they should focus on the optimization of the electricity demand when dealing with marine intensive aquaculture plants.

The relevance of some methodological choices was evaluated. The exclusion of capital goods was concluded to entail significant changes in CF results only for species from extensive aquaculture. Furthermore, decisions on allocation procedures proved to be a key source of variability in the final results for individual species.

Even if CF implies a tool limited to only one impact category (i.e., global warming) and to certain methodological limitations, it is highlighted as a valuable vehicle for a future environmental assessment framework based on life cycle concepts for products in general and for seafood products in particular.

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Chapter 13

pescaenverde as a software method for carbon footprint calculation in fishing systems[1]

Summary

This chapter acknowledges the importance of fishing products not only on a Galician scale, but also on a national level. Given their relatively high GHG emissions, linked especially, as seen throughout the entire dissertation, to fishing operations, **pescaenverde** is presented as an environmental software method that aims at providing companies related to the fishing sector in Spain with a feasible mechanism for calculating the CF of products arriving from fishing vessels. The methodological basis for CF calculation in this software is discussed throughout this chapter, as well as the main advantages of the software. Finally, a series of advantages and constraints of the software are discussed.

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[1] Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2012). SC-0019-2012. January 19th 2012. Registered software: "Software de cálculo de huella de carbono para el sector pesquero: pescaenverde" [in Spanish]

Index

13.1. Introduction

Throughout this dissertation the importance of fuel consumption in Galician fishing vessels has been proved through the compilation of data inventories for a wide span of fishing fleets. Additionally, the computation of these inventories through the use of LCA methodology has certified the importance of fuel consumption in fisheries from an environmental perspective. In fact, environmental burdens linked to diesel production and combustion were identified as those with the highest contribution for most impact categories in all the Galician fishing fleets that were assessed in this doctoral thesis.

This finding, while not novel, supports the idea that reliance on fossil fuels by modern fleets has triggered attention towards the GHG emissions that these marine industrial systems generate (Winther et al., 2009). Hence, the use of CF, which is the LCA of a product that focuses exclusively on the GWP impact category, as explained in Chapters 2 and 12, has experienced increasing use in fishing sector systems in the last few years (Winther et al., 2009; Iribarren et al., 2010).

While this interest in reporting the CF of a product was initiated mainly due to the pressure of certain NGOs and the interest in improving the environmental profile of marine products by stakeholders, consumers in many developed countries have started to obtain information regarding not only the origin of the seafood products they are consuming, but also environmental information through eco-labels. In fact, as mentioned in Chapter 2, some eco-labels that focus on seafood have started including CF data as part of the assessment they perform on a given fishery or fishing fleet.

However, social perception and some publications highlight the fact that eco-labels have had a limited success in Spain, both in implementation by companies and the impact on consumers (Chamorro-Mera, 2003). The main causes linked to the low level of penetration of eco-labels in Spain are: i) the perception that eco-labels are not the most appropriate method to promote environmental improvements; ii) rejection of the environmental criteria followed by the eco-labels, considering that they do not reflect the state-of-the-art of the sector; iii) the perception that certain environmental limitations through legislation are sufficient to show the environmental profile of the product; iv) economic costs linked to the eco-label; and v) the low recognition given by the Spanish market to eco-labels (Chamorro-Mera and Bañegil-Palacios, 2003).

Recent surveys performed by the FROM, however, have shown a high percentage of seafood consumers in Spain who are interested in the labelling of products. In fact, the percentage of people that admit checking the label of a seafood product has increased from 59% in 2003 to 71% in 2011 (FROM, 2007, 2011), as can be seen in Figure 13.1. Nevertheless, it is important to note that the question did not discriminate between environmental seafood labels and other types of seafood labels. Nevertheless, the strength of these data suggests that the introduction of new eco-labels in the Spanish market for seafood products may have reached an adequate stage.

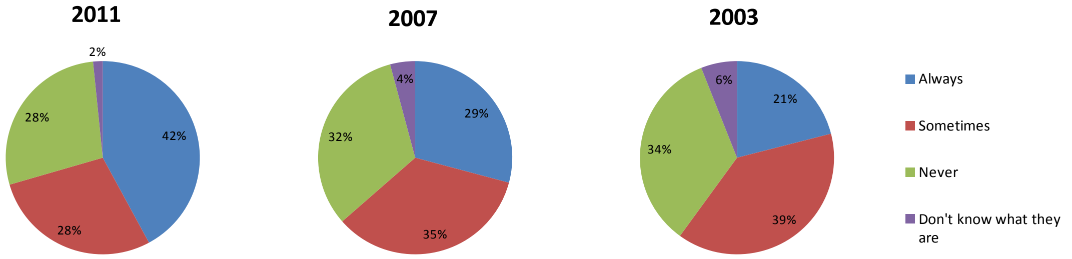


Figure 13.1. How often do consumers read the labelling of fresh seafood products?

Therefore, given the importance of fishing products not only on a Galician scale, but also on a national level, and given the relatively high GHG emissions linked to fishing operations, this chapter presents **pescaenverde**, which is an environmental software method that aims at providing companies related to the fishing sector in Spain with a feasible mechanism for calculating the CF of products arriving from fishing vessels. The methodological basis for CF calculation in this software is discussed throughout this chapter, as well as the main advantages and constraints of the software.

13.2. Software presentation

pescaenverde develops a software method that focuses specifically on calculating the CF of products captured by fishing vessels landing along the Spanish coast (Figure 13.2). Moreover, **pescaenverde** aims to become an important assessment tool in the fishing sector, in order to provide useful information to improve the management of Spanish fisheries, increase their fuel efficiency and contribute to reducing GHG emissions linked to these operations.

Figure 13.2. Software logo for **pescaenverde**.

Consequently, **pescaenverde** is presented as a simple user-friendly tool to calculate the CF of seafood products. The potential users of this software include all the major stakeholders of extractive fishing systems, such as skippers or fishermen, other stakeholders from the fishing sector, linked to auctions or processing industries, other groups of interest, such as NGOs, institutions or research centres, and seafood consumers. Hence, the utility and potential of **pescaenverde** is based on an attempt to set in motion technology transfer in the fishing sector regarding CF.

13.3. Calculation method

A specific framework for the standardization of CF calculation is currently being developed by ISO14067. However, there are a wide range of organizations that have already implemented their own specific standards, such as Carbon Trust with PAS 2050 (BSI, 2008). PAS 2050, as well as other CF approaches have developed their specific methodologies based on a life cycle perspective, using LCA requirements stated in ISO 14040:2006 and ISO 14044:2006 as reference documents (Carbon Trust et al., 2008).

The methodology used in **pescaenverde** has been developed based on the requirements stated by ISO (ISO 2006a; 2006b). This decision was based on the fact that this software attempts to provide detailed and easily understood results to the stakeholders and consumers of seafood products in Spain. Therefore, it was considered that the use of a more rigid methodology, such as PAS 2050, would limit the range of result reporting (BSI, 2008).

13.3.1. Goal, scope and inventory requirements of the methodology

pescaenverde, as abovementioned, is a software method that focuses on calculating the CF of landed seafood products. It is important to note that this first version of the software only includes the evaluation of the GHG emissions that occur in the fishing operation phase up to landing of the products at a given port. The rationale behind excluding on land stages and activities is linked to the fact that the software has been created based on the existing bibliography relating to seafood LCA, as well as the data and observations found throughout the present dissertation. Therefore, due to (i) the multiple pathways that seafood products may take once landed at a given port; (ii) the varied processing techniques that can be applied to certain elaborate fish products; (iii) mixing in some cases with other food production systems when the final product presents a multiple ingredient format; (iv) the fact that specific fish processing systems, such as canned fish or multiple ingredient products, have had limited coverage in the related literature, making it difficult to draw inventory data trends; and (v) the heavy dominance of the extractive fishing activities on the overall GHG emissions of seafood products (see Section II), **pescaenverde** only provides CF forecasting for raw products landed by fishing vessels or fleets.

Hence, all activities performed on the fishing vessels were included within the potential system boundaries in the computation method, including all the derived background processes. Based on a series of forces that drive result reporting in fisheries CF, a series of common ground data collection items can be identified when performing the inventory of a fishing fleet, regardless of the methodological and non-methodological choices that may be implemented. The use of the basic protocol proposed in **pescaenverde** may also help to enhance results between studies, which are in many cases useful in order to compare similar fleets, gear or for use in broader studies relating to food supply chains, meals or diets. Therefore, the following set of data inventory items were included in the software and are recommended for inclusion in CF studies regarding wild fish capture systems:

- *Diesel production and consumption.* Fuel consumption and its production has proved to be an important factor to take into account when analysing the CF of seafood products, due to the high FUI that many fishing fleets have.
- *Gear production and use.* This subsystem has been found to be particularly relevant in low energy intensity fisheries, as seen in Chapter 4, especially when gear transportation is bulky and/or easily lost or damaged.
- *Anti-fouling and boat paint.* Painting is usually an annual maintenance activity. Its main environmental burdens are linked with copper emissions to the ocean. However, the production of these paints creates a certain amount of GHG emissions that are included for computation in the software.
- *Cooling agents.* Recent literature has proved their importance in terms of GHG emissions in many fishing fleets (see Section II and Chapter 12; Winther et al., 2009; Ziegler et al., 2011). Consequently, their inclusion is recommended in fisheries studies provided that the analysed vessels present some sort of refrigeration system other than icing the catch.
- *Ice Production.* On land production in Spanish ports is common in coastal fishing fleets, as seen in Chapter 3. GHG emissions linked to on land production depend on the energy requirements of the ice factory. On board production, however, has not been assessed independently, since its production is based on diesel consumption mentioned in the fuel section. Therefore, deeper analyses regarding fuel use breakdown may help understand the energy implications of on board ice production. However, the latter scenario is not taken into consideration in the current software due to lack of bibliographic data.
- *Vessel construction.* Several studies have included vessel construction in the LCI (Hospido and Tyedmers, 2005), including the fishing fleets assessed in Sections II and III. However, this has always been a relatively simplistic inclusion of the main materials involved in vessel construction (i.e. steel, wood or polyester), without taking into account other important materials, such as technological goods on board. Furthermore, no fisheries LCA studies

have included ship dock systems, which may constitute an interesting system boundaries expansion for future research. Therefore, the computation of vessel construction in **pescaenverde** only assumes the basic construction elements taken into account to date in the bibliography.

- *Captures.* An effort to report a detailed inventory regarding the use of the natural resource (i.e. fish or other marine organisms) must be performed in order to guarantee the validity and transparency of a given study. Therefore, the software is designed to include up to 10 different marine species within the same production system, in order to obtain separate CF values for each of the captured species. Regarding data quality, it is recommended to use landed catch values from a primary data source.

13.3.2. Functional unit

Given the wide range of FUs that the users of a CF software could use, **pescaenverde** has introduced two different perspectives: mass, in kilograms or tonnes and economic, in Euros (Figure 13.3). The chosen mass units are based on the fact that the reference time period for assessment is one year of captures. This reference timeline was chosen based on the perspective adopted throughout the case studies undergone in this dissertation and other seafood related articles (Hospido and Tyedmers, 2005; Winther et al., 2009). Additionally, given that the production system evaluated in this software ends when the fish is landed at a port, the selection of bulk landings as FUs is expected. Therefore, kilograms and tonnes were considered the most suitable mass units for CF computation. Regarding an economic FU selection, the euro was chosen since it is the currency used in Spain and due to its commercial importance on a worldwide scale.

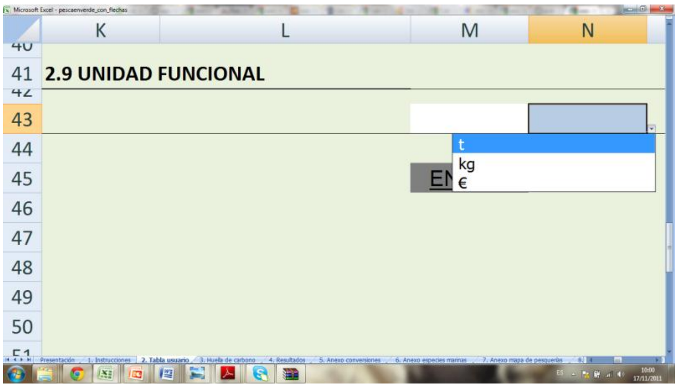


Figure 13.3. Caption of the functional unit section in the User table of **pescaenverde**.

13.3.3. Allocation

The proposed software includes result reporting based on economic or mass allocation. Therefore, it was not possible to follow the first recommendations by ISO standards when treating co-products, such as system expansion. Moreover, allocation strategies have proved to be a key feature in fisheries LCA conducted up to date, since they may affect results interpretation, as seen in Chapters 2 and 5. Hence, in the traditional mass and economic approaches seen in most literature studies, recent articles suggest the use of other allocation perspectives in fisheries, mainly linked to the energy content of the products or to other biophysical aspects (Pelletier and Tyedmers, 2011; Svanes et al., 2011).

However, in **pescaenverde** only mass and economic allocation were selected in order to maintain the user-friendly approach with which the software aims to reach consumers, and due to the fact that recently proposed allocation strategies for fisheries do not have, to date, solid support in the bibliography in terms of a clear biophysical indicator to use as reference.

13.4. Software structure

pescaenverde consists of a set of 9 Excel spreadsheets, as shown in Table 13.1, which can be divided into four major sections. In the first place, the presentation and Spreadsheet 1 (Instructions), provide the major features of the software, on how to handle its use and on some major advantages of applying it to fishing systems. Secondly, the user table (Spreadsheet 2) includes all the necessary data for the user to introduce the inventory data for CF computation. The third section (Spreadsheets 3 and 4) focuses on result presentation and classification. Finally, section four consists of a series of appendices with important information for the correct computation of the inventory data (Spreadsheets 5, 6 and 7) and for result interpretation (Spreadsheet 8).

Table 13.1. Structure of the proposed software.

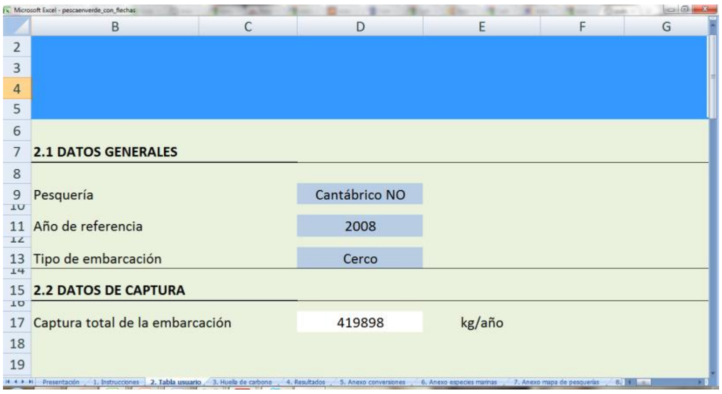
Note that the software is in Spanish. Spreadsheet names in this table correspond to translations

Spreadsheet	Description
Presentation	Brief description of the methodology and its major assumptions.
1. Instructions	Explanation for users on how to fill in the user table.
2. User table	Spreadsheet that includes all the inventory data the user must fill in.
3. Carbon footprint	Final global CF value for the selected FU, assuming bulk total catches. CF classification in accordance with literature results.
4. Results	Detailed CF results per landed marine species. Detailed CF results per input.
5. Appendix. Conversions	Conversion factors for the units used in the software.
6. Appendix. Marine species	List of the marine species included in the software. Together with the scientific name and the FAO code, species names are available in Spanish, Galician and English.
7. Appendix. Fisheries map	Map with the main fisheries where the Galician and other Spanish fishing fleets operate.
8. Appendix. Classification	Brief and general description of GHG emission mitigation measures depending on the CF of a given product.

13.5. Application of the software to the Galician coastal purse seining fleet

13.5.1. Life cycle inventory computation in the software

The example proposed for computation in the software is the average inventory data in 2008 for the Galician purse seining fleet analysed and discussed in Chapter 3 from an LCA perspective and in Chapter 12 from an exclusively CF approach (Figure 13.4). While Chapter 3 and 12 focused on the analysis of specific products landed by this fleet, **pescaenverde** allows an integrated approach in which the individual CF for each co-product is reported based on mass or economic allocation, as well as a global CF for the bulk of landed fish with respect to the selected FU. Hence, the species considered were Atlantic horse mackerel, with an economic value of 0.82 €/kg, as already discussed in Chapter 3, European pilchard (0.65 €/kg) and Atlantic mackerel (0.51 €/kg), as shown in Figure 13.5.



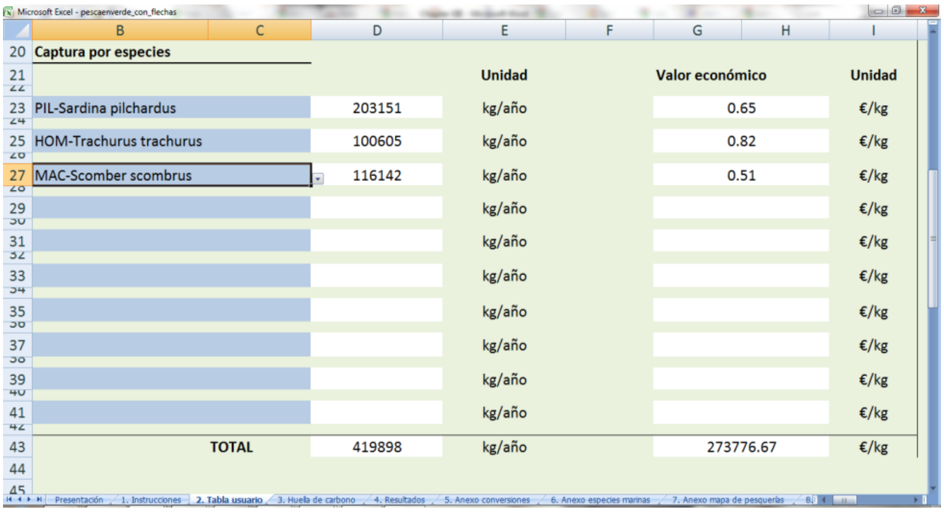
2.1 DATOS GENERALES

Pesquería: Cantábrico NO
Año de referencia: 2008
Tipo de embarcación: Cerco

2.2 DATOS DE CAPTURA

Captura total de la embarcación: 419898 kg/año

Figure 13.4. Caption of the User table. Users must include the fishing fleet characteristics, as well as the total landings of the vessel/fleet.

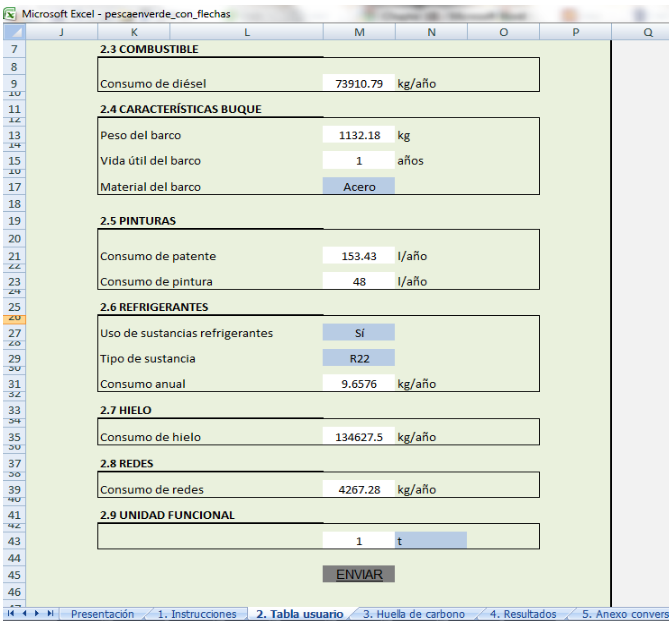


Captura por especies

		Unidad	Valor económico	Unidad
PIL-Sardina pilchardus	203151	kg/año	0.65	€/kg
HOM-Trachurus trachurus	100605	kg/año	0.82	€/kg
MAC-Scomber scombrus	116142	kg/año	0.51	€/kg
		kg/año		€/kg
		kg/año		€/kg
		kg/año		€/kg
		kg/año		€/kg
		kg/año		€/kg
		kg/año		€/kg
		kg/año		€/kg
TOTAL	419898	kg/año	273776.67	€/kg

Figure 13.5. Caption with detailed landing per species and economic value in the User table.

