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Artisanal fisheries analysis using the DPSIR framework and System Dynamics: the case of dredge fisheries in Portugal

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Artisanal fisheries analysis using the DPSIR framework and System Dynamics: the case of dredge fisheries in Portugal

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1. Introduction

Human demand for fish resources is growing worldwide, particularly in large urban centers of developing countries. Artisanal fisheries play an important role for supporting local and regional markets. According to the Food and Agriculture Organization of the United Nations (FAO) small scale marine fisheries account for 40% of the marine fish taken for human food (FAO, 1998).

The sustainable development of artisanal fisheries is essential to guarantee the preservation of the exploited ecosystems and the socio-economic stability of fishermen communities. To ensure the sustainability of artisanal fisheries, updated information about the whole system under analysis is required to improve stakeholders' communication and to provide them an accurate awareness of the sector's status. The selection and application of a set of indicators is a suitable process to address this need, gathering and organizing relevant data, consistently, over time.

This paper uses the Driving force, Pressure, State, Impact, Response (DPSIR) framework proposed by the European Environmental Agency (EEA, 1999) to select a set of indicators which aim to describe artisanal fisheries. The DPSIR framework adopts a multidisciplinary perspective, integrating economic, social, ecological and institutional dimensions. The selected set of DPSIR indicators was used to analyse the artisanal dredge fisheries in the south coast of Portugal. The Portuguese sector of artisanal fisheries plays an important economic, social and cultural role within coastal communities. Data on this sector are scarce, thus limiting the possibilities of establishing appropriate analysis for supporting management strategies and initiatives.

Fisheries can be seen as dynamic systems with biological, social and economic features interrelated. In this paper, we developed a System Dynamics model based on the information obtained from the DPSIR indicators. One of the scenarios tested consisted of imposing quotas that prohibit fisheries of species with low levels of biological stock. The other scenario represented an increase in fuel price and in first sale price of all species.

The paper is structured as follows. The DPSIR concept is reviewed in section 2. Section 3 includes a brief review of DPSIR applications in the fisheries context, and a set of DPSIR indicators for monitoring artisanal fisheries is presented. Section 4 illustrates the application of the selected DPSIR set of indicators to a practical case study – the artisanal dredge fleet that operates in the south coast of Portugal. Section 5 explores cause-effect relationships between the DPSIR indicators and presents the System Dynamics model with the corresponding results. Section 6 presents the conclusions.

2. DPSIR framework overview

In 1993 the Organization for Economic Co-operation and Development (OECD) proposed the Pressure, State, Response (PSR) framework (OECD, 1993). This framework aims to develop indicators of sustainable development, organizing them into three categories: pressure (P), state (S) and response (R). The PSR framework is based on a concept of causality: human activities pressure the environment, changing the quality and quantity of resources (state). Society responds to these changes with adaptive, preventive, and mitigative actions.

In 1999, the EEA introduced the Driving force, Pressure, State, Impact, Response (DPSIR) framework. This framework is an enhancement of the PSR framework, with the inclusion of two new categories: Driving forces (D) and Impact (I). The DPSIR framework considers causal relationships between D, P, S, I and R categories, as illustrated in Figure 1 (EEA, 1999).

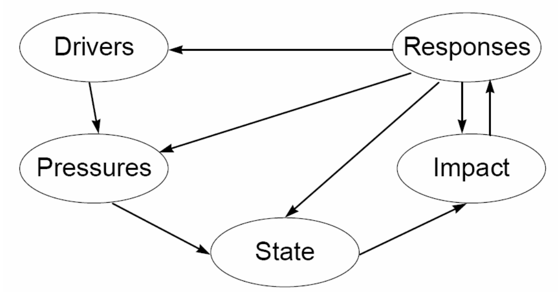

Figure 1. The DPSIR Framework (EEA, 1999).

The objective of the DPSIR framework is to provide a comprehensive description of a system, which is achieved by selecting appropriate indicators. Following the original guidelines of EEA (1999), all DPSIR indicators should be descriptive and aim to directly measure features of the real world. The identification of the key indicators is followed by the organization of the data available, and eventual suggestion of procedures to collect missing data for future analysis. This can contribute to facilitate the communication between stakeholders and improve the decision processes.

The EEA original guidelines (EEA, 1999) suggest the use of the DPSIR framework to describe environmental issues. However, the scope of application of this framework has been expanded to assess social, economic and institutional matters. Depending on the subject under analysis, the indicators of each category can be related to the ecologic, social, economic or institutional dimensions, and more than one dimension can be considered in each category.

Driving force indicators describe socio-economic needs and motivations that impel the existence of human activity. According to EEA (1999), a driving force describes social, demographic and economic developments in society. An example of a driving force mentioned in EEA (1999) is population growth. The term driving force has been employed to describe economic sectors that engender pressures. An example of this approach can be found in the Henriques *et al*. (2008), that described a DPSIR study to assess the ecologic status of a marine environment. In this study the selected driving forces were population, fishing, dredging activity, port activity, agriculture, aquaculture and industry. Less frequently, driving forces are considered both as anthropogenic and natural factors. In the Holman *et al*. (2008) study, social change, economic change and climate change were considered drivers to assess coastal zones.

Pressures are the human actions that can induce environmental change. In the review of DPSIR definitions in Maxim *et al*. (2009), it is stated that pressure indicators are normally linked to the unwanted changes, normally those human actions with potential to cause damage and degradation. The EEA (1999) report illustrates CO_2 emissions per sector and the amount of land used for roads as pressure indicators. In Henriques *et al*. (2008), industrial effluents discharges were considered an industry pressure.

The state may refer to natural systems status, to socio-economic status or to a combination of both. State indicators aim to illustrate the temporal changes of the system studied. When the study focuses the features of a natural system, chemical, physical and biological parameters can be considered. In the EEA (1999) report, atmospheric CO_2 concentrations, temperature and fish stocks are presented as examples. When the socio-economic dimension is included in the state, many different features can be measure, such as the living conditions of humans or the economic situation of an industry. The research of Pirrone *et al*. (2005), that applied the DPSIR framework to address eutrophization in a river, selected both natural and socio economic indicators to describe the state, including number of tourists and size of current population.

Impacts are the negative effects caused by human activities on the ecosystem and society. Impact indicators can encompass both ecologic and socio-economic aspects. Examples of ecologic impact indicators can be found in the Karageorgis *et al*. (2006) study of a river area, including reduction of wetlands, biodiversity loss and soil salinization. For an example of an integrated approach considering both ecologic and socio-economic impact indicators see Pirrone *et al*. (2005). Two of the socio-economic indicators selected in this research include reduced tourism and change in fisheries benefit.

Responses are all the measures adopted by society with the aim to improve the status of the system. These can correspond to preventive, adaptive or curative actions. Lin *et al*. (2007) studied temporal changes in a coastal wetland, and some response indicators specified were the rational use of coastal wetland, the waste water treatment capacity and the natural conservation area.

3. Methodology: the DPSIR framework applied to artisanal fisheries

The DPSIR framework has been suggested for the development of fisheries indicators by FAO (1999) and EEA (2002). However, few studies applied the DPSIR framework with exclusive focus on fisheries. The EEA (2002) report and the Mangi *et al*. (2007) study are two significant contributions concerning this theme. Fisheries are more often identified as a driving force indicator in the assessment of marine environments (e.g. Henriques *et al*., 2008; Ojeda-Martínez *et al*., 2009) and estuarines (e.g., Cave *et al*., 2003; Caeiro *et al*., 2004).

The EEA (2002) report recommends a set of DPSIR indicators for fisheries and aquaculture. This proposal is based on the review of fisheries and aquaculture indicators developed by international and regional fisheries and environmental organizations. In the EEA (2002) report, driving forces relate to social and economic aspects, describing demand and consumption of fish, as well as fishermen wages. Pressures include technical aspects of the fleet, the maximum sustainable yield, the induced mortality of fish and damage of nature. The state characterizes the biological conditions of species (target and non-target), and correlates the target species stock with fishing effort. Impacts assess the consequences of the fishing activity on the ecosystem and on society. Examples of impact indicators include discards, bycatch, damage of habitats and species, and the quality of the fish captured. Response indicators evaluate the effectiveness of management actions in fisheries.

Mangi *et al*. (2007) used DPSIR indicators to assess artisanal reef fisheries in Kenya. The driving force indicators selected describe social and economic stimulus for the practice of fisheries by local population, including unemployment, tradition and tourism. The pressure indicators express the fisheries undertaken and the technical characteristics of the gears used. State indicators evaluate biologic aspects of target and non-target species, such as fish population and coral mortality. The impact category identifies social and economic negative effects, when natural resources are heavily exploited. This includes declining in catches, uncertainty of livelihood benefits and social exclusion/conflicts. Responses describe legislation, territorial waters protection and population education and awareness.

This paper proposes a set of DPSIR indicators to describe artisanal fishery communities and associated marine ecosystems, which are presented in Table 1. This table provides the definition of each indicator and the corresponding units of measure. An annual periodicity of measure for each indicator is recommended. Indicators are organized into sub-indicators whenever this detail is considered relevant.

The driving force indicators proposed intend to describe the social and economic motivation for the existence of fishing activity. Therefore, the indicators selected describe the demand of the target species, the costs and revenue of the activity, and the socio-economic conditions of fishermen communities. This perspective is in agreement with the proposal of EEA (2002) and the study of Mangi *et al*. (2007).

Table 1. DPSIR indicators for artisanal fisheries.

	Indicator	Sub-indicator	Description	Units
Driving - Forces	Fishermen characterization	Number of fishermen		
		Economic context of fishermen households	Average monthly income in the household	Monetary
		Age of fishermen	Average age of fishermen in the community analysed	Years
		The influence of fisheries in the community	Percentage of families with at least one person working directly in fishery-related activities	
		Educational level of fishermen	Average educational level of fishermen	Years of schooling
	Demand of target species	Demand from local consumption	Volume and value of the local consumption per target species (including tourism)	Monetary and tonnes
		Exports	Volume and value of exports per target species	Monetary and tonnes
	Supply of target species	Imports	Volume and value of imports per target species	Monetary and tonnes
		Supply from aquaculture	Volume and value of the production from aquaculture per target species	Monetary and tonnes
		Supply from competing fleets	Volume and value of captures from commercial fleets per target species	Monetary and tonnes
	Activity costs	Fixed costs	Cost of license renewal and maintenance of vessels and gears.	Monetary
		Variable costs	Landing taxes (commission of the auctions authority and contributions to the social regime), cost of fuel, crew insurance, and contributions to producers organisations.	Monetary
	Target species price	First Sell price	Average price of each target species in the wholesale market	Monetary /kg
		Second Sell price	Average price of each target species in the second sale	Monetary /kg
Pressures	Fishing effort	Fishing trips	Total number of fishing trips	
		Fishing area	Area where the fisheries occur	Km^2
	Fishing power	Number of vessels	Number of artisanal vessels licensed	
		Crew members	Average number of fishermen per vessel	
		Vessels power	Average power of the fleet	kW
		Vessels GRT	Average GRT of the fleet	tonnes
		Vessels age	Average age of the fleet	Years
		Vessels length	Average length of the fleet	meters
	Number of licenses per vessel		Average number of fishing arts licensed per vessel	
	Declared catches		Volume of declared catches per target species	tonnes
	Non-complying with legislation catches		Estimation of the undeclared captures	tonnes
	Discards		Weight of organic material of animal origin, which is dumped at sea, dead or alive.	tonnes