Once these details were introduced in Spreadsheet 2 (User table), as seen in Figures 13.4 and 13.5, the average total landings for the 30 assessed purse seiners were included in the spreadsheet (Figure 13.5), as well as the individual landings per species and their economic value at the fish auction. The total annual inventory values were also included in the User table, as seen in Figure 13.6. Finally, the selected FU was 1 tonne of landed fish. Note that inventory data referred to 1 tonne of landed Atlantic horse mackerel is also available in Table 3.3 (see Chapter 3).

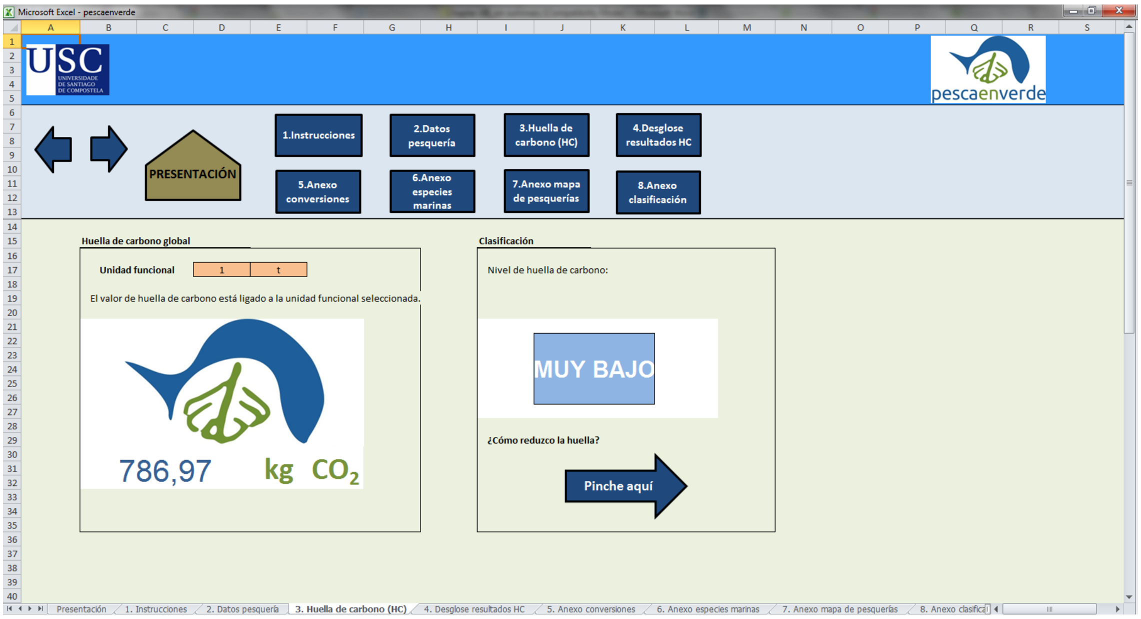


2.3 COMBUSTIBLE		
Consumo de diésel	73910.79	kg/año
2.4 CARACTERÍSTICAS BUQUE		
Peso del barco	1132.18	kg
Vida útil del barco	1	años
Material del barco	Acero	
2.5 PINTURAS		
Consumo de patente	153.43	l/año
Consumo de pintura	48	l/año
2.6 REFRIGERANTES		
Uso de sustancias refrigerantes	Sí	
Tipo de sustancia	R22	
Consumo anual	9.6576	kg/año
2.7 HIELO		
Consumo de hielo	134627.5	kg/año
2.8 REDES		
Consumo de redes	4267.28	kg/año
2.9 UNIDAD FUNCIONAL		
	1	t

Figure 13.6. Inventory data items for the average Galician purse seining vessel.

13.5.2. Result interpretation

The results obtained are thereafter presented in Speadsheets 3 and 4. Spreadsheet 3 presents the CF of the selected sample in terms of the FU selected in the User table spreadsheet, that is, based on the bulk landings of the vessel (Figure 13.7). Additionally, this same spreadsheet classifies the bulk CF of the vessels' or fleets' landings based on bibliographical results and on results obtained in this dissertation. However, it is important to note that this classification is an attempt to give simple guidelines to stakeholders and other users of the software. Therefore, the proposed classification may not be suitable for all the specific case studies. Nevertheless, it represents a series of assumptions that can be considered within the ranges of available CF studies of seafood products.



Huella de carbono global

Unidad funcional: 1 t

El valor de huella de carbono está ligado a la unidad funcional seleccionada.

786,97 kg CO_2

Clasificación

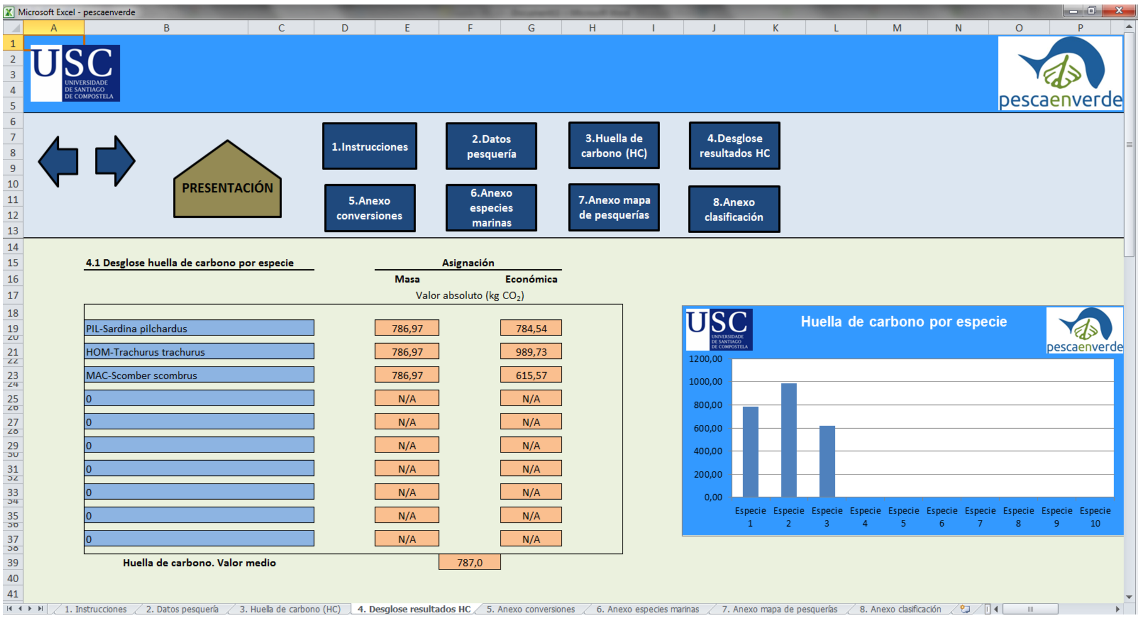
Nivel de huella de carbono:

MUY BAJO

¿Cómo reduzco la huella?

Figure 13.7. Carbon footprint results for the average Galician purse seining vessel (results per species).

In contrast, Spreadsheet 4 shows a detailed disaggregation of the results. Hence, the CF is broken down by species, taking into account mass and economic allocation, as seen in Figure 13.8. Additionally, in this same spreadsheet a breakdown by operational inputs is included, showing the contribution to the total CF of different activities, such as vessel construction or diesel combustion. This breakdown allows users to choose the way in which they want to report their results, since depending on their activity they may have more interest in economic or mass allocation, as well as different levels of interest in reporting the CF of different species.



4.1 Desglose huella de carbono por especie

	Asignación	
	Masa	**Económica**
	Valor absoluto (kg CO_2)	
PIL-Sardina pilchardus	786,97	784,54
HOM-Trachurus trachurus	786,97	989,73
MAC-Scomber scombrus	786,97	615,57
0	N/A	N/A
0	N/A	N/A
0	N/A	N/A
0	N/A	N/A
0	N/A	N/A
0	N/A	N/A
0	N/A	N/A
Huella de carbono. Valor medio	787,0	

Figure 13.8. Detailed carbon footprint results for the average Galician purse seining vessel (results per species).

Finally, the appendices of the software include additional information to make it more accessible for users, since they include a list of the main conversion the user may need to implement in order to insert the data inventory values in the software (Spreadsheet 6), a detailed list of fishing species in three different languages, as well as the FAO code for fishing species and the scientific name (Spreadsheet 5), a map with the main fisheries of Galician and Spanish fishing fleets (Spreadsheet 7) and, finally, a brief explanation of the main characteristics of the different classification levels included in the results table (Spreadsheet 8).

13.6. Advantages and constraints of the proposed software

The importance of this software is based on the following points:

- It constitutes the first available tool for calculating the CF of fishing vessels, as well as the fishing products landed by these.
- Currently, Spain is still the main fishing nation in the EU. Therefore, the use of this software has an important strategic value for Spain. Given that Galicia is the main fishing

region in Spain and the EU, it is expected that this software may be of interest for the approximately 5,000 fishing vessels registered throughout its coast.

- The increase in fuel prices in recent years implies that the fishing sector has to search for methods to control and monitor fuel consumption.
- Increasing environmental legislation, which has created stricter requirements regarding GHG emissions, urges the fishing sector to search for mechanisms to acquaint them with their emissions, in order to perform feasible GHG mitigation or reduction schemes.
- **pescaenverde** bases its CF estimates on current environmental legislative frameworks (ISO 2006a), using the characterization factors proposed by the IPCC.

However, **pescaenverde** in its current version only aims at estimating CF values for extractive fishing systems. Therefore, aquaculture systems are not taken into account. Furthermore, as explained earlier in this chapter, CF calculation was limited to the extractive phase of seafood, without taking into account on land stages of the supply chain. While these two factors may imply certain constraints concerning the applicability and the utility of the methodology, they also confer the method with a higher specificity. In fact, given that the most relevant results of this doctoral thesis relate to fishing operations Galicia, the software is adapted to the specific characteristics of the Galician fleet, its fisheries and its legislation. However, given the shared characteristics of many fleets and fisheries with other Spanish regions, such as Asturias, the Basque Country, Andalusia, which constitute other important fishing regions on a national scale, it is expected that this software can be used throughout the entire Spanish fishing sector.

13.6. References

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SECTION VI

CONCLUSIONS

Chapter 14

General conclusions

The main aim of this doctoral thesis was to assess the environmental performance of the extractive fishing sector in Galicia through the application of LCA and other complementary tools. Given that Galicia is currently the most important fishing region in Spain and one of the most fishing-dependent regions on a EU scale, many of the conclusions and perspectives obtained in this study may be extrapolated to other fishing fleets on a European or international level. General conclusions obtained in sections II, III, IV and V are detailed below.

Section II.

The current dissertation has focused on creating a detailed inventory of industrial fishing fleets in Galicia, assessing 89 vessels in the years 2008 or 2009. In fact, the total landings performed by these vessels added up to 41,506 tonnes of varied fish, representing roughly 20% of Galician fish landings. These fishing boats presented varied fishing gears and geographical locations concerning fish extraction. Furthermore, their captures included some of the most iconic and representative fishing species in the Galician fishing sector. These species included, but were not limited to, a series of demersal species, such as European hake, anglerfish, megrim or blue whiting, pelagic species, such as European pilchard, Atlantic horse mackerel or Atlantic mackerel, and cephalopods and crustaceans, such as common octopus, sepia or Norway lobster. When some of the most representative species of the different fishing fleets were analyzed in more detail, the following set of conclusions was gathered:

- The two Galician coastal industrial fishing fleets assessed (i.e. trawlers and purse seiners) showed a strong dependency on fuel consumption, which implies that the energy carrier is the main driver of the environmental impacts when conventional LCA impact categories are taken into account. In fact, this finding applied to all the other Galician fishing fleets assessed in this dissertation. Nevertheless, Atlantic horse mackerel captured by purse seining vessels displayed environmental impacts that ranged from 49% to 89% lower than those found in mackerel captured by trawlers.

- Concerning fishery-specific impacts, Atlantic horse mackerel landings by coastal trawlers implied an important impact on the seabed, as well as a high percentage of discards with respect to the total number of captured fish (42%). In contrast, purse seining vessels created minimal impact regarding seafloor damage, as well as a low discard rate.
- Given the high interannual fluctuations in pelagic fish abundance, an extended timeline analysis from an LCA perspective was suggested in order to confirm the range of environmental impacts obtained for this type of fisheries. However, for this particular case study, the Atlantic mackerel (NEAM) fishery in the Basque Country was selected, due to the lack of data availability for Galician fleets. Results confirmed the need to expand the timeframe of fisheries LCA on a regular basis when assessing small pelagic species, since strong annual environmental impact variations, of up to 324%, were detected between the years assessed in this study.
- Regarding demersal species, as far as it was possible to ascertain, it is the first LCA performed in Spanish demersal fisheries. In particular, given that it is the most consumed fish species on a national scale, as well as providing an important economic turnover to the Galician fishing sector, European hake was the species selected. Furthermore, this study is also characterized for being the first attempt to analyze the environmental impact generated through the life cycle of fresh fish consumption in Spain, one of the main fish-eating nations in the world. More specifically, European hake from the Northern Stock, captured by long liners and trawlers, was the product selected.
- Results for the European hake LCA showed increased environmental impacts for activities relating mainly to marine diesel consumption and, to a lesser extent, land transportation. Other activities, such as bait processing, electric consumption and plastic and organic waste disposal demonstrated lower contributions to the entire system. When analyzed in further detail, fresh European hake captured by long liners present reduced environmental burdens for all impact categories when compared to fillets arriving from trawlers. Reductions ranging from 18% to 32% were obtained when using long lining vessels to supply the hake market in all the conventional impact categories considered. Moreover, hake caught by long liners also displayed an improved environmental profile in terms of discards, seafloor impact and net primary productivity.

- Reduction of energy consumption, through improvement of vessel design and other less conventional techniques, such as redefining fishing quotas for the different fleets or the introduction of mother ships is highly recommended in order to reduce the environmental impacts related to fishing vessels operations in the Northern Stock. Furthermore, these key factors may represent substantial cost reductions when it comes to improving the environmental performance of the product assessed.
- Published fishery LCA studies to date mainly embrace fishing species belonging to European countries or other developed fishing nations. In fact, only one previous LCA study has released environmental information regarding fish extraction in an African nation EEZ. Therefore, the cephalopod fishery evaluated in the last chapter of Section II attempts to increase environmental impact information regarding seafood products extracted in developing countries that are then exported to industrialized nations. Hence, another representative species of the Galician fishing sector, frozen common octopus was analyzed from a "cradle to gate" perspective, including fishery activities by Galician trawlers in the Mauritanian EEZ, and on land activities in Mauritania up to its arrival in the country of destination.
- On board vessel activities were highlighted as the main hot spots regarding environmental burdens, mainly due to the high energy use of cephalopod trawling in Mauritania, but also to the industrialized characteristics of the vessels, with processing and packaging activities prior to seafood landing. Minimization of fuel consumption, together with fishery-specific impacts, such as discards or seafloor impact, and replacement of R22 by less harmful cooling agents, were considered important potential improvements. Post-harvesting operations were deemed insignificant for frozen octopus, regardless of the exporting route, provided marine freight is the selected transport method for this long shelf-life product.
- Hence, frozen common octopus extracted in Mauritanian waters, as long as the abundance of its stock is guaranteed, presented a sustainable post-harvesting supply chain up to its key importers. Therefore, the effectiveness of this tradable seafood product from an environmental point of view will depend primarily on its relative energy use in the fishery in comparison with other main octopus fishing areas in the world.

Section III.

The combined five-step LCA+DEA methodology proved to be a suitable methodology for fishing systems. However, its potential application to other facilities such as farms or wastewater treatment plants is feasible, as long as LCI data for multiple similar facilities are available. The new methodological approach for fisheries entailed appealing characteristics, among which, the following are highlighted:

- Avoidance of the use of average inventories when assessing a high number of similar facilities. In this sense, undesirable standard deviations are prevented.
- Facilitation and enrichment of the interpretation of the results for multiple LCAs. The LCA+DEA method is not limited to environmental impacts but adds an economic dimension to the sustainability assessment of fisheries by integrating an operational benchmarking of the vessels' performance.
- Means for eco-efficiency verification. The LCA+DEA approach reveals the link between operational efficiency and environmental impacts, quantifying the environmental consequences of operational inefficiencies. The application of LCA to the virtual targets quantitatively verifies whether the operational benchmarking leads to a better environmental performance.
- As shown for the trawling case study, in those cases where impact categories are not yet established or are out of consensus, the complementary use of DEA enables the quantification of potential improvements for controversial issues such as fish discarding. This advantage is possible due to the availability of a wide range of DEA models. Examples of specific models with interesting potentials of use include, among others, weighted models and OBad models.
- The underlying philosophy for the LCA+DEA method is to join the strengths and minimize the weaknesses attributable to both methodologies so that a synergistic effect is achieved by maintaining a quantitative character. Therefore, the final recommendation is to adopt this LCA+DEA approach as the regular methodology for the LCA of fisheries.

Concerning the use of the five-step LCA+DEA method for intra- and inter- assessment for a broad number of vessels belonging to six different Galician fishing fleets, permitted the computation of operational and environmental benchmarks regarding key consumption inputs.

- Results demonstrated the strong dependence of environmental impacts on one major operational input: fuel consumption. The potential for minimization of energy resources was greater for the less intensive fuel-consuming fleets, such as coastal purse seining and auxiliary mussel rafts vessels. Vessels belonging to fuel-intensive fleets generally showed an increased efficiency of fuel-related inputs in comparison with other operational inputs. Other secondary issues besides fuel activities, such as vessel construction or net consumption, presented slight impacts on the total environmental burdens of the vessels of the different fleets, but the reduction of these inputs through operational benchmarking may offer the skippers a substantial decrease in operational costs.
- The operational efficiency of the average vessel for the open sea and offshore fleets analyzed was significantly higher than that for the coastal fleets. The percentage of vessels that were deemed efficient was also reduced for coastal fleets.
- Future research dealing with the joint assessment of fleets could focus on determining the relationship between the degree of exploitation of the different fisheries and the efficiency shown by the fleets working in them, to assess whether low efficiencies can also be linked to overexploitation. Skippers, fisheries managers, and policymakers are expected to use this set of results as a valuable support for decision making.

Finally, the sole use of DEA has been applied previously for TE and CU identification in fishing fleets. However, in this doctoral thesis DEA was used to analyze the existence of a “skipper-effect” in the efficiency of purse seining vessels in the US menhaden fishery.

- Results obtained reaffirmed the existence of a skipper effect in all the ports analysed. Nevertheless, the differing patterns observed with respect to individual vessels in the ports evaluated demonstrated that skipper effect can be attested in different ways. For instance, skippers in the Atlantic fishery appeared to have similar skills, while skippers in the Gulf ports assessed showed a wider range of abilities.

- The confirmed importance of skipper effect in this fishery is expected to be of value for other fisheries and fishing fleets with similar characteristics, such as small pelagic species fisheries, where the instinct and knowledge of identifying shoals is extremely relevant.
- DEA presents itself as a feasible tool not only for determining the overall efficiency of fishing vessels, but also as a valid tool for identifying the specific sources of inefficiencies. Moreover, the results imply that policy-making and management in fisheries should pay closer attention to other issues besides CU when deploying vessels.

Section IV.

Detailed estimations on global discards were calculated for the Galician fishing fleet given the wide set of inventory data available, in order to improve global stock assessments and to quantify the damage that discards may have on wild ecosystems. In fact, as far as I was able to ascertain, this study constitutes the first integral research relating to global discard rates for the entire Galician fishing fleet.

- Results obtained prove the leading role of demersal trawlers in discard generation in the Galician fishing fleet, certifying that improved management measures in target stocks must take into account that alternative fishing gears other than trawling nets may reduce the amount of discards for certain species.
- The application of GDI as a new indicator in fishery life cycle studies achieved the important objective of integrating discard data as a fishery-specific impact in LCA studies. Its use did not succeed in determining the specific impacts that discards are potentially creating over a specific ecosystem in a given fishery, since discard patterns depend on a wide range of variables (stock abundance and distribution, fishery policy, landing restrictions, fishermen's behaviour, etc). Nevertheless, it constitutes a useful starting point to identify tendencies in discard and discard management in worldwide fisheries, thanks to its dynamic characteristics.
- In fact, to date, conventional impact categories used in LCA studies have focused on the environmental impacts that originate from the wide range of fishery-linked industrial activities. However, the driving force of most of these is linked to energy use. Therefore,

the proposed methodology, in the same way as other previously recommended biological impact categories (i.e. BRU or SIP), aims at increasing the usefulness of fisheries LCA as a management tool by adding a fishery-specific perspective to the assessment. Accordingly, the specific indicators for discards will generally prove feasible in fisheries LCA research and can be understood as a regular procedure to follow in fishery assessment.

Section V.

CF has proved to be a useful tool for the assessment of the life cycle GHG emissions associated with Galician fishing activity. Thus, through the calculation of the individual carbon footprints for a selection of species, the carbon footprint of the whole Galician fishing activity was estimated as a lump sum of the CFs attributed to commercial fishing (distinguishing between coastal, offshore and deep-sea fishing) and aquaculture (extensive farming and marine intensive aquaculture).

- An extended collection of climate change information regarding seafood was supplied. Beyond the regional interest of the CF results for the Galician fishing activity, reference values are provided for comparison with similar results from future studies as well as to allow complementary GHG assessments focused on the whole seafood supply chain. In fact, both LCA seafood community and seafood trade actors may potentially benefit from the multiple values computed throughout the research.
- CF arose as a potential support tool for decision-making within the fishing sector, leading to the identification of opportunities for climate change mitigation. Offshore fishing and marine-intensive aquaculture were found to be the subsectors where improvement actions are primarily encouraged. While efforts in the abatement of GHG emissions for commercial fishing and extensive aquaculture species should be centred on the minimization of the vessel's demand for fuel, they should focus on the optimization of the electricity demand when dealing with marine intensive aquaculture plants.
- The relevance of some methodological choices was evaluated. The exclusion of capital goods was found to entail significant changes in CF results only for species from extensive aquaculture. Furthermore, decisions on allocation procedures proved a key source of variability in the final results for individual species.

- Even if CF implies a tool limited to only one impact category (i.e., global warming) and to certain methodological limitations, it is highlighted as a valuable vehicle for a future environmental assessment framework based on life cycle concepts for products in general and for seafood products in particular.

Finally, **pescaenverde**, an environmental software method that aims at providing companies related to the fishing sector in Spain with a feasible mechanism for calculating the CF of products arriving from fishing vessels, was presented in Chapter 13. The methodological basis for CF calculation in the software was discussed throughout the chapter, as well as the main advantages and constraints of the software.

ADDITIONAL CONTENTS

Appendix I

Complementary tables

Table A.1. Fishing landings in Galicia by species in 2008 and economic turnover.
Source: Xunta de Galicia (2010).

Species name	Scientific name	FAO code	Species name (Galician)	Landings 2008 (t)	Economic value (€)
European hake	*Merluccius merluccius*	HKE	Pescada	26,438.96	98,267,828
Horse mackerel	*Trachurus trachurus*	HOM	Xurelo	24,258.76	19,870,651
Atlantic mackerel	*Scomber scombrus*	MAC	Xarda	16,141.18	8,258,121
European pilchard	*Sardina pilchardus*	PIL	Sardiña	15,021.76	9,759,050
Blue whiting	*Micromesistius poutassou*	WHB	Lirio	12,838.09	11,424,839
Chub mackerel	*Scomber japonicus*	MAS	Xarda pintada	8,810.94	3,144,844
Megrim	*Lepodorhombus spp.*	LEZ	Rapantes	6,437.19	28,973,448
Blackbellied angler	*Lophius budegassa*	ANK	Peixe sapo	4,281.62	23,888,350
Atlantic pomfret	*Brama brama*	POA	Castañeta	3,583.27	6,384,379
Common octopus	*Octopus vulgaris*	OCC	Polbo	3,239.70	15,824,725
Thronback ray	*Raja spp.*	SKA	Raias	3,027.99	5,415,827
Conger eel	*Conger conger*	COE	Congro	3,025.35	6,103,212
Lemon sole	*Microstomus kitt*	LEM	Mendo limón	2,880.00	8,754,004
Lesser flying squid	*Todaropsis eblanae*	TDQ	Pota pequena	2,796.88	4,397,981
Angler spp.	*Lophius piscatorius*	MON	Xuliana	1,993.45	10,415,452
Albacore	*Thunnus alalunga*	ALB	Bonito do Norte	1,945.38	6,932,462
Blue shark	*Prionace glauca*	BSH	Quenlla	1,806.60	2,662,000
Horned octopus	*Eledona cirrhosa*	OCM	Polbo cabezón	1,590.29	1,601,421
John Dory	*Zeus faber*	JOD	Sanmartiño	1,552.10	7,747,330
Witch flounder	*Glyptocephalus cynoglossus*	WIT	Coreano	1,520.47	5,407,580
Blackbelly rosefish	*Helicolenus dactylopterus*	BRF	Cabra de altura	1,181.62	4,197,340
Varied fish	*Piscis miscellanea*	XXX	Peixes mariños varios	1,158.23	1,254,357
Pouting	*Trisopterus luscus*	BIB	Faneca	1,132.99	1,841,452
Forkbeard	*Phycis phycis*	FOX	Bertorella de rocha	802.83	2,560,025
Swordfish	*Xiphias gladius*	SWO	Peixe espada	782.29	4,863,069
Common ling	*Molva molva*	LIN	Maruca	778.28	1,256,316
Sea urchin	*Paracentrotus lividus*	URM	Ourizo	747.95	1,987,498
Norway lobster	*Nephrops norvegicus*	NEP	Cigala	694.54	10,667,755
Bogue	*Boops boops*	BOG	Boga	639.70	117,819
Greater forkbeard	*Phycis blennoides*	GFB	Bertorella de lama	539.34	1,471,109
Shore rockling	*Gaidropsarus mediterraneus*	GGD	Barbada de area	523.96	1,576,350
Porbeagle	*Lamna nasus*	POR	Marraxo sardiñeiro	479.52	1,808,019
Common cuttlefish	*Sepia officinalis*	CTC	Choco	472.08	2,202,834
European squid	*Loligo vulgaris*	SQI	Lura	464.66	2,226,938

Table A.1. Fishing landings in Galicia by species in 2008 and 2009 (cont.).

Species name	Scientific name	FAO code	Species name (Galician)	Landings 2008 (t)	Economic value (€)
European Pollock	*Pollachis pollachius*	POL	Abadexo	438.17	2,388,706
Blue jack mackerel	*Trachurus picturatus*	JAA	Xurelo francés	401.98	84,967
Wreckfish	*Polyprion americanus*	WRF	Mero	361.14	4,702,544
Barnacle	*Mitella pollicipes*	PCB	Percebe	352.66	10,993,874
White sea bream	*Diplodus sargus*	SWA	Sargo común	314.46	1,770,441
European spider crab	*Maja squinado*	SCR	Centola	290.43	3,329,159
Shortfin squid	*Illex illecebrosus*	SQI	Pota voadora	287.91	415,420
European bittersweet	*Glycymeris glycymeris*	GKL	Rabioso	262.10	211,414
Ballan wrasse	*Labrus bergylta*	USB	Maragota	235.49	556,304
Black scorpionfish	*Scorpaena porcus*	SCO	Escarapote de pintas	216.56	590,153
Comber	*Serranus cabrilla*	BSX	Serrán de cabra	201.89	533,424
Tope shark	*Galeorhinus galeus*	GAG	Cazón	188.33	232,853
Shortfin mako	*Isurus oxyrinchus*	SMA	Marraxo azul	185.42	759,331
Bass	*Dicentrarchus labrax*	BSE	Robaliza	185.38	2,324,369
Red sea bream	*Pagellus bogaraveo*	SBR	Ollomol	178.34	1,721,750
Salerna	*Sarpa salpa*	SLM	Saboga	171.87	51,614
Mediterranean rainbow wrasse	*Coris julis*	COU	Doncela	151.77	788,273
Common scallop	*Pecten maximus*	SCE	Vieira	142.73	534,471
Red mullet	*Mullus surmutilus*	MUT	Salmonete de rocha	140.04	1,090,663
Axillary sea bream	*Pagellus acarne*	SBA	Pancho bicudo	127.41	483,603
Bigeye tuna	*Thunnus obesus*	BET	Atún patudo	126.67	920,391
Black sea bream	*Spondyliosoma cantharus*	BRB	Choupa	123.78	185,123
Haddock	*Melanogrammus aeglefinus*	HAD	Burro	122.49	172,857
Common sole	*Solea solea*	SOL	Linguado	120.18	2,083,977
Velvet swimcrab	*Necora puber*	LIO	Nécora	113.39	1,927,125
Escolar	*Lepidocybium flavobrunneum*	LEC	Escolar negro	104.20	245,025
Velvet belly lantern shark	*Etmopterus spinex*	SHL	Gata común	90.24	351,656
Small-spotted shark	*Scyliorhinus canicula*	SCL	Melgacho	87.67	47,798
Common prawn	*Palaemon serratus*	CPR	Camarón común	83.22	2,753,556
Scorpionfish	*Scorpaena scrofa*	SCO	Escarapote de pedras	81.91	362,328
Alfonsino	*Beryx decadactylus*	ALF	Castañeta vermella	80.30	596,707
Mediterranean horse mackerel	*Trachurus mediterraneus*	HMM	Xurelo do Mediterráneo	72.51	140,209
Beltfish	*Lepidopus eaudatus*	SFS	Peixe sabre prateado	71.03	99,026
Grey mullet	*Mugilidae*	MUL	Muxos	68.81	39,890

Table A.1. Fishing landings in Galicia by species in 2008 and 2009 (cont.).

Species name	Scientific name	FAO code	Species name (Galician)	Landings 2008 (t)	Economic value (€)
Thresher	*Alopias vulpinus*	ALV	Tiburón raposo	68.17	173,565
Mature dosinia	*Dosinia exoleta*	DSX	Reló	66.56	138,790
Black hake	*Merluccius senegalensis*		Pescada do Senegal	63.78	143,267
Mediterranean ling	*Mova dypterygia*	BLI	Peixe pau	59.82	136,437
Dwarf bobtail	*Sepiola rondeteli*	CTL	Chopiño	57.55	243,493
Turbot	*Psetta maxima*	TUR	Rodaballo	52.36	1,092,210
Oilfish	*Ruvettus pretiosus*	OIL	Cochinilla	51.63	93,385
Little tunny	*Euthynnus alletteratus*	LTA	Bacoreta	47.52	116,552
Whiting	*Merlangius merlangus*	WHG	Merlán	46.22	40,605
Beltfish	*Trichiurus lepturus*	LHT	Peixe sabre	39.82	97,879
Varied tuna species	*Thunnus spp.*	TUN	Atúns	36.44	325,863
Gilt-head bream	*Sparus aurata*	SBG	Dourada	35.31	362,208
Red mullet	*Mullus barbatus*	SHD	Salmonete de lama	32.83	270,768
European eel	*Anguilla anguilla*	ELE	Anguía	32.77	300,384
Cuckoo wrasse	*Labrus bimaculatus*	USI	Rei	30.20	149,488
BON	*Sarda sarda*	BON	Bonito do Atlántico	28.71	101,274
Saithe	*Pollachius virens*	POK	Fogoneiro	28.00	43,274
Garpike	*Belone belone*	GAR	Agulla	25.65	56,707
Kingklip	*Grenypterus capensis*		Rosada do Cabo	25.34	90,577
Sand sole	*Pegusa lascaris*	OAL	Acedía	24.40	216,150
Bullet tuna	*Auxis rochei*	FRZ	Melva	23.73	16,468
Cod	*Godus morhua*	COD	Bacallau	23.14	67,944
European flounder	*Platichthys flesus*	FLE	Solla	23.04	92,777
Common sea bream	*Pagrus pagrus*	RPG	Prago	21.82	274,236
Brill	*Scophthalmus rhombus*	BLL	Curuxo	20.09	295,630
Alfonsino	*Beryx splendens*	ALF	Castañeta macho	16.83	36,397
Skipjack tuna	*Katsuwomis pelamis*	SKJ	Bonito alistado	15.86	27,970
Black cardinal fish	*Epigonus telescopus*	EPI	Tomás	14.23	14,284
Brown crab	*Cancer pagurus*	CRE	Boi	13.33	89,117
Poor cod	*Trisopterus minutes*	POD	Fodón	13.28	20,458
Spiny dogfish	*Squalus acanthias*	DGS	Melga	13.00	34,675
Dogfish shark	*Squalidae*	DGX	Melgas	10.85	13,223
Common shore crab	*Carcinus maenas*	CRG	Cangrexo común	10.12	6,383
Common dentex	*Dentex dentex*	DEC	Dentón	9.08	42,697
Scarlet prawn	*Plesiopenaeus edwardsianus*	SSH	Carabineiro	8.16	138,714
Large-eye dentex	*Dentex macrophthalmus*	LED	Dentón ollón	7.62	10,464
European spiny lobster	*Palinurus elephex*	SLO	Lagosta	5.56	168,143
Atlantic saury	*Scomberesox saurus*	SAU	Alcrique	5.23	7,511
European anchovy	*Engraulis encrasicolus*	ANE	Bocarte	5.16	29,383
European lobster	*Homarus gammarus*	LBE	Lumbrigante	1.62	35,311

Table A.1. Fishing landings in Galicia by species in 2008 and 2009 (cont.).

Species name	Scientific name	FAO code	Species name (Galician)	Landings 2008 (t)	Economic value (€)
Other species	*Piscis miscellanea*	XXX	Outras especies	12,685.45	78,954,963
TOTAL	--	--	--	173,568.73	451,323,010

Table A.2. Other fishing species analyzed or cited in the present study.

Species name	Scientific name	FAO code	Species name (Galician)
Atlantic menhaden	*Brevoortia tyrannus*	MHA	Lacha tirana
Gulf menhaden	*Brevoortia patronus*	MHG	Lacha
Mussels	*Mytilus galloprovincialis*	MSM	Mexillón

Table B.1. Overall individual discards and discard rate for the coastal bottom trawling fleet.

Vessel	Discards (t/year)	Discard rate (% over catch)	Vessel	Discards (t/year)	Discard rate (% over catch)
V1	868.8	66.7	V13	472.2	26.2
V2	849.9	60.0	V14	395.1	29.6
V3	849.9	60.0	V15	747.4	63.1
V4	1,167.5	60.0	V16	215.2	33.0
V5	444.8	36.4	V17	199.8	25.8
V6	991.9	60.0	V18	431.8	42.9
V7	605.0	40.0	V19	781.9	36.4
V8	605.0	40.0	V20	272.6	45.4
V9	326.0	40.0	V21	272.6	45.4
V10	326.0	40.0	V22	315.1	42.7
V11	244.3	22.6	V23	37.9	5.2
V12	206.4	19.0	V24	75.1	17.7

Table B.2. Overall individual discards and discard rate for the purse seining fleet.

Vessel	Discards (t/year)	Discard rate (% over catch)	Vessel	Discards (t/year)	Discard rate (% over catch)
V1	6.7	3.5	V16	7.3	3.9
V2	10.6	4.8	V17	27.7	4.4
V3	7.1	4.9	V18	15.7	2.7
V4	10.9	2.7	V19	9.0	2.6
V5	11.8	2.3	V20	14.0	2.3
V6	12.9	3.9	V21	17.2	2.8
V7	29.0	4.8	V22	17.9	3.0
V8	14.5	2.5	V23	10.9	2.4
V9	22.5	4.1	V24	16.0	3.5
V10	3.6	3.9	V25	11.3	2.6
V11	25.0	3.9	V26	11.2	2.6
V12	13.1	3.0	V27	10.9	2.3
V13	5.1	3.2	V28	30.2	4.3
V14	4.3	2.2	V29	10.2	2.3
V15	5.8	2.6	V30	18.6	2.6

Table B.3. Characterization values for individual activities in the horse mackerel trawling fishery.

	ADP (kg Sb eq)	AP (kg SO_2 eq)	EP (kg PO_4^{3-} eq)	GWP (kg CO_2 eq)	ODP (kg CFC-11 eq)	METP (kg 1,4DCB eq)	POFP (kg C_2H_4 eq)
Vessel operation	0	23.8	4.64	1.59E3	0	2.11E5	0.34
Diesel production	11.8	3.03	0.30	252	2.29E-4	1.33E5	0.17
Vessel construction	1.81E-2	1.02E-2	1.50E-3	2.19	1.76E-7	4.37E3	7.81E-4
Ice production	0.21	0.27	1.39E-2	28.7	1.57E-6	4.81E3	1.00E-2
Trawl net production	0.13	7.67E-2	1.57E-2	16.8	1.66E-7	424	3.58E-3
Anti-fouling and paint manufacture	1.31E-2	2.79E-2	1.16E-3	1.11	1.23E-7	886	1.25E-3
Marine lubricant oil production	5.55E-2	1.16E-2	9.50E-4	1.96	1.38E-7	307	4.56E-4
Refrigerants	0	0	0	381	7.76E-3	0	0

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrophication Potential; GWP= Global Warming Potential; ODP= Ozone layer Depletion Potential; METP= Marine water Eco-Toxicity Potential; POFP= Photochemical Oxidant Formation Potential.

Table B.4. Characterization values for individual activities in the horse mackerel purse seining fishery.

	ADP (kg Sb eq)	AP (kg SO_2 eq)	EP (kg PO_4^{3-} eq)	GWP (kg CO_2 eq)	ODP (kg CFC-11 eq)	METP (kg 1,4DCB eq)	POFP (kg C_2H_4 eq)
Vessel operation	0	8.45	1.65	564	0	1.21E5	0.12
Diesel production	4.20	1.07	0.16	89.4	8.13E-5	6.41E4	6.10E-2
Vessel construction	9.65E-3	5.53E-3	3.33E-3	1.17	9.67E-8	3.16E3	4.15E-4
Ice production	0.21	0.27	5.08E-2	28.5	1.55E-6	1.80E4	9.95E-3
Seine net production	0.55	0.34	7.87E-2	72.4	8.1E-7	7.36E3	1.56E-2
Anti-fouling and paint manufacture	7.09E-3	1.59E-2	1.76E-2	0.61	6.62E-8	1.26E4	6.98E-4
Marine lubricant oil production	1.14E-2	2.37E-3	3.86E-4	0.40	2.84E-8	163.2	8.85E-5
Refrigerants	0	0	0	39.1	7.82E-4	0	0

ADP= Abiotic Depletion Potential; AP= Acidification Potential; EP= Eutrophication Potential; GWP= Global Warming Potential; ODP= Ozone layer Depletion Potential; METP= Marine water Eco-Toxicity Potential; POFP= Photochemical Oxidant Formation Potential.

Table C.1 and C.2 present the extended inventory data for fish landed in the NEAM season in Basque ports by coastal purse seiners in the 2001-2008 period. Data is referred to the selected FU in the study (1 ton of landed round fish during the NEAM season).

Table C.1. Inventory data for fish landed in the NEAM season in Basque ports by coastal purse seiners in the 2001-2004 period.

INPUTS					
From the technosphere					
Materials and fuels	**Units**	**2001**	**2002**	**2003**	**2004**
Diesel	Kg	31.53	41.12	75.93	34.63
Steel	Kg	7.01	19.32	31.54	9.80
Anti-fouling	G	884	2,271	3,889	1,249
Boat paint	G	310	1,012	1308.16	440
Marine lubricant oil	G	80.0	104.32	192.64	87.8
Ice	kg	125	125	125	125.2
Seine net[1]	kg	3.68	25.47	52.01	3.69
OUTPUTS					
To the technosphere					
Products	**Units**	**2001**	**2002**	**2003**	**2004**
Total round fish	t	1	1	1	1
NEAM	t	0.798	0.858	0.334	0.839
Other pelagic fish	t	0.202	0.142	0.666	0.161
To the environment					
Emissions to the atmosphere					
1. CO_2	kg	100.0	130.3	240.7	109.8
2. SO_2	g	315.0	411.2	759.3	346.1
3. VOC	g	75.7	98.7	182.2	83.1
4. NO_x	kg	2.27	2.96	5.47	2.49
5. CO	g	233	304.3	561.9	256
6. R22	g	4.08	9.04	23.31	4.52
Emissions to the ocean					
1. Xylene	g	80.9	207.8	354.8	114.4
2. Dicopper oxides	g	183	470.5	805.7	259
3. Zinc oxides	g	82.8	212.8	364.5	117.1
4. Nylon	g	421	1,166	1,986	423
5. Lead	g	93.2	258.3	440.1	93.5

[1] The seine net includes nylon, lead and cork as raw materials.