Table 1. DPSIR indicators for artisanal fisheries (continued).

	Indicator	Sub-indicator	Description	Units
State	Changes in target species abundance		Abundance of target species	g (biomass) /m^3
	Mean size of target species			Mm
	Changes in water temperature			ºC
	Change in primary production		Primary production using 14C incorporation	Rate of respiration
	Contamination		Concentration of pollutants in water	mg/l
	Tides		Average velocity of the tides	km/h
	Changes in water pH			pH
Impacts	Catch per trip		Weight of catches performed per species and trip	Kg
	Revenue per trip		Value of catches per species and per trip	Monetary
	Cost per trip		Value spent in activity costs per trip	Monetary
	Profitability per trip		Revenue minus variable costs	Monetary
	Catches quality for human consumption		Number of diseases episodes associated with the consumption of the target species.	
Responses	Enforcement and compliance		Type and frequency of monitoring activities	
	Subsidies		Total amount of money given to fishermen as subsidies	Monetary
	Educational programs	Number of training programs	Number of training programs available	
		Number of fishermen that attended training courses	Number of fishermen that attended training courses	
	Legislation	Limits of captures	Catch quotas for each target species	kg / trip
		Interdiction periods	Number of days that artisanal fisheries where interdicted	
		Technical characteristics of the fishing gears allowed	Description of the main features of the fishing gears allowed	
		Wholesale market regulation	Description of the commercialisation conditions concerning first sale.	

The pressure indicators selected aim to measure the stress induced by artisanal fisheries in the ecosystem. Accordingly, fishing effort indicators evaluate the intensity of fisheries and the fishing power indicators characterize the technology used. The indicators of catches (declared and non-declared) and discards assess the volume of biomass removed from the sea. The EEA (2002) and Mangi *et al.* (2007) pressure indicators share the same perspective.

To characterize the state, EEA (2002) and Mangi *et al.* (2007) suggested biological indicators of target and non-target species. In addition to the biological indicators, this study also proposes the use of physical and chemical indicators. Species' welfare is directly related with non-biological parameters of the ecosystem, such as the nutrient concentrations and the water temperature. Hence, non-biologic indicators are needed to ensure a proper awareness of the temporal changes of the ecosystem. This viewpoint is included in the EEA (1999) original guidelines of DPSIR. An application with chemical, physical and biological indicators can be found in Lin *et al.* (2007), which used DPSIR to assess coastal wetlands in China.

Regarding the impact category of indicators, this study considers the potential negative effects of the fishing activity for the human wellbeing, including social and economic aspects. The ecosystem changes are already included in the state category, and there is no need to repeat indicators in both categories. An analogous approach can be found in Mangi *et al.* (2007), which selected only the socio-economic features to describe the impacts of the overfishing problem in artisanal fisheries of Kenyan reefs. EEA (2002) considered both environmental and social impacts to evaluate fisheries impacts.

The response indicators selected aim to reflect society actions to enhance the system, including social, economic and environmental dimensions. This viewpoint is in agreement with Mangi *et al.* (2007) and EEA (2002). Therefore, the selected indicators intend to describe the type and frequency of monitoring procedures, the economic aid available to fishermen, the number and effectiveness of educational programs, and the regulation applicable.

4. DPSIR application to artisanal dredge fisheries

This section applies the DPSIR methodology described in the previous section to artisanal fisheries in the south coast of Portugal. The focus of the analysis concerns dredge fisheries. Artisanal vessels dedicated to dredge fisheries can be classified into two fleet segments: local and coastal. Local fleet vessels have an overall length lower than 9 meters and the coastal fleet vessels have an overall length between 9 and 14 meters. This fishing activity is performed with dredges towed by boat to harvest bivalve mollusks from the seabed. The four main bivalve target species in the south coast of Portugal are: surf clam (*Spisula* *solida*), donax clam (*Donax trunculus*), razor clam (*Ensis siliqua*) and striped venus (*Chamelea gallina*). These species are illustrated in Figure 2.