Table C.2. Inventory data for fish landed in the NEAM season in Basque ports by coastal purse seiners in the 2005-2008 period.

INPUTS					
From the technosphere					
Materials and fuels	**Units**	**2005**	**2006**	**2007**	**2008**
Diesel	kg	24.55	34.70	23.58	14.62
Steel	kg	9.98	20.63	10.32	7.15
Anti-fouling	g	1,257	1,308	1,335	930.5
Boat paint	g	452.2	982.1	464.9	332.1
Marine lubricant oil	g	192.6	88.0	59.8	37.1
Ice	kg	118.2	125.0	125.0	122.6
Seine net[1]	kg	6.89	11.29	10.46	2.65
OUTPUTS					
To the technosphere					
Products	**Units**	**2005**	**2006**	**2007**	**2008**
Total round fish	t	1	1	1	1
NEAM	t	0.933	0.893	0.976	0.981
Other pelagic fish	t	0.067	0.107	0.024	0.019
To the environment					
Emissions to the atmosphere					
1. CO_2	kg	77.8	110.0	74.7	46.3
2. SO_2	g	245.5	347.0	235.8	146
3. VOC	g	58.9	83.3	50.4	35.1
4. NO_x	kg	1.77	2.50	1.70	1.05
5. CO	g	181.7	256.8	174.5	108
6. R22	g	4.85	9.48	4.84	3.40
Emissions to the ocean					
1. Xylene	g	122.1	139.2	122.4	85.2
2. Dicopper oxides	g	280.2	314.5	276.7	193.0
3. Zinc oxides	g	124.6	142.3	125.1	87.2
4. Nylon	g	417.4	645.4	435.3	304.0
5. Lead	g	92.5	143.0	96.4	67.3

[1] The seine net includes nylon, lead and cork as raw materials.

Tables C.3a to C.3f presents the relative contributions to the selected impact categories for the different subsystems included within the system boundaries.

Table C.3a. Relative contribution (%) to ADP for the different subsystems in the assessed period.

ADP	2001	2002	2003	2004	2005	2006	2007	2008
Diesel production	70.0	54.1	57.3	70.9	61.8	60.2	58.9	56.6
Vessel construction	2.3	4.2	3.9	2.9	4.1	5.9	4.2	4.1
Ice production	7.6	5.0	2.9	7.0	9.1	6.6	9.6	13.2
Net production	18.3	33.7	33.0	16.9	21.8	24.6	23.9	23.0
Anti-fouling production	1.3	2.2	2.1	1.6	2.3	1.9	2.4	2.3
Boat paint production	0.4	0.6	0.6	0.5	0.7	0.6	0.7	0.7
Other	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2

ADP= abiotic depletion potential.

Table C.3b. Relative contribution (%) to AP for the different subsystems in the assessed period.

AP	2001	2002	2003	2004	2005	2006	2007	2008
*Diesel consumption	76.3	68.8	71.2	76.5	71.4	71.7	69.8	67.6
*Other vessel operations	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Vessel Operations	76.4	68.9	71.3	76.6	71.5	71.8	69.9	67.7
Diesel production	9.7	8.8	9.1	9.7	9.1	9.1	8.9	8.6
Vessel construction	0.7	1.5	1.4	0.9	1.3	2.0	1.4	1.4
Ice production	5.3	4.1	2.3	4.8	6.8	5.1	7.3	10.2
Net production	5.9	12.8	12.2	5.4	7.5	8.8	8.5	8.2
Anti-fouling production	1.9	3.8	3.6	2.4	3.6	3.1	3.9	3.8
Other	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1

AP= acidification potential; *= included in vessel operations.

Table C.3c. Relative contribution (%) to EP for the different subsystems in the assessed period.

EP	2001	2002	2003	2004	2005	2006	2007	2008
*Diesel consumption	69.8	56.5	59.1	68.2	59.8	60.6	57.6	56.1
*Other vessel operations	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
Vessel Operations	69.9	56.6	59.1	68.3	59.9	60.6	57.7	56.2
Diesel production	6.6	5.3	5.6	6.4	5.7	5.7	5.4	5.3
Vessel construction	2.0	3.9	3.6	2.5	3.5	5.2	3.7	3.6
Ice production	4.7	3.3	1.9	4.2	5.5	4.2	5.8	8.1
Net production	6.6	12.8	12.3	5.9	7.6	9.0	8.5	8.3
Anti-fouling production	10.1	18.0	17.5	12.6	17.7	15.3	18.8	18.4
Other	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

EP= eutrophication potential; *= included in vessel operations.

Table C.3d. Relative contribution (%) to GWP for the different subsystems in the assessed period.

GWP	2001	2002	2003	2004	2005	2006	2007	2008
*Diesel consumption	60.8	47.5	48.6	61.5	53.6	51.1	51.2	49.3
*Other vessel operations	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.2
Vessel operations	61.0	47.6	48.7	61.7	53.8	51.2	51.4	49.5
Diesel production	9.7	7.5	7.8	9.8	8.5	8.1	8.1	7.8
Vessel construction	1.8	3.3	3.1	2.3	3.2	4.5	3.3	3.2
Ice production	6.7	4.5	2.5	6.2	8.1	5.8	8.5	11.8
Cooling agent emission	4.2	6.2	8.9	4.3	6.0	8.3	6.3	6.1
Net production	15.6	29.1	27.5	14.4	18.6	20.6	20.5	19.8
Anti-fouling production	0.8	1.5	1.3	1.1	1.5	1.2	1.6	1.5
Other	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3

GWP= global warming potential; *= included in vessel operations.

Table C.3e. Relative contribution (%) to ODP for the different subsystems in the assessed period.

ODP	2001	2002	2003	2004	2005	2006	2007	2008
Diesel production	9.4	5.2	3.8	9.3	6.0	4.2	5.5	5.5
Vessel construction	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Ice production	0.4	0.2	0.1	0.4	0.3	0.2	0.3	0.5
Cooling agent emission	89.7	94.1	95.8	89.8	93.1	95.2	93.6	93.4
Net production	0.2	0.2	0.1	0.2	0.1	0.1	0.2	0.2
Other	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2

ODP= ozone layer depletion potential.

Table C.3f. Relative contribution (%) to ADP for the different subsystems in the assessed period.

METP	2001	2002	2003	2004	2005	2006	2007	2008
*Anti-fouling emission to ocean	82.0	84.5	84.8	83.5	84.4	82.7	84.6	84.1
*Other vessel operations	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
Vessel Operations	82.4	84.9	85.2	83.8	84.7	83.0	84.9	84.4
Diesel production	3.4	1.6	1.7	2.7	1.7	1.9	1.5	1.5
Vessel construction	2.4	2.7	2.5	2.4	2.5	4.1	2.4	2.4
Ice production	2.1	0.8	0.5	1.5	1.4	1.2	1.4	2.0
Net production	0.8	0.8	0.8	0.5	0.5	0.7	0.5	0.5
Anti-fouling production	8.9	9.2	9.2	9.1	9.2	9.0	9.2	9.0
Other	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.2

METP= marine aquatic eco-toxicity potential; *= included in vessel operations.

Table D.1. Individual total catch and discards for the assessed Northern Stock trawling and long lining vessels.

Long lining vessels				Trawling vessels			
Vessel	**Catch (t/year)**	**Discards (t/year)**	**Discard rate (%)**	**Vessel**	**Catch (t/year)**	**Discards (t/year)**	**Discard rate (%)**
1	651	11.5	1.8	**1**	468	170	36.3
2	621	7.4	1.2	**2**	438	142	32.4
3	275	5.6	2.0	**3**	786	272	34.6
4	146	4.2	2.9	**4**	1,242	698	56.2
5	222	3.0	1.4	**5**	1,137	637	56.2
6	207	7.2	3.5	**6**	992	465	46.9
7	204	0.9	0.4	**7**	730	220	30.2
8	259	5.2	2.0	**8**	369	128	34.7
9	196	3.0	1.5	**9**	495	154	31.1
10	227	2.8	1.2				
11	217	3.4	1.6				
12	249	3.0	1.2				

Table E.1. DEA matrix for coastal purse seining taking into account economic inputs.

DMU	Input 1	Input 2	Input 3	Output
1	49,500	8,795	235	274,505
2	49,500	7,212	152	214,399
3	54,000	9,024	247	368,961
4	54,000	9,143	247	350,205
5	46,665	19,064	236	439,576
6	29,025	8,209	108	372,569
7	54,000	6,019	215	380,904
8	43,538	10,009	139	360,964
9	40,500	8,897	240	282,878
10	40,725	8,897	240	289,285
11	14,513	2,779	62	261,438
12	14,850	2,779	59	259,051
13	27,000	7,412	178	294,364
14	48,375	6,540	129	291,064
15	38,700	6,195	126	472,854

DMU= decision making unit; Input 1: Diesel (€/year); Input 2: Net consumption (€/year); Input 3: Hull material (€/year); Output: Economic turnover (€/year).

Tables F.1a through F.1d specify the individual vessel efficiencies (Φ) for each port on a weekly basis, after computation using DEA window analysis. These tables represent the results for the main DEA matrices.

Table F.1a. Weekly efficiencies for vessels based in Port 1.

	Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6	Vessel 7	Vessel 8	Vessel 9	Vessel 10
Week 1	72.2	73.7	93.0	57.3	100	82.3	100	100	76.8	63.6
Week 2	73.9	72.6	73.3	46.4	68.8	100	100	42.6	79.8	91.9
Week 5	100	93.4	80.1	53.7	80.7	96.8	100	71.1	72.6	100
Week 6	96.4	83.3	100	100	56.9	92.3	100	81.9	100	87.3
Week 7	62.3	79.2	100	100	99.0	99.8	100	80.6	100	96.0
Week 9	90.0	48.6	96.7	42.5	88.4	68.6	100	67.4	94.1	100
Week 10	93.1	100	96.1	55.7	98.8	100	100	91.5	75.3	89.8
Week 11	78.7	76.3	81.8	79.0	74.5	92.1	100	100	80.8	100
Week 12	100	66.3	90.2	52.1	100	96.9	100	60.9	99.3	94.9
Week 13	88.0	59.1	83.0	70.6	72.5	88.2	100	54.6	66.2	91.0
Week 14	62.0	60.5	63.2	60.4	72.3	69.6	100	100	90.8	100
Week 15	100	63.8	96.5	81.4	77.6	61.5	100	100	68.6	98.3
Week 16	83.2	56.9	88.9	100	71.8	82.1	100	93.3	66.9	100
Week 17	60.6	81.1	100	70.1	100	64.2	100	71.9	90.1	91.4
Week 18	97.7	85.2	87.3	100	100	97.9	77.2	100	63.6	90.4
Week 19	100	59.5	71.7	92.9	80.2	73.8	75.7	81.5	100	100
Week 20	100	95.4	100	100	81.6	100	71.5	83.1	100	89.2
Week 21	95.1	73.2	64.1	100	76.7	100	98.5	98.3	79.0	100
Week 22	60.5	98.5	100	91.6	100	100	62.9	63.8	70.3	72.4
Week 23	70.0	71.6	96.3	100	97.4	57.0	100	82.0	74.6	99.3
Week 24	100	98.8	63.7	79.4	100	70.4	99.7	92.6	100	97.9
Week 25	81.2	89.0	90.6	100	89.4	82.4	100	66.5	68.0	95.9
Week 26	86.6	50.7	75.3	66.9	64.2	99.7	60.4	74.8	100	100
Week 27	60.4	91.6	89.6	70.3	100	79.9	49.7	100	69.5	94.5
Week 28	97.0	91.0	63.6	60.0	100	70.1	100	100	54.9	100
Average	84.4	76.8	85.8	77.2	86.0	85.0	91.8	82.3	81.6	93.7

Table F.1b. Weekly efficiencies for vessels based in Port 2.

	Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6	Vessel 7	Vessel 8	Vessel 9	Vessel 10
Week 1	65.5	100	86.3	100	81.7	46.1	58.1	95.4	100	42.9
Week 2	91.2	83.6	73.1	100	50.2	67.2	100	98.4	100	82.6
Week 5	64.1	57.4	69.7	100	58.9	51.5	67.1	100	80.9	58.9
Week 6	79.9	100	100	96.4	67.3	75.2	100	100	100	30.7
Week 9	97.1	92.7	100	100	78.4	51.5	54.5	70.4	100	86.0
Week 10	100	55.6	64.7	68.4	82.4	71.0	92.6	100	100	100
Week 11	60.1	77.1	97.2	100	88.3	100	51.3	100	100	51.2
Week 12	89.0	66.2	70.1	90.3	92.2	83.2	46.9	100	72.7	82.5
Week 13	84.0	81.2	80.4	81.0	70.6	84.3	65.1	100	100	69.0
Week 14	100	75.6	100	89.4	98.0	84.5	59.7	100	97.3	75.7
Week 15	81.5	88.4	100	62.6	83.4	82.7	72.2	100	100	100
Week 16	100	50.8	54.1	67.2	82.9	61.3	57.4	100	100	65.6
Week 17	63.9	91.2	85.8	90.4	75.4	49.9	76.0	100	100	93.2
Week 18	76.6	88.3	92.0	64.9	81.6	100	49.6	100	100	100
Week 20	90.7	82.6	100	94.1	84.7	100	100	96.5	100	68.9
Week 21	100	48.8	49.5	96.5	91.1	45.2	44.9	100	100	60.2
Week 22	75.2	42.5	100	64.5	67.1	28.4	56.5	100	100	54.5
Week 23	77.4	53.2	66.1	100	41.6	100	60.3	94.7	100	44.8
Week 24	90.6	73.3	100	54.6	59.6	71.1	93.0	100	73.5	63.0
Week 25	70.4	86.5	98.2	68.8	45.0	56.2	55.7	100	64.1	45.0
Week 26	91.5	89.8	100	74.5	62.7	64.2	64.2	100	100	81.9
Week 27	83.1	56.4	90.8	100	85.0	60.0	85.1	100	80.7	77.7
Week 28	77.8	86.4	97.8	100	77.9	47.6	50.2	100	100	100
Average	83.0	75.5	85.9	85.4	74.2	68.7	67.8	98.1	94.3	71.1

Table F.1c. Weekly efficiencies for vessels based in Port 3.

	Vessel 1	**Vessel 2**	**Vessel 3**	**Vessel 4**	**Vessel 5**	**Vessel 6**	**Vessel 7**	**Vessel 8**
Week 1	100	100	99.6	71.0	100	100	24.1	57.2
Week 2	89.6	94.2	77.8	69.2	100	100	50.4	89.3
Week 3	76.3	100	100	27.8	75.9	76.0	45.6	92.0
Week 5	57.6	100	100	71.9	98.0	95.0	86.9	82.9
Week 6	52.7	62.3	72.4	59.3	53.7	100	100	84.6
Week 7	89.7	72.3	86.2	100	88.0	100	98.3	91.6
Week 9	63.0	84.3	100	63.2	57.2	100	42.2	48.3
Week 10	82.5	81.4	100	83.8	63.7	78.5	100	100
Week 11	100	82.2	100	68.3	74.1	100	38.3	72.8
Week 13	50.5	65.1	97.3	69.8	86.0	100	65.2	71.9
Week 14	80.6	70.4	71.2	99.9	100	100	63.8	94.9
Week 15	53.0	41.3	62.9	84.2	39.8	100	34.3	73.2
Week 16	69.4	95.3	85.7	87.2	82.1	100	66.0	100
Week 17	100	59.9	79.3	95.0	60.8	100	57.0	100
Week 18	36.3	85.8	100	72.3	63.4	100	84.4	76.0
Week 19	73.5	100	79.8	95.9	97.5	100	67.3	77.5
Week 20	74.1	57.0	81.4	87.0	100	100	67.1	92.5
Week 21	67.0	90.1	80.7	65.3	100	100	100	98.1
Week 22	83.0	51.8	100	67.2	40.4	100	57.9	61.3
Week 23	100	79.5	100	64.7	66.2	100	70.9	88.8
Week 24	62.4	81.9	59.4	80.0	100	100	100	100
Week 25	83.2	70.9	57.6	89.7	100	100	93.7	57.1
Week 26	100	59.1	47.2	100	56.5	100	67.4	83.5
Week 27	98.2	80.8	100	57.1	70.2	50.0	100	73.4
Week 28	93.0	100	47.2	73.8	73.9	88.3	100	92.5
Average	77.4	78.6	83.4	76.1	77.9	95.5	71.2	82.4

Table F.1d. Weekly efficiencies for vessels based in Port 4.

	Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6	Vessel 7	Vessel 8	Vessel 9	Vessel 10
Week 7	49.0	100	85.7	85.5	81.4	75.2	70.5	100	100	100
Week 8	75.9	79.6	97.9	80.7	100	99.3	80.0	98.3	98.8	77.8
Week 10	71.0	61.1	75.7	100	94.4	90.9	100	100	69.2	73.8
Week 11	77.4	64.4	73.8	98.1	100	73.3	76.3	81.1	100	89.0
Week 12	99.8	74.9	80.1	95.1	95.6	92.7	100	80.1	99.1	100
Week 13	65.8	73.2	69.1	73.0	75.6	64.1	100	100	65.5	54.3
Week 14	90.4	80.1	77.2	76.0	100	51.0	95.0	82.1	97.9	100
Week 15	75.5	59.1	66.8	97.0	100	65.4	91.3	100	99.3	76.4
Week 16	57.1	74.3	100	93.5	78.2	87.0	57.7	69.6	100	54.1
Week 17	84.1	76.4	66.7	100	100	100	100	87.7	65.0	89.7
Week 18	83.0	91.0	93.6	87.2	90.0	89.6	80.2	100	87.2	85.3
Week 19	96.5	51.2	83.2	85.1	63.7	86.0	100	100	61.3	100
Week 20	66.2	71.5	77.8	74.1	99.6	93.3	100	86.2	84.1	82.6
Week 21	81.3	79.3	70.5	86.8	100	100	79.5	88.2	89.3	100
Week 22	85.8	56.7	100	100	59.5	97.9	78.3	100	50.6	71.0
Week 23	87.1	92.2	71.2	100	83.2	76.0	65.8	100	94.7	100
Week 24	100	84.6	77.1	100	94.8	82.7	96.1	89.3	71.7	100
Week 25	94.3	100	65.2	62.2	93.9	76.3	100	91.1	81.8	100
Week 26	74.1	90.8	87.2	78.0	51.3	100	100	69.7	69.0	62.1
Week 27	92.8	86.2	72.0	100	77.2	81.1	100	94.4	80.4	62.2
Week 28	100	76.5	67.6	74.2	100	94.2	100	88.5	90.7	100
Week 29	100	62.8	73.3	100	78.2	100	61.9	77.9	76.8	81.9
Week 30	92.1	88.8	61.8	100	100	79.3	92.1	54.1	100	50.6
Week 34	100	63.7	65.9	80.8	66.4	87.1	71.4	96.2	100	100
Average	83.3	76.6	77.5	88.6	86.8	85.1	87.3	89.0	84.7	83.8

Table G.1. Individual total catch and discards for the assessed Azores fishery long lining vessels.

Vessel	Catch (t/year)	Discards (t/year)	Discard rate (%)
1	560	32.4	5.8
2	52	5.9	11.5
3	169	12.4	7.3
4	124	7.5	6.0
5	280	27.7	9.9

Table H.1. Carbon footprint estimation for the annual coastal purse seining and trawling of non-evaluated species in Galicia.