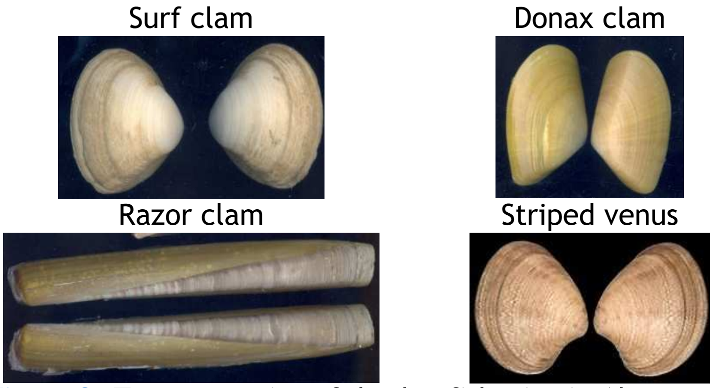

Figure 2. Target species of dredge fisheries in Algarve coast.

Two types of dredges can be used in this fishery: the grid dredge (GD), where the catch is retained in a metallic grid, and the traditional dredge (TD), where the catch is retained in a net bag attached to the dredge mouth, as illustrated in Figure 3. The GD is the most recent dredge, that was introduced in 2000. At the moment, the TD is only used for targeting razor clams, while the GD is used to catch the other species. A detailed description of this fishing gear can be found in Gaspar *et al.* (2003).

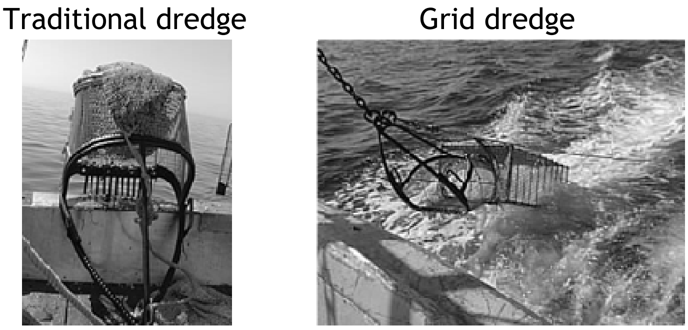

Figure 3. Dredges used in the bivalve fishery.

The data used in this research were provided by the Portuguese General Directorate of Fisheries and Aquaculture (DGPA) and the National Laboratory of Marine Research (INRB-L/IPIMAR), and concerns the period from 2001 to 2009. However, it was not possible to obtain data for some indicators due to the lack of historical records.

4.1. Driving Forces

Fishermen characterization

For the fishermen characterization indicator, data concerning the number, age and educational level of fishermen were only available for 2005. The total number of fishermen working in dredge fisheries was 149 (considering both skippers and crew members) and their average age was 45 years old. The educational level was classified in three levels. The low level corresponds to the completion of the 1st cycle of basic school or less. The medium level corresponds to the frequency of 2nd and 3rd cycles of basic school. The high level corresponds to the completion of the 3rd cycle of basic school or more. According to this classification, the majority of skippers had a medium educational level (52%), and a significant proportion (30%) had a low educational level. It was not possible to know the educational level of crew members.

Demand of target species

The data concerning the demand of target species are not available. It is only possible to describe qualitatively the main sources of demand. Both striped venus and razor clam have high levels of demand from Spain, so almost all the captures are exported to Spain. Donax clam is mainly consumed by the local population, although a small proportion is also exported to Spain. The surf clam is sold both at the local market and exported to Spain.

Supply of target species

The target species of dredge fisheries are not caught by commercial fleets in Portuguese territorial waters and are not produced in aquaculture. Beyond the captures of the artisanal fleet, the clam supply from other origins corresponds mainly to the imports from Vietnam. However, the proportion of imported bivalves in the Portuguese market is not known.

Activity costs

Table 2 presents the data concerning the fixed and variable activity costs per vessel. The calculation of fuel costs considers the product of the average fuel price (annual estimate provided by the Portuguese oil company GALP) and the total fuel consumption per vessel and per year. Table 2 shows that the fuel costs have increased consistently over the years. This is mainly due to the rise in fuel prices in the period analysed. The other variable costs correspond approximately to 20% of the total revenue. These are distributed as follows: 1%

of the revenue goes to Bivalve Producers Organization, 3% is taken as commission of the auctions authority, 10% for contributions to the social regime and 6% is crew insurance. The fixed costs include vessel and gear maintenance (approximately 400€ per vessel and per year) and licence renewal (approximately 20€ per vessel and per year).

Table 2. Annual activity costs.

		2001	2002	2003	2004	2005	2006	2007	2008
Fuel price (€/litre)		0.246	0.298	0.312	0.373	0.493	0.546	0.550	0.678
Variable costs (€)	Fuel costs	3759	4011	4362	4680	6677	6963	7389	na
	Other costs	5304	9090	13176	9713	11262	7088	5533	5156
Fixed costs (€)		420	420	420	420	420	420	420	420

Price of target species

The average first sell price of target species in wholesale market is shown in Table 3.

Table 3. Average price of target species in the wholesale market (€/kg).

	2001	2002	2003	2004	2005	2006	2007	2008
Surf clam	0.55	0.75	0.59	0.50	0.50	0.51	0.50	0.89
Donax clam	1.54	1.56	1.57	1.57	1.56	1.56	1.59	2.30
Razor clam	1.89	2.00	–	1.50	1.90	2.00	–	–
Striped venus	1.49	1.50	1.44	1.50	1.50	1.50	1.50	1.51

The prices of surf clam and donax clam remained stable between 2001 and 2007, but increased considerably in 2008. The price of the razor clam changed considerably over the years. For the striped venus, no relevant price changes were observed in the period analyzed.

4.2. Pressures

Fishing effort

The number of fishing trips done in each year is summarized in Table 4. Only the trips for which the vessels landed the fishing haul in the wholesale market were counted in the statistics reported.

Table 4. Total number of fishing trips.

	2001	2002	2003	2004	2005	2006	2007	2008
Fishing trips	6291	7465	7740	8102	7732	5316	6582	5723

Looking at the evolution of the total number of fishing trips over the years, it can be observed an increasing tendency between 2001 and 2004, and a decreasing tendency after 2004. Regarding the fishing area, dredge fisheries are allowed at depths exceeding 2.5 meters and must be held further than 300 meters from the coastline during the bathing season, as stated in the legislation (DR Portaria no. 1102-E/2000). In Portugal, dredge fisheries operate between 3 and 20 m depth (Constantino *et al.*, 2009).

The Portuguese south coast has four main harbours with registered dredge fishing vessels: Faro, Olhão, Tavira and Vila Real de Santo António (VRSA). The vessels that operate from each of these harbours choose fishing locations that minimize the navigation time between the harbour and the bivalve beds. Figure 4 shows the limits of the four main harbours and the bathymetric lines of 0, 3, 5, 11, 12 and 15 m of depth. The bathymetric lines define the areas where the target species live: surf clam within 3 and 12 m of depth, donax clam within 0 and 5 m of depth, razor clam within 3 and 11 m of depth and striped venus within 3 and 15 m of depth.

Figure 4. Fishing area and bathymetric lines of the harbours Faro, Olhão, Tavira and Vila Real de Santo António (VRSA).

The Portuguese south coast is not to the west of Faro exploited due to the rocky nature of the substrata and deplection of bivalves stocks in that area. Table 5 details the dredge fishing area of each species in the four ports considered.

Fishing power

The total number of vessels that operated with dredge gears in the south coast of Algarve is 67 (35 local and 32 coastal vessels). These vessels were licensed at least in one year between 2001 and 2008. As some vessels may only have a dredge fishery license for some of the years analyzed, the total number of vessels that were active in each year changes over time. The main characteristics of licensed vessels are summarized in Table 6.

Table 5. Fishing area for each target species (km^2).

	Faro	Olhão	Tavira	VRSA	Total
Surf clam	33	19	32	30	114
Donax clam	16	12	15	13	56
Razor clam	28	18	26	24	96
Striped venus	48	24	48	47	166
Total area (between 0 and 15 m depth)	58	31	57	55	200

Table 6. Main characteristics of vessels.

	2001	2002	2003	2004	2005	2006	2007	2008
Number of vessels	50	52	54	59	52	53	54	52
Average crew members	–	–	–	–	3	–	–	–
Average vessel power (kW)	53.9	54.1	53.9	53.8	55.4	55.5	55.2	55.1
Average vessel GRT (t)	6.1	6.1	6.1	6.2	6.4	6.7	6.7	6.7
Average vessel age	27.5	27.6	27.6	26.1	25.2	22.7	22.7	22.5
Average vessel length (m)	8.8	8.8	8.8	8.8	8.9	8.9	8.9	8.9

The number of vessels operating in dredge fisheries has been stable over the years, with the maximum value recorded in 2004. Regarding crew size, data are available only for 2005, and indicates that artisanal vessels operate with 3 fishermen on average. The average power and GRT of vessels shows an increasing tendency, which is related with the acquisition of new and more powerful vessels.

Number of licenses per vessel

Each vessel has, on average, 3 fishing arts licensed. This means they can chose to diversify their activity between three different fisheries on average, provided they previously inform the authorities that they will operate with a different gear. After starting to use a gear, they must use it for at least one month.

Catches

Table 7 summarizes the estimates of the annual weight of captures for each target species.

Table 7. Annual quantities caught (in tonnes).

	2001	2002	2003	2004	2005	2006	2007	2008
Surf clam	173	256	2124	2088	738	165	312	217
Donax clam	432	246	314	488	496	350	388	304
Razor clam	94	18	0	42	16	1	0	0
Striped venus	41	777	642	186	711	522	233	76
Total captures	740	1297	3080	2805	1961	1037	933	598

In 2003 and 2004 the quantities captured of surf clam were extremely high, as the biological stock of this species was particularly abundant. Striped venus also presented maximum captures in 2002 and 2005, which can also be related to the high level of biological stock. Donax clam captures were stable over the years. The captures of razor clam are quite low, so it can be considered a marginal species compared with the other three.

4.3. State

Changes in target species abundance

The abundance of target species is measured by a biomass indicator (g per 5 minutes of tow), and is presented in Figure 5. The biomass stock indicator was obtained from bivalve research surveys, specifically designed to evaluate the conservation status of the commercial species. The surveys are carried out in a yearly basis onboard the IPIMAR research vessels. Details on both sampling design and procedures can be found in Rufino *et al*. (2010).

In order to give an idea of sustainability of the biological stock levels, we classified the species abundance in three levels, as shown in Figure 5. The low level corresponds to dangerous conditions of species' abundance, and is associated to values lower than 50 g/5 min tow. The medium level describes a biological stock level that can easily regenerate, corresponding to values between 51 and 125 g/min tow. The high level indicates a good state of the species abundance, and corresponds to values higher than 126 g/5 min tow.