Coastal fishing species	Scientific name	Fishing gear	Catch rate (t/y)	Carbon footprint (t CO_2e/y)
European anchovy	*Engraulis encrasicolus*	Seining	5.16	3.81
Bogue	*Boops boops*	Seining	639.70	472.74
Bass	*Dicentrarchus labrax*	Seining	185.38	136.99
Salerna	*Sarpa salpa*	Seining	171.87	127.01
White sea bream	*Diplodus sargus*	Seining	314.46	232.39
Mediterranean horse mackerel	*Trachurus mediterraneus*	Seining	72.51	53.59
Blue jack mackerel	*Trachurus picturatus*	Seining	401.98	297.06
Red sea bream	*Pagellus bogaraveo*	Trawling	178.34	203.31
Lesser flying squid	*Todaropsis eblanae*	Trawling	2,796.88	3,188.44
TOTAL	-	-	4,766.27	4.715.34

Table H.2. Carbon footprint estimation for the annual coastal trolling and artisanal fishing of non-evaluated species in Galicia.

Coastal fishing species	Scientific name	Fishing gear	Catch rate (t/y)	Carbon footprint (t CO_2e/y)
Varied tuna species	*Thunnus spp.*	Trolling	36.44	54.30
Skipjack tuna	*Katsuwonus pelamis*	Trolling	15.68	23.36
Atlantic bonito	*Sarda sarda*	Trolling	28.71	42.78
Albacore	*Thunnus alalunga*	Trolling	1,945.38	2,898.62
Atlantic horse mackerel	*Trachurus trachurus*	Artisanal	114.71	170.91
Atlantic mackerel	*Scomber scombrus*	Artisanal	61.98	92.34
Sand sole	*Pegusa lascaris*	Artisanal	24.40	36.35
Atlantic saury	*Scomberesox saurus*	Artisanal	5.23	7.80
Little tunny	*Euthynnus alletteratus*	Artisanal	47.52	70.81
Splendid alfonsino	*Beryx splenders*	Artisanal	16.83	25.07
European spider crab	*Maja squinado*	Artisanal	290.43	432.74
Common two-banded seabream	*Diplodus vulgaris*	Artisanal	4.51	6.72
Dwarf bobtail	*Sepiola rondeleti*	Artisanal	57.55	85.75
Black seabream	*Spondyliosoma cantharus*	Artisanal	123.78	184.44
Meagre or stone basse	*Argyrosomus regius*	Artisanal	1.30	1.94
Brill	*Scophthalmus rhombus*	Artisanal	20.69	30.83

Table H.2. Carbon footprint estimation for the annual coastal trolling and artisanal fishing of non-evaluated species in Galicia (cont).

Coastal fishing species	**Scientific name**	**Fishing gear**	**Catch rate (t/y)**	**Carbon footprint (t CO_2e/y)**
Common dentex	*Dentex dentex*	Artisanal	9.08	13.52
Large-eye dentex	*Dentex macrophthalmus*	Artisanal	7.62	11.36
Mediterranean rainbow wrasse	*Coris julis*	Artisanal	151.77	226.14
Gilt-head bream	*Sparus aurata*	Artisanal	35.31	52.61
Scorpionfish	*Scorpaena scrofa*	Artisanal	81.91	122.04
Black scorpionfish	*Scorpaena porcus*	Artisanal	216.57	322.69
Dragonet	*Callionymus lyra*	Artisanal	2.44	3.63
Bib or Pouting	*Trisopterus luscus*	Artisanal	1,132.99	1,688.15
Poor cod	*Trisopterus minutus*	Artisanal	13.28	19.79
Crayfish or European spiny lobster	*Palinurus elephas*	Artisanal	5.56	8.29
Caramote prawn	*Penaeus kerathurus*	Artisanal	0.66	0.98
Sea lamprey	*Petromyzon marinus*	Artisanal	0.01	0.01
Common sole	*Solea solea*	Artisanal	120.18	179.07
Thickback sole	*Microchirus variegatus*	Artisanal	0.06	0.09
Leafscale gulper shark	*Centrophorus squamosus*	Artisanal	0.93	1.39
European lobster	*Homarus gammarus*	Artisanal	1.62	2.41
Ballan wrasse	*Labrus bergylta*	Artisanal	235.49	350.88
Spiny dogfish	*Squalus acanthias*	Artisanal	13.00	19.37
Small-spotted catshark	*Scyliorhinus canicula*	Artisanal	87.67	130.63
Dogfish shark	*Squalidae spp.*	Artisanal	10.85	16.16
Muraena helena	*Muraena helana*	Artisanal	0.06	0.09
Grey mullet	*Mugilidae spp.*	Artisanal	68.81	102.53
Velvet swimcrab	*Necora puber*	Artisanal	113.39	168.95
Sea urchin	*Paracentrotus lividus*	Artisanal	747.95	1,114.44
Axillary seabream	*Pagellus acarne*	Artisanal	127.41	189.84
Grey triggerfish	*Balistes carolinensis*	Artisanal	0.73	1.09
Horned octopus	*Eledone cirrhosa*	Artisanal	1,590.29	2,369.53
Southern shortfin squid	*Illex coindetii*	Artisanal	3.64	5.42
Northern shortfin squid	*Illex illecebrosus*	Artisanal	287.91	428.99

Table H.2. Carbon footprint estimation for the annual coastal trolling and artisanal fishing of non-evaluated species in Galicia (cont).

Coastal fishing species	Scientific name	Fishing gear	Catch rate (t/y)	Carbon footprint (t CO_2e/y)
Common sea bream	*Pagrus pagrus*	Artisanal	21.82	32.51
Midsize squid	*Alloteuthis media*	Artisanal	6.79	10.12
Turbot	*Psetta maxima*	Artisanal	52.36	78.01
Red mullet	*Mullus barbatus*	Artisanal	32.83	48.92
Red mullet	*Mullus surmuletus*	Artisanal	140.04	208.66
Small European locust lobster	*Scyllarus arctus*	Artisanal	1.40	2.08
Comber	*Serranus cabrilla*	Artisanal	201.89	300.82
Painted comber	*Serranus scriba*	Artisanal	9.77	14.56
Topknot	*Zeugopterus punctatus*	Artisanal	0.13	0.20
Grey wrasse	*Symphodus cinereus*	Artisanal	7.77	11.58
Common scallop	*Pecten maximus*	Artisanal	142.73	212.67
Quenn	*Aequipecten opercularis*	Artisanal	420.42	626.43
Atlantic or European Pollock	*Pollachius pollachius*	Artisanal	252.73	376.57
Common cuttlefish	*Sepia officinalis*	Artisanal	305.33	454.94
Conger eel	*Conger conger*	Artisanal	975.47	1,453.45
Sea robin	*Triglidae spp.*	Artisanal	219.85	327.57
European squid	*Loligo vulgaris*	Artisanal	295.36	440.08
Common octopus	*Octopus vulgaris*	Artisanal	2,429.77	3,620.36
Thornback ray	*Raja spp.*	Artisanal	2,270.99	3,383.78
Angler spp.	*Lophius piscatorius*	Artisanal	1,993.45	2,970.24
Other species	*Spp.*	Artisanal	1,158.23	1,725.77
Hake eggs	*Merluccius merluccius*	Varied	80.00	119.20
TOTAL	-	-	18,881.47	28,133.38

Table H.3. Carbon footprint estimation for the annual Galician offshore fishing of non-evaluated species.

Offshore fishing species	**Scientific name**	**Fishing gear**	**Fishing area**	**Catch rate (t/y)**	**Carbon footprint (t CO_2e/y)**
Common cuttlefish	*Sepia officinalis*	Trawling	Mauritania	166.76	595.32
Common octopus	*Octopus vulgaris*	Varied	Mauritania	809.92	3,328.79
Lesser-flying squid	*Todaropsis eblanae*	Varied	Mauritania	932.29	3,598.65
Cod	*Gadus morhua*	Varied	Varied	23.14	70.56
Common pandora	*Pagellus erythrinus*	Varied	Varied	8.11	24.74
Giant Scarlet Prawn	*Plesiopenaeus edwardsianus*	Varied	Varied	8.17	24.90
School Shark or Snapper Shark	*Galeorhinus galeus*	Varied	Varied	188.33	574.39
Common smooth-hound	*Mustelus mustelus*	Varied	Varied	7.35	22.42
Torbay sole	*Glyptocephalus cynoglossus*	Varied	Varied	1,520.47	4,637.44
Velvet belly lantern shark	*Etmopterus spinax*	Varied	Varied	90.24	275.24
Common dab	*Limanda limanda*	Varied	Varied	0.58	1.77
European squid	*Loligo vulgaris*	Varied	Varied	169.30	516.37
Bullet tuna	*Auxis rochei rochei*	Varied	Varied	23.73	72.39
Lemon sole	*Microstomus kitt*	Varied	Varied	2,880.00	8,784.00
Whiting	*Merlangius merlangius*	Varied	Varied	46.22	140.98
Atlantic wreckfish	*Polyprion americanus*	Varied	Varied	361.15	1,101.49
Common ling eggs	*Molva molva*	Varied	Varied	0.50	1.52
Mediterranean ling	*Molva dipterygia*	Varied	Varied	59.83	182.47
Largehead hairtail or beltfish	*Trichiurus lepturus*	Varied	Varied	110.95	338.39
Cuckoo wrasse	*Labrus bimaculatus*	Varied	Varied	30.20	92.12
Mediterranean slimehead	*Hoplostethus mediterraneus*	Varied	Varied	10.08	30.73
Wedge sole	*Dicologlossa cuneata*	Varied	Varied	3.82	11.64
John Dory	*Zeus faber*	Varied	Varied	1,552.10	4,733.90
Common thresher shark	*Alopias vulpinus*	Varied	Varied	68.17	207.92
Bulls-eye	*Epigonus telescopus*	Varied	Varied	14.24	43.42
Thornback ray	*Raja spp.*	Varied	Varied	757.00	2,308.84
TOTAL	-	-	-	9,842.63	31,720.40

Appendix II

DEA models

Window analysis model formulation

The DEA model used to assess the US menhaden fishery was the “window analysis” model. The DEA framework used to implement window analysis was the “input-oriented slacks based measure of efficiency” model (SBM-I). Prior to the formulation of the model, a list of symbols are explained:

n → number of DMUs

t → number of periods

p → window length ($p \leq k$)

$j = 1, 2,..., N$ → index on the DMU

M → number of different inputs consumed by the DMU

$k = 1, 2,\ldots, M$ → index on inputs consumed

x_{kj} → amount of input k consumed by DMU j

y_j → amount of output generated by DMU j

0 → index of the DMU being assessed

$(\lambda_{10},\lambda_{20},\ldots,\lambda_{N0})$ → linear combination coefficient vectors to assess unit 0

σ_{k0} → slack (i.e., potential reduction) in the consumption of input k by DMU 0

Φ_0 → efficiency score for DMU 0

The formula in order to calculate the total number of DMUs is as follows (Charnes and Cooper, 1991):

$$n(t - p + 1)p \qquad \text{[Eq. A.1]}$$

Moreover, the SBM-I formulation used in the window analysis is presented below:

$$\Phi_0 = \mathrm{Min}\left(1 - \frac{1}{M}\sum_{k=1}^{M}\frac{\sigma_{k0}}{x_{k0}}\right)$$

subject to

$$\sum_{j=1}^{N}\lambda_{j0}x_{kj} = x_{k0} - \sigma_{k0} \quad \forall\, k$$

$$\sum_{j=1}^{N}\lambda_{j0}y_{j0} = y_0 \quad \forall\, k$$

$$\lambda_{j0} \geq 0 \;\forall\, j, \sigma_{k0} \geq 0 \;\forall\, k$$

The objective function of this model is non-linear, even though it is easily linearized. It represents the average reduction in the inputs consumed by DMU 0. This model attempts to find feasible operating points that consume fewer inputs with respect to the current units (DMU 0), without reducing output levels. If this objective is accomplished, then: $\Phi_0<1$. On the contrary, if it is not viable to reduce the consumption of any input without output loss, then $\Phi_0 = 1$ (because $\sigma_{k0} = 0 \;\forall\, k$). In the latter case DMU 0 is said to be efficient.

Appendix III

Acronyms

ADP	Abiotic Depletion Potential	*ICES*	International Council for the Exploration of the Sea
AP	Acidification Potential	*ILCD*	International Reference Life Cycle Data System
BRU	Biotic Resource Use	*IPCC*	Intergovernmental Panel on Climate Change
CF	Carbon Footprint	*IUU*	Illegal, Unregulated and Unreported fishing
CFCs	ChloroFluoroCarbons	*LCA*	Life Cycle Assessment
CFP	Common Fisheries Policy	*LCI*	Life Cycle Inventory
CRS	Constant Returns to Scale	*LCIA*	Life Cycle Impact Assessment
CU	Capacity Utilization	*MARM*	Ministry for Environment, Rural and Marine Affairs
DEA	Data Envelopment Analysis	*METP*	Marine water Eco-Toxicity Potential
DMU	Decision Making Units	*MSC*	Marine Stewardship Council
EEZ	Exclusive Economic Zone	*MSY*	Maximum Sustainable Yield
EP	Eutrophication Potential	*MTL*	Mean Trophic Level
EPA	Environmental Protection Agency	*NEAM*	North-East Atlantic Mackerel
EU	European Union	*NGOs*	Non-Governmental Organizations
FADs	Fish Aggregating Devices	*NPP*	Net Primary Productivity
FAO	Food and Agriculture Organization	*ODP*	Ozone layer Depletion Potential
FETP	Fresh water aquatic Eco-Toxicity Potential	*POFP*	Photochemical Oxidant Formation Potential
FiB	Fishery in Balance index	*PPS*	Production Possibility Set

Acronyms (cont.)

FROM	Regulation and Organization Fund for the Fish and Marine Cultures Market[1]	*SIP*	Seafloor Impact Potential
FU	Functional Unit	*SSB*	Spawning Stock Biomass
FUI	Fuel Use Intensity	*TAC*	Total Allowable Catch
GHG	GreenHouse Gas	*TE*	Technical Efficiency
GWP	Global Warming Potential	*UN*	United Nations
HCFCs	HydroChloroFluoroCarbons	*UNCED*	United Nations Conference on Environment and Development
HTP	Human Toxicity Potential	*WCED*	World Commission on Environment and Development

[1] Acronyms in Spanish.

Appendix IV

Resumo

Na actualidade a pesca é o único tipo de caza que se mantén aínda a un nivel industrial como fonte de nutrición para facer fronte á demanda alimentaria a escala mundial. No entanto, no século XXI a maior parte das pescarías encóntranse nunha situación de sobreexplotación, o que está a xerar unha serie de impactos ambientais importantes nas devanditas pescarías. Entre estes impactos, destacan a redución na abundancia dos *stocks* pesqueiros ou a alteración dos ecosistemas mariños. Ademais, a industria pesqueira creceu dun modo exponencial nas décadas posteriores á Segunda Guerra Mundial, o que propiciou que numerosas actividades pesqueiras, desenvolvidas a bordo dos buques ou en operacións terrestres, como o procesado ou a distribución, se convertesen en importantes fontes de impactos ambientais.

Neste contexto, Galicia, no noroeste da Península Ibérica, é a rexión europea máis importante en termos de pesca descargada e valor económico. De feito, o sector pesqueiro e a súa industria asociada representan case un 10% do PIB galego. En torno a cinco mil embarcacións galegas están rexistradas para desenvolver actividades extractivas ao longo do litoral galego, así como en zonas máis afastadas, coma os caladoiros de Gran Sol, Azores, Terranova, Mauritania, Namibia ou Chile. Polo tanto, Galicia está a converterse nun centro de distribución de peixe fresco e procesado para grande parte da Península Ibérica, tanto España como Portugal, e para outros países da Unión Europea. Porén, os retos ambientais que ten que afrontar a pesca a nivel mundial nos próximos anos, coa fin de satisfacer a demanda alimentaria dunha poboación humana en ascenso, ao mesmo tempo que asegure unha explotación sustentábel dos recursos pesqueiros, son de vital importancia en particular para o sector pesqueiro galego.

A importancia que está a cobrar na actualidade a sustentabilidade ambiental desencadeou no desenvolvemento de numerosas ferramentas de xestión ambiental, co obxectivo de avaliar e monitorizar os impactos ambientais relacionados con actividades humanas. Debido ao seu enfoque de ciclo de vida para avaliar o rendemento ambiental de produtos, procesos e servizos, a Análise de Ciclo de Vida (ACV), unha metodoloxía estandarizada para avaliar os aspectos ambientais e impactos potenciais asociados cun produto, é presentada como a ferramenta de xestión ambiental principal que se usará ao longo desta tese de doutoramento. A ACV é unha metodoloxía que está estruturada en catro fases diferenciadas, segundo se recolle na ISO 14040:

- Definición do obxectivo e alcance. A aplicación que se propón da metodoloxía, os motivos que conduciron á realización do estudo ou os destinatarios previstos son algunhas das suposicións que son tidas en conta nesta etapa.
- Análise de inventario. Nesta etapa obtéñense os datos precisos e os procedementos de cálculo necesarios para cuantificar as entradas e saídas relevantes do sistema que se estea a analizar.
- Avaliación de impacto. Avalíase a importancia dos impactos ambientais potenciais calculados usando os resultados a través de métodos de cálculo específicos.
- Interpretación dos resultados. Extráense as conclusións e recomendacións necesarias para a toma de decisións ou para transmitir os resultados a un público determinado, sempre de forma consistente cos obxectivos e o alcance que se determinaron na primeira fase do ACV.

A ACV ten sido aplicada con bastante frecuencia en varios procesos relacionados co sector primario, como a gandaría e a agricultura. De feito, produtos que despois se usan no sector bioenerxético ou alimentario, son os que máis se teñen examinado a través da ACV. Porén, a análise de produtos de orixe pesqueira desde unha perspectiva de ACV ten sido limitada. De feito, unha grande maioría destes estudos centráronse na análise de frotas e especies de países escandinavos.

Polo tanto, esta tese de doutoramento céntrase na aplicación da ACV en sistemas de produtos alimentarios de orixe pesqueira relacionados coa pesca extractiva de Galicia. En primeiro lugar, a ampla selección de frotas pesqueiras e especies mariñas que foron inventariadas e analizadas permitiron presentar un volume de resultados moi grande coa fin de entender o perfil ambiental destes produtos. Ademais, nalgúns casos os datos inventariados permitiron non só analizar as especies pesqueiras extraídas pola frota galega, pero tamén as cadeas de distribución destes produtos até o consumidor. En segundo lugar, proponse un protocolo específico para o uso da ACV en combinación cunha metodoloxía de xestión denominada Análise por Envoltura de Datos (DEA), que se basea en modelos de programación lineal, para estudar a eficiencia relativa dunha serie de unidades de decisión. O uso conxunto de ambas as metodoloxías persegue incluír a verificación da ecoeficiencia e a obtención de puntos de referencia operacionais de forma integrada co avaliación ambiental de embarcacións pesqueiras. Ademais, o uso individual da DEA é proposta para avaliar a importancia das aptitudes das tripulacións á hora de analizar a eficiencia dunha embarcación. O terceiro bloque temático desta tese atinxe a cuantificación de descartes mariños no sector pesqueiro galego, que foi posíbel grazas á mostra conseguida en diferentes frotas do sector pesqueiro de Galicia. Ademais, suxírese unha categoría de impacto para ACV específica para descartes mariños, coa fin de incluír aspectos relacionados co ecosistema mariño na metodoloxía. Por último, unha perspectiva semellante á seguida para os descartes mariños usouse para calcular a pegada de carbono do sector pesqueiro de Galicia. Ademais, axúntase a esta tese un CD cun software de cálculo da pegada de carbono para sistemas pesqueiros. Polo tanto, esta tese de doutoramento divídese en seis seccións:

- Introdución.
- Catro capítulos relacionados coa aplicación da ACV a catro procesos pesqueiros.
- Tres capítulos nos cales se combina a ACV coa Análise por Envoltura de Datos (DEA), unha metodoloxía de xestión .
- Dous capítulos que se centran na problemática dos descartes na pesca galega.
- Dous capítulos que abordan a pegada de carbono do sector pesqueiro galego, así como a presentación dunha ferramenta de cálculo das emisións de gases de efecto invernadoiro para o seu uso específico no sector pesqueiro.
- Conclusións xerais (Capítulo 14).