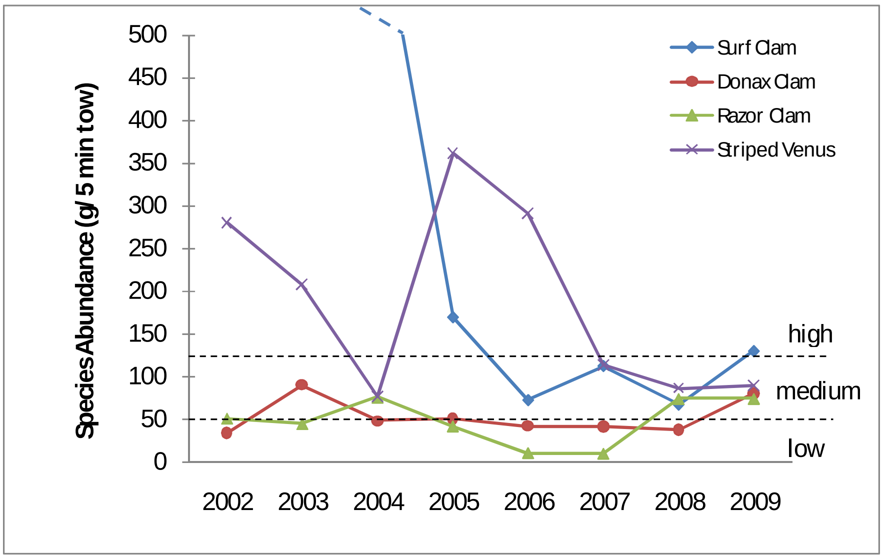

Figure 5. Target species abundance (g/5min tow).

The biological stock of surf clam shows a decreasing tendency between 2002 and 2006. The values in 2002, 2003 and 2004 were very high (987, 857 and 666 g/5 min tow, respectively) but decreased significantly in 2005, after two years of intensive captures, as reported in Table 7. Between 2006 and 2008 the stock was in the medium level of abundance. In 2009 we can observe a recovery that brought the species back to the high level of abundance.

Both donax clam and razor clam denote unsafe abundance levels in some years. Donax clam had consistently low values of biologic stock, with the exception of years 2003 and 2009. Note that the stock recovery occurred in the year immediately after a year of captures lower than usual (see years 2002 and 2008 in Table 7). Razor clam values of abundance were in the medium level in 2004, 2008 and 2009. These improvements coincide with years that follow a period of unreported captures (see Table 7). The biologic stock of striped venus was high in most years between 2002 and 2006, with the exception of year 2004. Note that the captures of this species were very high in the two previous years. After 2007, the abundance has been in the medium level.

Mean size of target species

The mean size of target species is presented in Table 8 and no major changes are noticeable.

Table 8. Mean size of target species (in mm).

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Surf clam	26	22	26	24	21	23	22	20	24
Donax clam	27	29	31	32	31	28	27	29	29
Razor clam	104	83	98	105	100	99	89	69	90
Striped venus	26	21	25	23	21	22	21	22	25

Contamination

The biotoxins level describes the bivalve contamination with microalgae toxins. These can constitute a threat to human health, as the consumption of contaminated bivalves is poisoning. In the south coast of Portugal, episodes of bivalve contamination with Paralytic Shellfish Poisoning (PSP) toxins occurred in 1992, 1994 and 1995. Contamination with Diarrhetic Shellfish Poisoning (DSP) toxins occurred every year between 2003 and 2006 (Vale *et al.*, 2008). The species where this contamination was verified were donax clam (with DSP and PSP) and surf clam (with PSP). In Portugal, a regular monitoring program is implemented since 1986 for PSP toxins, since 1987 for DSP toxins, and since 1996 for Amnesic Shellfish Poisoning (ASP) toxins (Vale *et al.*, 2008). Regulatory limits for the biotoxins levels (regulation EC 853/2004) are 80 µg STX equiv. / 100g for PSP, 16µg OA equiv. / 100g for DSP, and 20 µg DA /g shellfish meat for ASP. It would be interesting to know the concentration of other types of pollutants in the coastal waters, but this information is not available.

4.4. Impact

In relation to impact indicators, data are only available to calculate the average catch, revenue and cost per trip indicators, reported in Table 9. The catch and revenue per trip relate to the average weight and value of captures considering all target species. The cost per trip indicator only includes the fuel costs. The highest levels of both the catch per trip and the revenue per trip were observed in 2003. Since then, it can be observed a declining tendency in these two indicators, and an increasing trend in the fuel cost per trip.

Table 9. Impact indicators.

	2001	2002	2003	2004	2005	2006	2007	2008
Catch per trip (kg)	106	165	353	287	231	183	132	97
Revenue per trip (€)	192	303	418	311	363	334	216	218
Cost per trip (€)	71	90	116	113	119	139	106	–
Profitability per trip (€)	121	213	302	198	244	195	110	–

4.5. Responses

Subsidies

The European funds for fisheries are attributed to the national authority. These funds are then distributed competitively to fishermen according to their applications for funds for vessel maintenance. It wasn't possible to collect data concerning the total amount of subsidies attributed to artisanal dredge fisheries.

Educational programs

There are mandatory professional courses for fishermen. The total number of fishermen that participated in these courses was 2679 in 2008 and 6376 in 2009. These number correspond to the entire Portuguese fishery sector (DGPA, 2008).