Sección I: Introdución

O primeiro capítulo da tese inclúe unha breve contextualización do sector pesqueiro na actualidade, primeiro a nivel mundial e en segundo lugar, enfocándose no sector en Galicia. Polo tanto, discútense os principais problemas de índole pesqueira que afectan o sector na actualidade, así como algúns dos retos para as próximas décadas. A nivel rexional, no entanto, incídese na importancia do sector a día de hoxe nesta rexión tradicionalmente mariñeira, así como na importancia estratéxica que ten a extracción sustentábel dos recursos mariños no sector pesqueiro galego. Por último, faise tamén fincapé no feito de que unha parte importante do pescado fresco e conxelado, así como en conserva, que se consome en España e outros países da Unión Europea, é desembarcado en portos galegos, que son, polo tanto, o berce das cadeas de distribución pesqueira máis complexas e antigas do continente.

O Capítulo 2 aborda os principais avances no mundo da xestión ambiental nas últimas décadas, así como o feito de que nos últimos anos se desenvolveron numerosas ferramentas de xestión ambiental, co obxectivo de avaliar os impactos ambientais das actividades humanas. Ademais sinálase á ACV como unha das metodoloxías cun maior recoñecemento e implantación neste ámbito. Por último, discútese a aplicación da ACV ao sector pesqueiro, sinalando as súas vantaxes, limitacións e innovacións recentes.

Sección II: Aplicación da ACV a produtos característicos da frota pesqueira galega

O uso da ACV nunha serie de frotas galegas permitiu avaliar tres artes de pesca diferenciadas: arrastre de fondo, palangre e cerco con xareta. De feito, as frotas inventariadas abranguen embarcacións de baixura, de altura e de gran altura. A relevancia do estudo débese ademais ao carácter precursor do mesmo, xa que até a data só a frota atuneira de gran altura fora analizada coa perspectiva de ACV en España. Preséntanse inventarios detallados para cada unha das frotas avaliadas. Ademais, a discusión dos resultados céntrase na comparativa ambiental entre as diferentes artes de pesca, sobre todo cando máis dunha frota captura unha mesma especie pesqueira, nas principais fontes de impacto ambiental nos sistemas analizados, en propor unha serie de accións de mellora para reducir os impactos e por último, na inclusión dunha serie de indicadores na ACV para reflectir os impactos directos sobre os ecosistemas mariños.

O xurelo (*Trachurus trachurus*) é unha das especies máis emblemáticas do litoral galego. Aínda que esta especie peláxica se soe identificar coa frota de cerco, o certo é que unha boa proporción das capturas tamén se leva a cabo con arrastreiros. Polo tanto, no capítulo 3 da tese o obxectivo fundamental foi avaliar e comparar os impactos ambientais asociados coas operacións pesqueiras, ligadas á extracción de xurelo, por parte destas dúas artes de pesca: cerco con xareta e arrastre de fondo. O inventario obtido para a análise incluíu a operación dos buques, así como as entradas e saídas máis relevantes asociadas ao consumo de fuel, á arte de pesca, á construción do buque ou ao consumo de patente para os barcos. O inventario obtívose a través de cuestionarios cubertos por un total de 54 patróns ou armadores. Os resultados demostraron que os impactos ambientais máis importantes están ligados á produción e consumo de fuel. Ademais, identificouse que a perda de axentes refrixerantes por parte dos buques supón un impacto ambiental importante nas categorías de esgotamento da capa de ozono e mudanza climática.

Cando se comparan as dúas artes de pesca, o xurelo capturado con embarcacións de cerco presenta uns impactos ambientais substancialmente menores para todas as categorías de impacto. A redución de impactos ambientais situouse entre un 49% e un 89% dependendo da categoría de impacto. A porcentaxe de captura descartada na frota arrastreira tamén se identificou como un impacto ambiental elevado. A revisión das cotas pesqueiras e das estratexias de pesca polas diferentes frotas na pescaría do xurelo, así como a redución dos consumos enerxéticos, a través da introdución de combustíbeis alternativos ou melloras tecnolóxicas, son necesarias para reducir o custo ambiental dunha actividade altamente dependente en combustíbeis fósiles.

No entanto, o anterior estudo non tivo en conta posíbeis mudanzas anuais na abundancia dos stocks pesqueiros, moi comúns en pequenas especies peláxicas, como o xurelo ou a xarda, xa que só tivo en conta datos de inventario do ano 2008. Polo tanto, o obxectivo de analizar durante un período de tempo máis prolongado unha pescaría peláxica, para avaliar os efectos das variacións de stock nos resultados de impacto ambiental, levouse a cabo inventariando a frota de cerco do País Vasco, que nos meses de febreiro, marzo e abril extrae xarda do caladoiro nacional. Os datos de inventario recolléronse para oito temporadas de pesca de xarda entre 2001 e 2008. Os resultados obtidos demostraron que os impactos ambientais estiveron dominados nos anos avaliados pola intensidade enerxética da pescaría, a pesar do reducido uso de fuel con respecto á frota de cerco galega e outras dispoñíbeis na bibliografía. De todos os xeitos, encontráronse grandes diferenzas no impacto ambiental entre os anos inventariados, o que se atribúe ás importantes variacións interanuais na abundancia de xarda neste caladoiro, xa que o esforzo pesqueiro se mantivo relativamente constante durante os oito anos. En canto aos impactos relacionados ás categorías de impacto de carácter biolóxico, como os descartes e o impacto sobre o solo mariño, pódese considerar que foron reducidos con respecto a outras frotas de cerco. Polo tanto, a ampla variación nos impactos ambientais dunha temporada a outra evidenciou a necesidade de incrementar a marxe temporal dos inventarios nos estudos de ACV de pesca, coa fin de conseguir unha visión máis global do perfil ambiental dunha determinada pescaría ou especie. Ademais, esta perspectiva pode ser útil para mellorar os inventarios doutras actividades que dependen exclusivamente da extracción de organismos dos seus hábitats naturais.

Por último, nesta sección tamén se analizaron as frotas galegas que faenan nos caladoiros de Gran Sol e Mauritania. En primeiro lugar, no Gran Sol analizáronse dúas frotas diferentes, por unha banda os arrastreiros que capturan pescada, peixe sapo e rapantes fundamentalmente, e por outra os palangreiros de fondo que capturan especialmente pescada e outras especies demersais, como a castañeta ou o congro. En segundo lugar, en Mauritania avaliouse a frota arrastreira de cefalópodos, que captura polbo, lura, sepia e algunhas especies de peixe demersais, como a pescada do Senegal ou a acedía.

No caladoiro do Gran Sol comparáronse as dúas frotas en termos de captura de pescada, coa fin de destacar as diferenzas ambientais de capturar esta especie, a que máis valor económico lle supón á frota de pesca, en función da arte de pesca. Os resultados acadados reflicten un maior impacto ambiental da pescada capturada pola frota arrastreira para todas as categorías de impacto ambiental, incluídas a cuantificación de descartes e o impacto sobre o solo mariño, excepto en termos de diminución do ozono estratosférico. Ademais, en ambos os casos se analizou tamén a cadea de procesado, distribución, venda e consumo da pescada fresca unha vez descargada nos portos galegos, demostrando que independentemente da frota escollida, os impactos ambientais máis notábeis son os referidos á extracción do produto no caladoiro.

En canto á extracción de polbo no caladoiro pesqueiro de Mauritania, e o seu posterior procesado e envío aos principais puntos de venda (Xapón, España e Italia), cómpre sinalar que debido a que os impactos ambientais do produto se concentraron na etapa extractiva, non se detectaron diferenzas significativas á hora de exportar os produtos aos distintos portos de recepción (As Palmas en España, Ancona en Italia e Toquio en Xapón), sempre e cando o produto exportado sexa conxelado e se transporte en barco de mercadorías. No entanto, o envío de polbo fresco á Península Ibérica en avión mostrou uns impactos ambientais elevados para a etapa de transporte. Estes resultados suxiren que as medidas de minimización dos impactos deben concentrarse na etapa extractiva do proceso, sempre e cando se garanta un transporte mariño dos produtos a exportar.

Por último, cabe sinalar que nestas frotas de altura analizadas, o principal foco de impacto ambiental está ligado á produción e consumo de fuel por parte dos buques, de forma máis acusada que no caso das frotas de baixura. Ademais, o uso de axentes conxelantes para a refrixeración das cámaras frías xera elevados impactos á capa de ozono, polo cal se recomenda a substitución destes axentes, como o R22, por outros máis inocuos. En canto ás distintas artes de pesca, semella que o uso de técnicas de arrastre produce un elevado número de descartes en certos caladoiros, así como un impacto significativo sobre o solo mariño.

Sección III: Uso combinado de ACV+DEA

A DEA é unha metodoloxía de xestión que permite comparar a eficiencia de múltiplas unidades con características colectivas semellantes. O seu uso en combinación coa ACV pode considerarse axeitado para a súa aplicación a frotas pesqueiras, unha nova perspectiva metodolóxica para ligar as avaliacións ambientais e socioeconómicas das mesmas, co obxectivo de crear sinerxías a partir do seu uso integrado.

O uso de ACV+DEA evita problemas coas desviacións estándares que xorden cando os usuarios da ACV traballan con inventarios promedio. Ademais, este novo enfoque facilita a interpretación de resultados, así como a verificación da ecoeficiencia. Ademais, unha serie de vantaxes adicionais poden ser exploradas con este método. Polo tanto, as análises de super-eficiencia para facilitar a identificación das unidades de referencia, a integración dunha variante económica para enriquecer a análise de sustentabilidade ou o uso do "window-analysis" para avaliar a eficiencia das unidades en termos de impactos ambientais durante períodos de tempo determinados son algunhas das aplicacións que se propoñen no capítulo 8 da tese.

De xeito adicional, aplicouse o método de ACV+DEA a unha serie de embarcacións de frotas galegas, moitas das cales xa foron analizadas con perspectiva de ACV na Sección II, incluíndo frotas de baixura, altura e gran altura, coa finalidade de realizar unha avaliación sectorial tanto a nivel de intrafrota como de interfrota. As consecuencias ambientais das ineficiencias operacionais foron cuantificadas e estimáronse os valores de referencia para os buques ineficientes. Os resultados demostran a dependencia dos impactos ambientais nunha única entrada: o consumo de fuel. As frotas pesqueiras cunha intensidade enerxética maior, como a frota de arrastre de Mauritania, mostraron uns niveis de eficiencia moi altos, mentres que as frotas de baixura, a pesar de teren uns impactos ambientais máis baixos por tonelada de peixe capturado, presentan unhas eficiencias máis reducidas. Por último, a pesar das pequenas contribucións ao impacto ambiental doutras entradas operacionais, como os materiais de construción do buque, o uso de patentes ou os materiais da arte de pesca, estas poden contribuír notabelmente ao aforro económico se son minimizadas.

No Capítulo 9 desta sección exponse o uso exclusivo da DEA en estudos de avaliación ambiental de pescarías. Así, usando unha perspectiva de "window-analysis", analizáronse 40 barcos pertencentes á pescaría de lacha nos Estados Unidos. Xa que estas embarcacións de cerco pertencentes a unha mesma empresa mostran unhas características de operación, tecnolóxicas e técnicas moi semellantes entre elas, e ademais non están suxeitas a cotas pesqueiras nin restricións de ningún tipo, asumiuse que usando a DEA as ineficiencias identificadas nas análises poden ser atribuíbeis ás habilidades da tripulación. Os resultados obtidos, de feito, mostran diferenzas importantes entre as embarcacións incluídas no estudo, o que suxire que parte das ineficiencias que se detectan en estudos de ACV+DEA non poden ser atribuídas directamente a cuestións tecnolóxicas ou operacionais, mais de aptitudes das tripulacións.

Sección IV: Descartes mariños e a súa integración na ACV

O principal problema vinculado aos descartes é a enorme cantidade de biomasa desaproveitada por parte das embarcacións pesqueiras á hora de faenar. Ademais, esta reducida eficiencia pesqueira está agravada polo feito de que os descartes en moitas ocasións implican unha mortalidade case segura deses individuos, coa consecuente influencia nas cadeas tróficas e ecosistemas mariños. Neste estudo, grazas aos amplos datos de inventario dispoñíbeis, asegurando unha grande representatividade no sector pesqueiro galego, estimáronse os descartes totais producidos pola frota galega en 2008. A estimación dos descartes elaborouse de xeito individual para as frotas pesqueiras galegas inventariadas, ao adicionar os datos primarios obtidos dun total de 89 buques pesqueiros, e datos secundarios para aquelas frotas que non foron inventariadas directamente. Os resultados mostraron que aproximadamente 60.250 toneladas de organismos mariños foron descartadas pola frota galega en 2008, representando un 16,9% das capturas. A grande parte destes descartes estaban vinculados a frotas arrastreiras e en menor medida, a frotas palangreiras. Polo tanto, esta estimación pode axudar a mellorar a análise dos stocks pesqueiros e axudar a cuantificar os danos que os descartes xeran nos ecosistemas mariños.

En base aos resultados obtidos con respecto aos descartes mariños, propúxose un índice específico de descartes co obxectivo de desenvolver o uso de indicadores específicos dos ecosistemas mariños nos estudos de ACV de pesca. Polo tanto, o índice global de descartes (IGD) pretende ser un indicador de medición de descartes de aplicación sinxela e aplicábel a calquera pescaría do mundo. Preséntase como un índice dinámico que busca caracterizar e normalizar as proporcións de descarte entre pescarías a través dunha comparativa directa coas proporcións globais de descartes publicadas periodicamente pola FAO. Ademais, preséntase tamén unha versión simplificada do índice para cando os datos dispoñíbeis de descartes non sexan o suficientemente detallados como para proceder ao seu cálculo co método principal. Por último, propóñense dous indicadores máis para mellorar a cuantificación de vertidos de biomasa por parte de buques pesqueiros.

A aplicación do IGD ás frotas galegas presentou datos substancialmente diferentes aos obtidos cando se usaron categorías de impacto convencionais. Neste senso, as categorías de impacto convencionais estaban fortemente condicionadas pola intensidade enerxética da pescaría, mentres que os resultados obtidos para o IGD mostraron tendencias variábeis debido a unha maior dependencia nun número de factores máis heteroxéneo.

Sección V: Pegada de carbono

A pegada de carbono mide a cantidade de CO_2 e outros gases de efecto invernadoiro que se emiten á atmosfera debido ás actividades antropolóxicas vinculadas a un determinado proceso, produto ou sistema. Nesta sección estimouse a pegada de carbono do sector pesqueiro galego. De feito, para este estudo tivéronse en conta datos de inventario da acuicultura extensiva e intensiva, datos disponíbeis a raíz de estudos previos levados a cabo en Galicia, para o cálculo dun valor de pegada de carbono global. Os resultados mostraron que a actividade pesqueira en Galicia supón un 3% das emisións de gases de efecto invernadoiro de Galicia e un 0,2% das emisións do Estado, recalcando a importancia deste sector en termos de emisións de gases de efecto invernadoiro.

Por último, no capítulo 13 da tese proponse un software de cálculo de pegada de carbono adaptado ás características específicas dos sistemas pesqueiros, coa finalidade de permitir que os distintos actores do sector pesqueiro, tanto a nivel galego como a nivel estatal poidan calcular a pegada de carbono ligada á extracción de peixe e outras especies mariñas.

Appendix V

Resumen

En la actualidad la pesca es el único tipo de caza que se mantiene todavía a un nivel industrial como fuente de nutrición para hacer frente a la demanda alimentaria a escala mundial. Sin embargo, en el siglo XXI la mayor parte de las pesquerías se encuentran en una situación de sobreexplotación, lo que está generando una serie de impactos ambientales importantes en dichas pesquerías. Entre estos impactos, destacan la reducción en la abundancia de los stocks pesqueros o la alteración de los ecosistemas marinos. Además, la industria pesquera creció de un modo exponencial en las décadas posteriores a la Segunda Guerra Mundial, lo que propició que numerosas actividades pesqueras, desarrolladas a bordo de los buques o en operaciones terrestres, como el procesado o la distribución, se convirtieran en importantes fuentes de impactos ambientales.

En este contexto, Galicia, en el noroeste de la península Ibérica, es la región europea más importante en términos de pesca descargada y valor económico. De hecho, el sector pesquero y su industria asociada representan casi un 10% del PIB gallego. En torno a cinco mil embarcaciones gallegas están registradas para desarrollar actividades extractivas a lo largo del litoral gallego, así como en zonas más alejadas, como los caladeros de Gran Sol, Azores, Terranova, Mauritania, Namibia o Chile. Por lo tanto, Galicia está convirtiéndose en un centro de distribución de pescado fresco y procesado para gran parte de la península Ibérica, tanto España como Portugal, y para otros países de la Unión Europea. Sin embargo, los retos ambientales que tiene que afrontar la pesca a nivel mundial en los próximos años, con el fin de satisfacer la demanda alimentaria de una población humana en ascenso, al mismo tiempo que asegurando una explotación sostenible de los recursos pesqueros, son de vital importancia para el sector pesquero gallego en particular.

La importancia que está cobrando en la actualidad la sostenibilidad ambiental desencadenó en el desarrollo de numerosas herramientas de gestión ambiental, con el objetivo de evaluar y monitorizar los impactos ambientales relacionados con actividades humanas. Debido a su enfoque de ciclo de vida para evaluar el rendimiento ambiental de productos, procesos y servicios, el Análisis de Ciclo de Vida (ACV), una metodología estandarizada para evaluar los aspectos ambientales e impactos potenciales asociados a un producto, es presentado como la herramienta de gestión ambiental principal que se usará a lo largo de esta tesis doctoral. El ACV es una metodología que está estructurada en cuatro fases diferenciadas, según se recoge en la ISO 14040:

- Definición del objetivo y alcance. La aplicación que se plantea de la metodología, los motivos que condujeron a la realización del estudio o el público al que va dirigido son algunas de las suposiciones que se tienen en cuenta en esta etapa.
- Análisis de inventario. En esta etapa se obtienen los datos precisos y los procedimientos de cálculo necesarios para cuantificar las entradas y salidas relevantes del sistema que se esté analizando.
- Evaluación de impacto. Se evalúa la importancia de los impactos ambientales potenciales calculados usando los resultados a través de métodos de cálculo específicos.
- Interpretación de los resultados. Se extraen las conclusiones y recomendaciones necesarias para la toma de decisiones o para transmitir los resultados a un público determinado, siempre de forma consistente con los objetivos y el alcance que se determinaron en la primera fase del ACV.

El ACV ha sido aplicado con bastante frecuencia en varios procesos relacionados con el sector primario, como la ganadería y la agricultura. De hecho, algunos productos que después se usan en el sector bioenergético o alimentario, son los que más se han examinado a través del ACV. Sin embargo, el análisis de productos de origen pesquero desde una perspectiva de ACV ha sido limitado. De hecho, una gran mayoría de estos estudios se centraron en el análisis de flotas y especies marinas de países Escandinavos.

Por lo tanto, esta tesis doctoral se centra en la aplicación del ACV a sistemas de productos alimentarios de origen pesquero relacionados con la pesca extractiva en Galicia. En primer lugar, la amplia selección de flotas pesqueras y especies marinas que se inventariaron y analizaron permitieron presentar un volumen de resultados muy grande con el fin de entender el perfil ambiental de estos productos. Además, en algunos casos los datos inventariados permitieron no solo analizar las especies pesqueras extraídas por la flota gallega, sino también las cadenas de distribución de estos productos hasta el consumidor. En segundo lugar, se propone un protocolo específico para el uso del ACV en combinación con una metodología de gestión denominada Análisis por Envoltura de Datos (DEA), que se basa en modelos de programación lineal para estudiar la eficiencia relativa de una serie de unidades de decisión. El uso conjunto de ambas metodologías persigue incluir la verificación de la ecoeficiencia y la obtención de puntos de referencia operacionales de forma integrada con la evaluación ambiental de embarcaciones pesqueras. Además, el uso individual del DEA se propone para evaluar la importancia de las aptitudes de las tripulaciones a la hora de analizar la eficiencia de una embarcación. El tercer bloque temático de esta tesis atañe la cuantificación de descartes marinos en el sector pesquero gallego, que fue posible gracias a la muestra conseguida en diferentes flotas del sector. Además, se sugiere una categoría de impacto para ACV específica para descartes marinos, con el fin de incluir aspectos ambientales relacionados con el ecosistema marino en la metodología. Por último, una perspectiva semejante a la seguida para los descartes marinos se usó para calcular la huella de carbono del sector pesquero gallego. Además, se adjunta a esta tesis un CD con un software de cálculo de la huella de carbono para sistemas pesqueros. Por lo tanto, esta tesis de doctorado se divide en seis secciones:

- Introducción.
- Cuatro capítulos relacionados con la aplicación de ACV a cuatro procesos pesqueros.
- Tres capítulos en los que se combina el ACV con el Análisis por Envoltura de Datos (DEA), una metodología de gestión.
- Dos capítulos que se centran en la problemática de los descartes en la pesca gallega.
- Dos capítulos que abordan la huella de carbono del sector pesquero gallego, así como la presentación de una herramienta de cálculo de las emisiones de gases de efecto invernadero para su uso específico en el sector pesquero.
- Conclusiones generales (Capítulo 14).