Legislation

The Portuguese legislation started to define limits on daily captures for each target species and per vessel type in 2001 (DR Portaria no. 543-D/2001; DR Portaria no. 1072/2002; DR Portaria no. 230/2003; Portaria no. 688/2005;). These limits are summarized in Table 10.

Table 10. Limits of daily captures (kg) per species and per vessel.

		2001	2002	2003	200	200	200	200	200	200
Per vessel	Until 1.8 GRT	110	75[1]	75[2]	75[2]	145	145	145	145	145
	Between 1.8 and 2.8 GRT	165	110[1]	110[2]	110[2]	215	215	215	215	215
	Between 2.8 and 3.8 GRT	210	140[1]	140[2]	140[2]	275	275	275	275	275
	More than 3.8 GRT	300	200[1]	200[2]	200[2]	390	390	390	390	390
Per species	Surf clam	200	200	400	400	225	225	225	225	225
	Donax clam	220	150	150	150	150	150	150	150	150
	Razor clam	100	50	50	50	30	30	30	30	30
	Striped venus	100	200	200	200	250	250	250	250	250

[1] *These limits shall be increased by 50% if more than half of the catch is of surf clam (Spisula Solida).*
[2] *These limits shall be increased by 200% if more than half of the catch is of surf clam (Spisula Solida).*

In 2003 and 2004 the Portuguese legislation encouraged surf clam captures, which had a significant impact on the captures of this species (see Table 7). It is defined by legislation a season closure period between May 1 and June 15 (DR Portaria no. 419-B/2001), which represents 46 days per year. In 2006 the interdiction period was between March 1 and April 30 (DR Portaria no. 208-A/2006). Extraordinary interdictions are imposed when episode of biotoxins occur. In addition, if the biological stock of species is very low, the fisheries can also be interdicted for that species (e.g., this occurred for two months, in March and April 2006, for all target species of dredge fisheries in the south coast of Portugal, DR Portaria no. 208-A,/2006). Fisheries are allowed six days per week (between Sunday and Friday) and each vessel can make a single trip per day.

Technical characteristics of dredge vessels and gears are also regulated. Vessels used for dredge fishing are limited to a maximum power of 73,5 kW (DR Portaria no. 254/2008). The maximum width of the dredge mouth is 1 meter and the interval among teeth must be larger than 15 mm, both for GD and TD (DR Portaria no. 1102-E/2000). Concerning the GD the grid bars must be metallic and parallel, disposed in the direction of the length (DR Portaria no. 1423-B/2003). The bars can have a maximum length of 125 cm, a dredge mouth with maximum height of 50 cm and a maximum width of 80 cm. Other relevant regulations for dredge gears are summarized in Table 11 (although TD is essentially used for targeting razor clam, the minimum size of the mesh of the net bag is regulated for all the target species).

Table 11. Regulated characteristics of dredges according to target species (DR Portaria no. 1423-B/2003).

Species	Length of the teeth (GD and TD)	Distance among bars (GD)	Minimum size of the mesh (TD)
Surf clam	200 mm	≥ 12 mm ± 0,5mm	≥ 30 mm
Donax clam	200 mm	≥ 8 mm ± 0,5mm	≥ 30 mm
Razor clam	550 mm	≥ 9 mm ± 0,5mm	≥ 30 mm
Striped venus	200 mm	≥ 12 mm ± 0,5mm	≥ 30 mm

5. System dynamics model

The DPSIR analysis described in the previous sections provides a structured source of information that can be used to guide management actions to promote the sustainability of artisanal fisheries, both in social, economic and biological dimensions.

System Dynamics is a simulation method that allows the prediction of the future behavior of a system considering feasible scenarios. This requires the representation of the system components and their interrelations through algebraic equations. These equations are based on observations from the real world or on experimental data. A detailed description of Systems Dynamics concepts can be found in Thompson *et al*. (2010).

The System Dynamics model described in this section intends to illustrate the potential of this technique for managerial decision aid. The results obtained should be interpreted with caution, as the relationships included in the model should be further validated by all stakeholders, and the data on all indicators should be collected systematically for a longer time period. The model was developed using the Vensim PLE Plus software. It considers the coastal fleet, the local fleet and the four target species (surf clam, donax clam, razor clam and striped venus) separately, using an annual periodicity. The outcomes from simulations of different scenarios can foresee biological, social and economic impacts on the dredge fisheries system, supporting stakeholders' management decisions.

Figure 6 illustrates only a part of the global model of dredge fisheries. It represents the activity of the coastal fleet, and the variables associated to the surf clam species. The full model includes the other three target species of dredge fisheries (donax clam, razor clam and stripped venues). Some of the interrelations between the surf clam species and the other species are shown in Figure 6 using dashed lines. Similarly, the interrelations between the coastal fleet and the local fleet (whose model is identical to the one shown for the coastal fleet) are represented by a dashed line.

Next we briefly describe the main assumptions underlying the construction of the System Dynamics model. The model represents the stock of each species as the difference between its natural growth and the weight captured. The natural growth of each species is defined according to the formulas of Shaefer (1991). The model assumes a constant growing rate of 0.8 per year for all species. The maximum biological level of a species was considered to be 1000 g/5 min tow. This value had to be converted to tonnes to be included in the Shaefer (1991) equation. This conversion was done by considering that 5 min tow covers an area of 28.8 m^2. Therefore, the maximum biological stock is estimated multiplying the 1000 g/28.8 m^2 by the area where the species can be captured, as shown in Table 5.