Sección I: Introducción

El primer capítulo de la tesis incluye una breve contextualización del sector pesquero en la actualidad, primero a nivel mundial, y, en segundo lugar, enfocándose en el sector en Galicia. Por lo tanto, se discuten los principales problemas de índole pesquera que afectan al sector, así como algunos de los retos para las próximas décadas. A nivel regional, sin embargo, se incide en la importancia del sector a día de hoy en esta región tradicionalmente marinera, así como en la importancia estratégica que tiene la extracción sostenible de los recursos marinos en el sector pesquero gallego. Por último, se hace también hincapié en el hecho de que una parte importante del pescado fresco y congelado, así como en conserva, que se consume en España y otros países de la Unión Europea, es desembarcado en puertos gallegos, que son, por lo tanto, la cuna de las cadenas de distribución pesquera más complejas y antiguas del continente.

El Capítulo 2 aborda los principales avances en el mundo de la gestión ambiental en las últimas décadas, así como el hecho de que en los últimos años se desarrollaron numerosas herramientas de gestión ambiental, con el objetivo de evaluar los impactos ambientales de las actividades humanas. Al mismo tiempo, se señala al ACV como una de las metodologías con un mayor reconocimiento e implantación en este ámbito. Por último, se discute la aplicación del ACV al sector pesquero, señalando sus ventajas, limitaciones e innovaciones recientes.

Sección II: Aplicación del ACV a productos característicos de la flota pesquera gallega

El uso del ACV en una serie de flotas gallegas permitió evaluar tres artes de pesca diferenciadas: arrastre de fondo, palangre y cerco con jareta. De hecho, las flotas inventariadas abarcan embarcaciones de bajura, de altura y de gran altura. La relevancia del estudio se debe además al carácter precursor del mismo, ya que hasta la fecha sólo la flota atunera de gran altura había sido analizada con la perspectiva de ACV en España. Se presentaron una serie de inventarios detallados para cada una de las flotas evaluadas. Además, la discusión de los resultados se centra en la comparativa ambiental entre las diferentes artes de pesca, sobre todo cuando más de una flota captura una misma especie pesquera, en las principales fuentes de impacto ambiental en los sistemas analizados, en proponer una serie de acciones de mejora para reducir los impactos y, por último, en la inclusión de una serie de indicadores en el ACV que reflejan los impactos directos sobre los ecosistemas marinos.

El jurel (*Trachurus trachurus*) es una de las especies más emblemáticas del litoral gallego. Aunque esta especie pelágica se suele identificar con la flota del cerco, lo cierto es que una proporción importante de las capturas también se lleva a cabo con barcos de arrastre. Por lo tanto, en el Capítulo 3 de la tesis el objetivo fundamental fue evaluar y comparar los impactos ambientales asociados con las operaciones pesqueras ligadas a la extracción de jurel por parte de estas dos artes de pesca: cerco con jareta y arrastre de fondo. El inventario obtenido para el análisis incluyó la operación de los buques, así como las entradas y salidas más relevantes asociadas al consumo de fuel, a las artes de pesca, a la construcción del buque o al consumo de patente en los barcos. El inventario se obtuvo a través de cuestionarios cubiertos por un total de 54 patrones o armadores. Los resultados demostraron que los impactos ambientales más importantes están vinculados a la producción y consumo de fuel. Además, se identificó que la pérdida de agentes refrigerantes por parte de los buques supone un impacto ambiental importante en las categorías de agotamiento de la capa de ozono y cambio climático.

Cuando se comparan las dos artes y pesca, el jurel capturado con embarcaciones de cerco presenta unos impactos ambientales sustancialmente menores para todas las categorías de impacto. La reducción de impactos ambientales se situó entre un 49% y un 89% dependiendo de la categoría de impacto. El porcentaje de captura descartado en la flota arrastrera también se identificó como un impacto ambiental elevado. Por lo tanto, la revisión de las cuotas pesqueras y de las estrategias de pesca por las diferentes flotas en la pesquería del jurel, así como la reducción de los consumos energéticos, a través de la introducción de combustibles alternativos o mejoras tecnológicas, son necesarios para reducir el coste ambiental de una actividad altamente dependiente en combustibles fósiles.

Sin embargo, el anterior estudio no tuvo en cuenta posibles cambios anuales en la abundancia de los stocks pesqueros, muy comunes en pequeñas especies pelágicas, como el jurel o la caballa, ya que sólo tuvo en cuenta datos de inventario del año 2008. Por lo tanto, el objetivo de analizar durante un período de tiempo más prolongado una pesquería pelágica para evaluar los efectos de las variaciones de stock en los resultados de impacto ambiental se llevó a cabo inventariando la flota de cerco del País Vasco, que en los meses de febrero, marzo y abril extrae caballa del caladero nacional. Los datos de inventario se recogieron para ocho temporadas de pesca de caballa entre 2001 y 2008. Los resultados obtenidos demostraron que los impactos ambientales estuvieron dominados en los años evaluados por la intensidad energética de la pesquería, a pesar del reducido uso de fuel con respecto a la flota de cerco gallega y otras disponibles en la bibliografía. De todas formas, se encontraron grandes diferencias en el impacto ambiental entre los años inventariados, que se atribuye a las importantes variaciones interanuales en la abundancia de caballa en este caladero, ya que el esfuerzo pesquero se mantuvo relativamente constante durante los ocho años. En cuanto a los impactos relacionados a las categorías de impacto de carácter biológico, como los descartes y el impacto sobre el suelo marino, puede considerarse que fueron bajos con respecto a otras flotas de cerco. Por lo tanto, la amplia variación en los impactos ambientales de una temporada a otra evidenció la necesidad de incrementar el margen temporal de los inventarios en los estudios de ACV de pesca, con el fin de conseguir una visión más global del perfil ambiental de una determinada pesquería o especie. Además, esta perspectiva puede ser útil para mejorar los inventarios de otras actividades que dependen exclusivamente de la extracción de organismos de sus hábitats naturales.

Por último, en esta sección también se analizaron las flotas gallegas que faenan en los caladeros de Gran Sol y Mauritania. En primer lugar, en el Gran Sol se analizaron dos flotas diferentes. Por un lado, los barcos de arrastre que capturan merluza, rape y gallo fundamentalmente, y, por otra, los palangreros de fondo que capturan especialmente merluza y otras especies demersales, como la palometa o el congrio. En segundo lugar, en Mauritania se evaluó la flota arrastrera de cefalópodos, que captura pulpo, calamar, sepia y algunas especies de pescado demersales, como la merluza de Senegal o la acedía.

En el caladero del Gran Sol se compararon las dos flotas en términos de captura de merluza, con el fin de destacar las diferencias ambientales de capturar esta especie, la que más valor económico le supone a la flota de pesca, en función de las artes de pesca. Los resultados conseguidos reflejan un mayor impacto ambiental de la merluza capturada por la flota arrastrera para todas las categorías de impacto ambiental, incluidas la cuantificación de descartes y el impacto sobre el suelo marino, excepto en términos de disminución del ozono estratosférico. Además, en ambos casos, se analizó también la cadena de procesado, distribución, venta y consumo de la merluza fresca una vez descargada en los puertos gallegos, demostrando que independientemente de la flota elegida, los impactos ambientales más notables son los referidos a la extracción del producto en el caladero.

En cuanto a la extracción de pulpo en el caladero pesquero de Mauritania, y su posterior procesado y envío a los principales puntos de venta (Japón, España e Italia), hay que señalar que debido a que los impactos ambientales del producto se concentraron en la etapa extractiva, no se detectaron diferencias significativas a la hora de exportar los productos a los distintos puertos de recepción (Las Palmas en España, Ancona en Italia y Tokio en Japón), siempre y cuando el producto exportado sea congelado y se transporte en barco de mercancías. Sin embargo, el envío de pulpo fresco a la península Ibérica en avión mostró unos impactos ambientales elevados para la etapa de transporte. Estos resultados sugieren que las medidas de minimización de dichos impactos deben concentrarse en la etapa extractiva del proceso, siempre y cuando se garantice un transporte marino de los productos a exportar.

Por último, cabe señalar que en ambas flotas de altura analizadas, el principal foco de impacto ambiental está ligado a la producción y consumo de fuel por parte de los buques, de forma mucho más acusada que en el caso de las flotas de bajura. Además, el uso de agentes congelantes para la refrigeración de las cámaras frías genera elevados impactos a la capa de ozono, por la cual se recomienda la sustitución de estos agentes, como el R22, por otros más inocuos. En cuanto a las distintas artes de pesca, todo indica a que el uso de técnicas de arrastre produce un elevado número de descartes en ciertos caladeros, así como un impacto significativo sobre el suelo marino.

Sección III: Uso combinado de ACV+DEA

El DEA es una metodología de gestión que permite comparar la eficiencia de múltiples unidades con características colectivas semejantes. Su uso en combinación con el ACV puede considerarse adecuado para su aplicación a flotas pesqueras, como una nueva perspectiva metodológica para ligar las evaluaciones ambientales y socioeconómicas de las mismas, con el objetivo de crear sinergias a partir de su uso integrado.

El uso de ACV+DEA evita problemas con las desviaciones estándares que surgen cuando los usuarios de ACV trabajan con inventarios promedio. Este nuevo enfoque facilita la interpretación de resultados, así como la verificación de la ecoeficiencia. Además, una serie de ventajas adicionales pueden ser exploradas con este método. Por el tanto, los análisis de super-eficiencia para facilitar la identificación de las unidades de referencia, la integración de una variante económica para enriquecer el análisis de sostenibilidad o el uso del "window-analysis" para evaluar la eficiencia de las unidades en términos de impactos ambientas durante períodos de tiempo determinados son algunas de las aplicaciones que se proponen en el capítulo 8 de la tesis.

De manera adicional, se aplicó el método de ACV+DEA a una serie de embarcaciones pertenecientes a las flotas gallegas, la mayoría de las cuales ya fueron analizadas con perspectiva de ACV en la Sección II, incluyendo flotas de bajura, altura y gran altura, con la finalidad de realizar una evaluación sectorial tanto a nivel de intraflota como de interflota. Las consecuencias ambientales de las ineficiencias operacionales fueron cuantificadas y se estimaron los valores de referencia para los buques que presentaban ineficiencias. Los resultados demuestran la dependencia de los impactos ambientales en una única entrada: el consumo de fuel. Las flotas pesqueras con una intensidad energética mayor, como la flota de arrastre de Mauritania, mostraron unos niveles de eficiencia muy altos, mientras que las flotas de bajura, a pesar de tener unos impactos ambientales más bajos por tonelada de pescado capturado, presentan una eficiencia más reducida. Por último, a pesar de las pequeñas contribuciones al impacto ambiental de otras entradas operacionales, como los materiales de construcción del buque, el uso de patentes o los materiales de las artes de pesca, estas pueden contribuir notablemente al ahorro económico si son minimizadas.

En el Capítulo 9 de esta sección se expone el uso exclusivo del DEA en estudios de evaluación ambiental de pesquerías. Así, usando una perspectiva de "window-analysis", se analizaron 40 barcos pertenecientes a la pesquería de lacha (*Brevoortia* spp.) en los Estados Unidos. Ya que estas embarcaciones de cerco pertenecientes a una misma empresa muestran unas características de operación, tecnológicas y técnicas muy semejantes entre ellas, y además no están sujetas a cuotas pesqueras ni restricciones de ningún tipo, se asumió que usando el DEA las ineficiencias identificadas en el análisis pueden ser atribuibles a las habilidades de la tripulación. Los resultados obtenidos, de hecho, muestran diferencias importantes entre las embarcaciones incluidas en el estudio, lo que sugiere que parte de las ineficiencias que se detectan en estudios de ACV+DEA no pueden ser atribuidos directamente a cuestiones tecnológicas u operacionales, sino que se deben en parte a diferencias en las aptitudes de las tripulaciones.

Sección IV: Descartes marinos y su integración en el ACV

El principal problema vinculado a los descartes es la enorme cantidad de biomasa desaprovechada por parte de las embarcaciones pesqueras a la hora de faenar. Esta reducida eficiencia pesquera está agravada por el hecho de que los descartes en muchas ocasiones implican una mortalidad casi segura de esos individuos, con la consecuente influencia en las cadenas tróficas y ecosistemas marinos. En este estudio, gracias a los amplios datos de inventario disponibles, asegurando una gran representatividad en el sector pesquero gallego, se estimaron los descartes totales producidos por la flota gallega en 2008. La estimación de los descartes se elaboró de manera individual para las flotas pesqueras gallegas inventariadas, al agregar los datos primarios obtenidos de un total de 89 buques pesqueros, y los datos secundarios para aquellas flotas que no fueron inventariadas directamente. Los resultados mostraron que aproximadamente 60.250 toneladas de organismos marinos fueron descartados por la flota gallega en 2008, representando un 16,9% de las capturas. Una gran parte de estos descartes estaban vinculados a flotas arrastreras y, en menor medida, a flotas palangreras. Por lo tanto, esta estimación puede ayudar a mejorar el análisis de los stocks pesqueros y ayudar a cuantificar los daños que los descartes generan en los ecosistemas marinos.

En base a los resultados obtenidos, se propuso un índice específico de descartes con el objetivo de desarrollar el uso de indicadores específicos de los ecosistemas marinos en los estudios de ACV del sector pesquero. Por lo tanto, el índice global de descartes (IGD) pretende ser un indicador de medición de descartes de aplicación sencilla y aplicable a cualquier pesquería del mundo. Se presenta como un índice dinámico que busca caracterizar las proporciones de descartes entre las distintas pesquerías a través de una comparativa directa con las proporciones globales de descartes publicadas periódicamente por la FAO. Además, se presenta también una versión simplificada del índice para cuando los datos disponibles de descartes no sean lo suficientemente detallados como para proceder a su cálculo con el método principal. Por último, se proponen dos indicadores adicionales para mejorar la cuantificación de vertidos de biomasa por parte de buques pesqueros.

La aplicación del IGD a las flotas gallegas presentó datos sustancialmente diferentes a los obtenidos cuando se usaron categorías de impacto convencionales. En este sentido, las categorías de impacto convencionales estaban fuertemente condicionadas por la intensidad energética de la pesquería, mientras que los resultados obtenidos para el IGD mostraron tendencias variables debido a una mayor dependencia en un número de factores más heterogéneo.

Sección V: Huella de carbono

La huella de carbono mide la cantidad de CO_2 y otros gases de efecto invernadero que se emiten a la atmósfera debido a las actividades antropogénicas vinculadas a un determinado proceso, producto o sistema. En esta sección se estimó la huella de carbono del sector pesquero gallego. De hecho, para este estudio, se tuvieron en cuenta también datos de inventario de la acuicultura extensiva e intensiva. Estos datos estaban disponibles a raíz de estudios previos llevados a cabo en Galicia, y se utilizaron con el fin de obtener un valor de huella de carbono global. Los resultados mostraron que la actividad pesquera supone un 3% de las emisiones de gases de efecto invernadero de Galicia y un 0,2% de las emisiones del Estado, recalcando la importancia de este sector en términos de emisiones de gases de efecto invernadero.

Por último, en el capítulo 13 de la tesis se propone un software de cálculo de huella de carbono adaptado a las características específicas de los sistemas pesqueros, con la finalidad de permitir que los distintos actores del sector pesquero, tanto a nivel gallego como a nivel estatal puedan calcular la huella de carbono ligada a la extracción de pescado y otras especies marinas.

Appendix VI

Curriculum vitae

PERSONAL DATA

Name	Ian Vázquez Rowe
Adress	18, Rue Glesener
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Phone	+(352)691242334
e-mail	ianvazquez2002@yahoo.es; ian.vazquez@tudor.lu
ID card.	44.848.227-K (Spain)
Date of birth	29/12/1984
Nationality	Spanish and British

ACADEMIC BACKGROUND

May 2006	***Bachelor of Science in Biology.*** University of Texas at Arlington
October 2008	***Master of Science in Environmental Engineering***. School of Engineering. University of Santiago de Compostela
Spring 2012 (expected)	***PhD in Chemical Engineering.*** School of Engineering. University of Santiago de Compostela Thesis supervisors: María Teresa Moreira and Gumersindo Feijoo. Title: *Fishing for solutions. Environmental and operational assessment of selected Galician fisheries and their products.*

LANGUAGES

Spanish	Mother tongue Minor in Spanish at the University of Texas at Arlington.
Galician	Mother tongue
English	Mother tongue. First Certificate English (FCE). Cambridge University. (June 2001) Proficiency Certificate English (PCE). Cambridge Univeristy. (December 2001) TOEFL Exam (February 2002)
French	Elementary (spoken and read). High school and bachelor credit hours.
Italian	High comprehension and speaking level. Medium writing skills. Four years at the School of Languages (Level B1). Erasmus at Università La Sapienza di Roma (May-October 2008)
Portuguese	High comprehension level. Medium speaking skills.

RESEARCH STAYS

School for Resource and Environmental Studies (Dalhousie University). Halifax (Canada). June-September 2011.

Centre Recherche Public Henri Tudor. Esch-sur-Alzette (Luxembourg). January-March 2012.

PARTICIPATION IN RESEARCH PROJECTS

White biotechnology for added value products from renewable plant polymers: Design of tailor-made biocatalysts and new industrial bioprocesses (BIORENEW). European Union (NMP2-CT-2006-026456). Project leader: María Teresa Moreira Vilar.

Integrated European Network for biomass and waste reutilisation for Bioproducts (AQUATERRE). European Union (212654). Project leader: María Teresa Moreira Vilar.

Sustainable production of Biologically Active Molecules of Marine Based Origin (BAMBOO). European Union (FP7-KBBE-2010-4). Project leader: María Teresa Moreira Vilar.

Carbon footprint of selected elaborated seafood products. **Pescanova SA.** Waiting for national funding. Currently analyzing one pilot product. Project leader: Juan Mallo (Pescanova) and Gumersindo Feijoo (USC).

Indirect Land Use change effects in consequential Life Cycle Assessment of bioenergy (LUCAS). Fonds National de la Recherche Luxemboorg. Project leader: Enrico Benetto.

Accelerating Renewable Energies by Valorization of Biogene Organic Raw Materials (ARBOR 2020). European Union. Interreg IVb North West Europe. Project leader: Daniel Koster.

SCHOLARCHIPS AND CONTRACTS

Xunta de Galicia Master Thesis Grant at the University of Santiago de Compostela. October 2006-September 2008.

Xunta de Galicia Erasmus Grant at Università La Sapienza (Rome). May 2008-September 2008.

Research contract at the Univeristy of Santiago de Compostela. October 2008-January 2010.

Scholarship Holder of the Department of Economy and Industry of the Xunta de Galicia (María Barbeito Program) at USC. January 2010-December 2011.

Centre Recherche Public Henri Tudor. R&D Engineer. January 2011-to date.

COURSES

Title: Footprint Expert TM Training Course (20 h)
Organized by: Carbon Trust Association
Place and date: London, March 2011

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1.- **Authors:** Vázquez-Rowe, I., Moreira, M.T. & Feijoo, G.
Title: Estudio del Impacto Ambiental de las Operaciones Forestales en Galicia
Participation: Poster
Conference: Medio Rural, Agricultura y Cambio Climático
Place: A Coruña (Spain) **Date**: 26 March, 2009

2.- **Authors:** Vázquez-Rowe, I., Moreira, M.T. & Feijoo, G.
Title ACV Comparativo de Pesca do Xurelo (*Trachurus trachurus*) nos Caladoiros do Litoral Galego
Participation: Poster
Conference: XII Foro dos Recursos Mariños e da Acuicultura das Rías Galegas
Place: O Grove (Spain) **Date**: 8-9 October, 2009

2010

1.- **Authors:** Vázquez-Rowe, I., Iribarren, D., Hospido, A., Moreira, M.T. & Feijoo, G.
Title: Linking fuel consumption and eco-efficiency in fishing vessels. A brief case study on selected Galician fisheries
Participation: Oral
Conference: 1st International Symposium on Fishing Vessel Energy Efficiency
Place: Vigo (Spain) **Date**: 18 May, 2010

2.- **Authors:** Vázquez-Rowe, I., Iribarren, D., Moreira, M.T. & Feijoo, G.
Title: A double perspective on the joint implementation of Life Cycle Assessment and Data Envelopment Analysis
Participation: Oral
Conference: SETAC Europe 20th Annual Meeting
Place: Seville (Spain) **Date**: 27 May, 2010

3.- **Authors:** Vázquez-Rowe, I., Iribarren, D., Hospido, A., Moreira M.T. & Feijoo, G.
Title: The importance of operational inputs in the environmental assessment of seafood. A case study with Galician fisheries (NW Spain)
Participation: Poster
Conference: LCA Agrifood
Place: Bari (Italy) **Date**: 22-24 September, 2010

4.- **Authors:** Iribarren, D., Hospido, A., Vázquez-Rowe, I., Moreira, M.T. & Feijoo, G.
Title: Estimating the carbon footprint of the Galician fishing sector (NW Spain)
Participation: Oral
Conference: LCA Agrifood
Place: Bari (Italy) **Date**: 23 September, 2010

5.- **Authors:** Cambria, D., Vázquez-Rowe, I., González-García, S., Moreira, M.T. & Feijoo, G.
Title: A Life Cycle Assessment study
Participation: Poster
Conference: 14th International Trade Fair of Material and Energy Recovery and Sustainable Development
Place: Rimini (Italy) **Date**: 3-6 November, 2010

2011

1.- **Authors:** Ramos, S., Vázquez-Rowe, I., Feijoo, G. & Zufía, J.
Title Timeline LCA study of the European hake fishery (*Merluccius merluccius*) in the Basque Country
Participation: Poster
Conference: LCM
Place: Berlin (Germany) **Date**: 28-31 August, 2011

2.- **Authors:** Vázquez-Rowe, I.
Title A pegada do carbono: aplicación na industria da acuicultura, mexillón e rodaballo
Participation: Oral
Conference: XIV Foro dos Recursos Mariños e da Acuicultura das Rías Galegas
Place: O Grove (Spain) **Date**: 6 October, 2011

3.- **Authors:** Moreira, M.T., Vázquez-Rowe, I., Villanueva-Rey, P. & Feijoo, G.
Title The importance of timeline analysis in viticulture. A case study based on *Rías Baixas* production area (NW Spain)
Participation: Poster
Conference: LCA XI
Place: Chicago (United States) **Date**: 4-6 October, 2011

2012

1.- **Authors:** Vázquez-Rowe, I., Hospido, A., Moreira, M.T. & Feijoo, G.
Title Review and future perspectives in the environmental assessment of seafood production systems
Participation: Oral presentation
Conference: 8th International Conference on Life Cycle Assessment in the Agri-Food Sector
Place: Saint Malo (France) **Date**: 2-4 October, 2012

2.- **Authors:** Golkowska, K., Vázquez-Rowe, I., Koster, D. & Benetto, E.
Title Life cycle assessment of ammonia stripping of biogas digestate
Participation: Oral presentation
Conference: 4th International Symposium on Energy from Biomass and Waste
Place: Venice (Italy) **Date**: 12-15 November, 2012

PUBLICATIONS

Published

1.- G. Feijoo, S. González-García, **I. Vázquez Rowe** and M.T. Moreira (2009): Biocombustibles: retos y oportunidades. *Evaluación y Gestión de los Impactos en la Producción y Uso de Biocombustibles.* Pages: 281-97. Editors: J.M. Lema Rodicio and P.M. Bugallo. ISBN 13: 978-84-613-4672-1.

2.- **I. Vázquez-Rowe,** D. Iribarren, M.T. Moreira and G. Feijoo (2010): Combined application of life cycle assessment and data envelopment analysis as a methodological approach for the assessment of fisheries. *International Journal of Life Cycle Assessment*, 15(3): 272–83.

3.- D. Iribarren, **I. Vázquez-Rowe**, A. Hospido, M.T. Moreira and G. Feijoo (2010): Further potentials in the joint implementation of the life cycle assessment and data envelopment analysis. *Science of the Total Environment*, 408(22): 5265-72.

4.- D. Iribarren, **I. Vázquez-Rowe**, A. Hospido, M.T. Moreira and G. Feijoo (2010): Estimation of the carbon footprint of the Galician fishing activity (NW Spain). *Science of the Total Environment*, 408(22): 5284-5294.

5.- **I. Vázquez-Rowe**, M.T. Moreira and G. Feijoo (2010): Life cycle assessment of horse mackerel fisheries in Galicia (NW Spain): Comparative analysis of two major fishing methods. *Fisheries Research*, 106(3): 517-27.

6.- **I. Vázquez-Rowe**, M.T. Moreira and G. Feijoo (2011): Estimating global discards and their potential reduction for the Galician fishing fleet (NW Spain). *Marine Policy*, 35(2): 140-47.

7.- D. Iribarren, **I. Vázquez-Rowe**, A. Hospido, M.T. Moreira and G. Feijoo (2011): Updating the carbon footprint of the Galician fishing activity (NW Spain). *Science of the Total Environment,* 409(8): 1609-11.

8.- I. Vázquez-Rowe, D. Iribarren, A. Hospido, M.T. Moreira and G. Feijoo (2011): Computation of operational and environmental benchmarks within selected Galician fishing fleets (NW Spain). *Journal of Industrial Ecology,* 15, 776-95.

9.- I. Vázquez-Rowe, M.T. Moreira and G. Feijoo (2011): Life Cycle Assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock. *Fisheries Research,* 110(1): 128-35.

10.- S. Ramos, **I. Vázquez-Rowe**, I. Artetxe, M.T. Moreira, G. Feijoo and J. Zufía (2011): Environmental assessment of the Atlantic mackerel (Scomber scombrus) season in the Basque Country. Increasing the time line delimitation in fishery LCA studies. *International Journal of Life Cycle Assessment,* 16(7), 599-610.

11.- I. Vázquez-Rowe, M.T. Moreira and G. Feijoo (2011): Environmental assessment of frozen common octopus (Octopus vulgaris) captured by Spanish fishing vessels in the Mauritanian EEZ. *Marine Policy,* 36(1), 180-88.

12.- I. Vázquez-Rowe, P. Villanueva-Rey, M.T. Moreira and G. Feijoo (2012): Environmental analysis of *Ribeiro* wine from a timeline perspective: harvest year matters when reporting environmental impacts. *Journal of Environmental Management,* 98, 73-83.

13.- I. Vázquez-Rowe, P. Villanueva, D. Iribarren, M.T. Moreira and G. Feijoo (2012): Joint Life Cycle Assessment and Data Envelopment Analysis of grape production for vinification in the Rías Baixas appellation (NW Spain). *Journal of Cleaner Production,* 27, 92-102.

14.- I. Vázquez-Rowe, M.T. Moreira and G. Feijoo (2012): Inclusion of discard assessment indicators in fisheries life cycle assessment studies. Expanding the use of fishery-specific impact categories. *International Journal of Life Cycle Assessment*, doi: 10.1007/s11367-012-0395-x.

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[1]

Submitted for publication

1.- D. Cambria, **I. Vázquez-Rowe**, S. González-García, M.T. Moreira, G. Feijoo and D. Pierangeli (2012): Comparative Life Cycle Assessment study of three winter wheat production systems in the European Union. *Environmental Engineering and Management Journal.*

2.- I. Vázquez-Rowe, A. Hospido, M.T. Moreira and G. Feijoo (2012): Review: Best practices in Life Cycle Assessment implementation in fisheries: improving and broadening environmental assessment for seafood production systems. *Trends in Food Science & Technology.*

3.- I. Vázquez-Rowe and P. Tyedmers (2012): Identifying the importance of the "skipper effect" within sources of measured inefficiency in fisheries through data envelopment analysis (DEA). *Fisheries Research.*

4.- I. Vázquez-Rowe, P. Villanueva-Rey, M.T. Moreira, and G. Feijoo (2012): Carbon footprint of a multi-ingredient seafood product from a business-to business perspective. *Resources, Conservation and Recycling.*

5.- R. Parker, **I. Vázquez-Rowe**, and P. Tyedmers (2012): The importance of fuel use in purse seining fisheries for Skipjack and Yellowfin. *Fish and Fisheries.*

6.- D. Iribarren and **I. Vázquez-Rowe** (2012): Is labour a suitable input in LCA+DEA studies? Insights on the combined use of economic, environmental and social parameters. *Science of the Total Environment.*

7.- S. Ramos, **I. Vázquez-Rowe**, I. Artetxe, M.T. Moreira, G. Feijoo and J. Zufía (2012): Operational efficiency and environmental impact fluctuations of the Basque trawling fleet using LCA+DEA methodology. *Marine Policy.*

REGISTERED SOFTWARE

1.- I. Vázquez-Rowe, M.T. Moreira and G. Feijoo (2012): SC-0019-2012. January 19th 2012. Registered software: "Software de cálculo de huella de carbono para el sector pesquero: pescaenverde" [in Spanish].

OTHER INTERESTING DATA

Reviewer for the following international journals:

- International Journal of Environmental Research.
- Journal of Industrial Ecology.
- Journal of Cleaner Production.
- Journal of Environmental Management.
- Aquaculture.
- Environmental Engineering and Management Journal.

-Honourable mention for Master Thesis project: *CO_2 sequestration through wet accelerated carbonation of steel slag*. National Association of Industrial Plants. Milan-Italy. July 2009.

-Outstanding Academic Achievement. University of Texas at Arlington. 2005-2006.

-Freshman Honours List 2002-2003. Superior Academic Achievement. University of Texas at Arlington.

-Tennis. Member of the tennis team at the University of Texas at Arlington (2002-2006).

-Tennis. Captain of the tennis team at the University of Santiago de Compostela (2006-2011).

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Activity description

Name	Atlantic horse mackerel, marine fishing (Trachurus trachurus)		
Type	Agriculture		
ID	03	03.1	0311
Synonym	Atlantic horse mackerel.		
Local name	Xurelo (Galician); jurel (Spanish).		
Life Cycle Stages included	Raw materials; Production.		
System boundaries	At plant		
System boundaries description (Starting and ending activities)	From the vessel operations to the landing of Atlantic horse mackerel at a Galician port.		
System boundaries description (Included activities)	The dataset includes all stages of fishing operations at sea: fuel consumption, production of fuel, emission of cooling agents, ice production, paint and anti-fouling production, marine lubricant oil production, emissions linked to anti-fouling paints, vessel construction, net production, discards and waste material linked to lost nets.		
System boundaries description (Excluded activities)	Seafloor use and other biological aspects were left aside, as well as onland port operations.		

Functional unit

Functional unit	1 ton of landed horse mackerel
Comment	The FU considers whole wet weight Atlantic horse mackerel

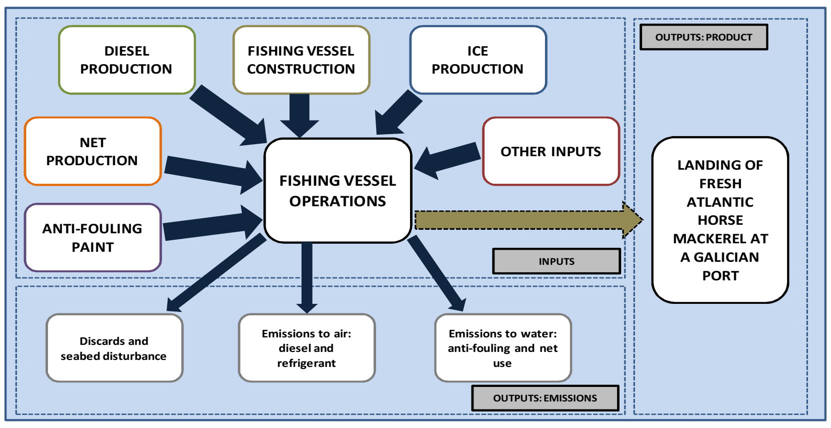
Time Period

Start of the period	01/01/2008
End of the period	31/12/2008
Comment	Data was collected for the 2008 fishing season for 30 purse seining vessels (18% of the fleet).

Geographical information

Country	**ES**
Region	Galicia
City	Santiago de Compostela (main research); several Galician port towns.
Comment	Data was obtained from the ports of Portonovo, Vigo, Portosín, Cambados and Sada.

Technology

Classification	Current
Technology description	
Flow diagram	
Comment	

LCI Method

Inventory type	**Unit process, single operation**
LCI method principle	Attributional
Comments on LCI method principle	The LCI is entirely done with an attributional methodology
LCI method approach	Not applicable
Comments on LCI method approach	Mass allocation was assumed in this study

LCI Data

Extrapolation	
Sampling procedure	Data were obtained from 30 coastal Galician purse seining vessels. Data correspond to landings performed in 2008.
Criteria for inclusion or exclusion of data	
Comment	

Data coverage

Data origin	Average data
National production volume	24,000 tonnes (Galicia only).
Considered production volume	3,030 tonnes
Percentage supply or production covered	12,63%
Comment	Highly representative, especially considering that total horse mackerel landings also include other gears, out of the scope.

Validation

Type of review	Independent external review
Method of review	Expert judgement
Review details	This inventory has been reviewed and published in a scientific journal

Author	
Author name or Project	Ian Vázquez Rowe
Center/University/Research group name	Research Group of Environmental Engineering and Bioprocesses/University of Santiago de Compostela
Author contact details	ianvazquez2002@yahoo.es
Publication date	30/09/2010
Data entry by	
Name	Ian Vázquez Rowe
Contact details	ianvazquez2002@yahoo.es
Data of data entry	19/11/2011
Data reviewed by	
Name	Three anonymous reviewers assigned by Fisheries Research.
Contact details	Fisheries Research
Data of last review	30/09/2010
Data sheet status in the database	
Data sheet status	Working draft
Access	Public inventory
Copyright	Universidade de Santiago de Compostela
Inventory publication	
Inventory publication	Published
Published source	Vázquez-Rowe, I., Moreira, M.T., Feijoo, G., 2010. Life cycle assessment of horse mackerel fisheries in Galicia (NW Spain): Comparative analysis of two major fishing methods. Fisheries Research, 106: 517-527

Exchanges							**(Activity name)**		
Type	**Name**	**Unit**	**Compartment**	**Subcompartment**	**Formula**	**Cas number**	**Amount**	**Comment**	**Source(s)**
0 - Reference flow	Horse mackerel (Trachurus trachurus)	1 ton	N/A	N/A	N/A	N/A	1,00E+00		
3 - From technosphere	Diesel, combustion by the fishing vessel engine	kg	N/A	N/A	N/A	N/A	1,76E+02	Average repoted value by skippers	
3 - From technosphere	Steel	kg	N/A	N/A	N/A	N/A	2,70E+00		Abeijón Hermanos Shipyard, p. comm.
3 - From technosphere	Wood	g	N/A	N/A	N/A	N/A	2,30E+00		Abeijón Hermanos Shipyard, p. comm.
3 - From technosphere	Ice	kg	N/A	N/A	N/A	N/A	3,21E+02	Average repoted value by skippers	
3 - From technosphere	Seine net	kg	N/A	N/A	N/A	N/A	1,02E+01	Average repoted value by skippers	
3 - From technosphere	Boat paint	g	N/A	N/A	N/A	N/A	1,13E+02	Average repoted value by skippers	
3 - From technosphere	Anti-fouling paint	g	N/A	N/A	N/A	N/A	3,65E+02	Average repoted value by skippers	
3 - From technosphere	Marine lubricant oil	g	N/A	N/A	N/A	N/A	4,47E+02	Average repoted value by skippers	
4 - To environment	Chlorodifluoromethane	mg	air		R22	000075-45-6	2,30E+01		Kinarte, personal communication
4 - To environment	Carbon dioxide	kg	air		CO2	000124-38-9	5,58E+03		EMEP-Corinair 2006
4 - To environment	Carbon monoxide	kg	air		CO2	000630-08-0	1,30E+00		EMEP-Corinair 2006
4 - To environment	Nitrogen oxides	kg	air		Nox	011104-93-1	1,30E+01		EMEP-Corinair 2006
4 - To environment	Dioxin, 1,2,3,7,8,9-hexachlorod	mg	air			019408-78-3	3,50E-02		EMEP-Corinair 2006
4 - To environment	Methane	g	air		CH4	000074-82-8	8,80E+00		EMEP-Corinair 2006
4 - To environment	Dinitrogen monoxide	g	air		N2O	010024-97-2	1,41E+01		EMEP-Corinair 2006
4 - To environment	Sulfur dioxide	kg	air		SO2	007446-09-5	1,76E+00		EMEP-Corinair 2006
4 - To environment	Policyclic aromatic hydrocarbons	g	air		PAH	130498-29-2	3,52E+02		EMEP-Corinair 2006
4 - To environment	Arsenic	mg	air		As	007440-38-2	8,80E+00		EMEP-Corinair 2006
4 - To environment	Cadmium	mg	air		Cd	007440-43-9	1,76E+00		EMEP-Corinair 2006
4 - To environment	Chromium	mg	air		Cr	007440-47-3	7,04E+00		EMEP-Corinair 2006
4 - To environment	Copper	mg	air		Cu	007440-50-8	8,80E+00		EMEP-Corinair 2006
4 - To environment	Mercury	mg	air		Hg	007439-97-6	8,80E+00		EMEP-Corinair 2006
4 - To environment	Nickel	mg	air		Ni	007440-02-0	1,23E+01		EMEP-Corinair 2006
4 - To environment	Lead	mg	air		Pb	007439-92-1	1,76E+00		EMEP-Corinair 2006
4 - To environment	Selenium	mg	air		Se	007782-49-2	3,52E+01		EMEP-Corinair 2006
4 - To environment	Zinc	mg	air		Zn	007440-66-6	8,80E+01		EMEP-Corinair 2006
4 - To environment	Total small particles	g	air		TSP	012789-66-1	1,94E+02		EMEP-Corinair 2006
4 - To environment	Xylene	g	water		C6H4C2H6	001330-20-7	3,31E+01		Hempel, 2008; Hospido and Tyedmers, 2005
4 - To environment	Copper ions	g	water		Cu	017493-86-6	7,57E+01		Hempel, 2008; Hospido and Tyedmers, 2005
4 - To environment	Zinc ions	g	water		Zn	023713-49-7	3,43E+01		Hempel, 2008; Hospido and Tyedmers, 2005
4 - To environment	Ethyl-benzene	g	water		C6H5CH2CH3	000100-41-4	8,54E+00		Hempel, 2008; Hospido and Tyedmers, 2005
4 - To environment	4,5-Dichloro-2-octyl-3(2H)-isot	g	water			064359-81-5	3,65E+00		Hempel, 2008; Hospido and Tyedmers, 2005
4 - To environment	Ethanol	g	water		C2H6O	000064-17-5	3,65E+00		Hempel, 2008; Hospido and Tyedmers, 2005
4 - To environment	4-Methyl-2-pentanone	g	water			000108-10-1	3,65E+00		Hempel, 2008; Hospido and Tyedmers, 2005
4 - To environment	Chlorine	g	water		Cl	007782-50-5	1,06E+01	Measured form bilge waters	
4 - To environment	Strontium	kg	water		Sr	007440-24-6	3,48E+01	Measured form bilge waters	
4 - To environment	Rubidium	kg	water		Rb	007440-17-7	5,50E+00	Measured form bilge waters	
4 - To environment	Bromine	kg	water		Br	007726-95-6	3,21E+02	Measured form bilge waters	