The pattern of captures of each species is significantly different for the coastal and local fleets. The average weight captured per trip by each fleet is detailed in Table 12, with species differentiation.

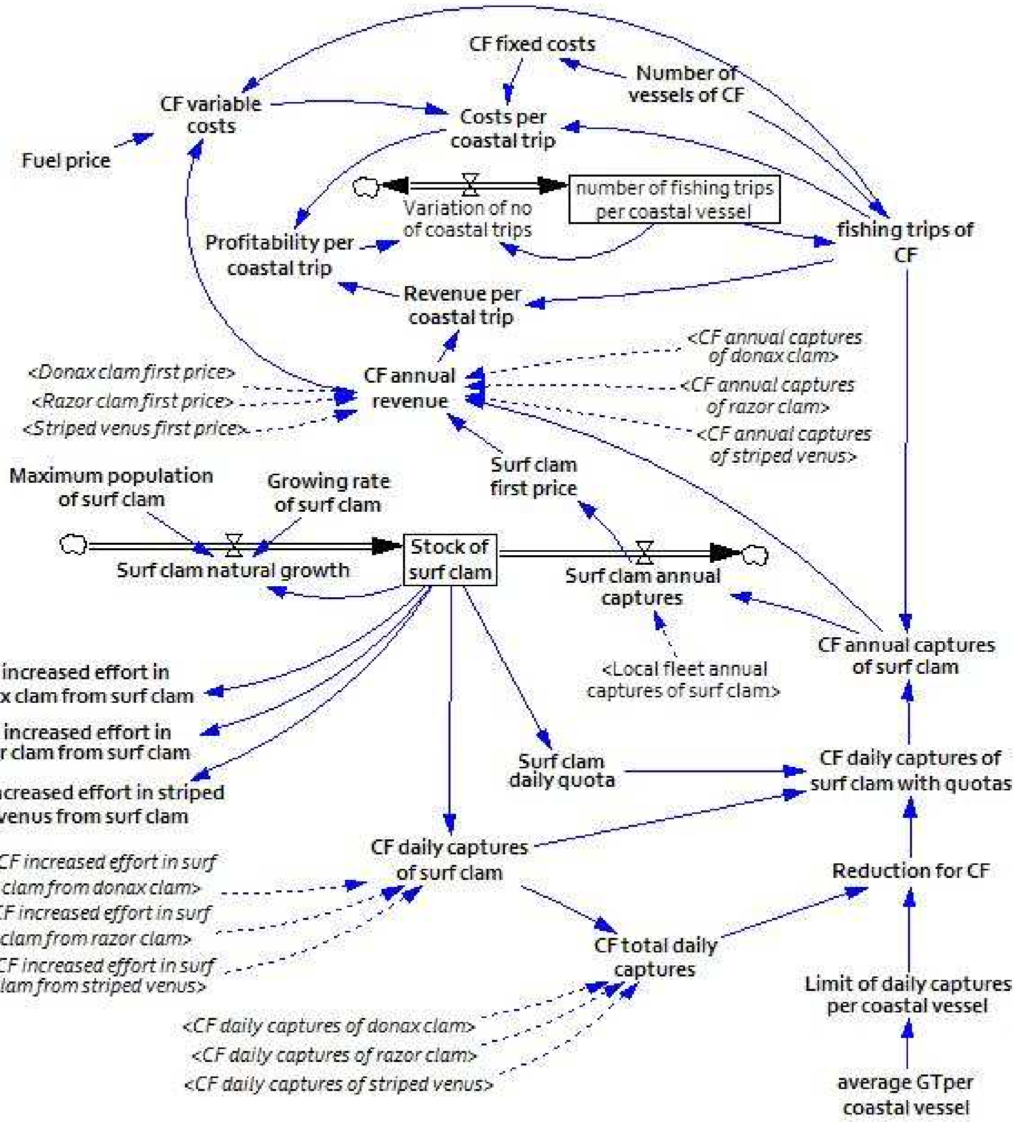

Figure 6. System Dynamics model scheme for the coastal fleet (CF) and surf clam.

Table 12. Weight captured per trip by each fleet.

		2001	2002	2003	2004	2005	2006	2007	2008
Surf clam	Local	9	10	99	59	10	1	8	13
	Coastal	29	40	302	277	120	42	59	41
Donax clam	Local	51	36	53	69	57	60	51	56
	Coastal	55	15	19	29	41	39	37	26
Razor clam	Local	1	0	0	0	0	0	0	0
	Coastal	17	3	0	7	3	0	0	0
Striped venus	Local	1	52	21	5	53	55	21	5
	Coastal	10	113	101	27	93	99	39	14

The donax clam was the species most fished by the local fleet, representing 50% of the weight captured. For this fleet, both surf clam and striped venus species represented 25% of the weight captured. Regarding the coastal fleet, the most important species was the surf clam, accounting for 54% of the weight captured. Striped venus and donax clam accounted for 29% and 15% of the weight captured, respectively. The razor clam species was not significant for any fleet.

In the System Dynamics model, the weight captured per vessel and per trip was considered to be dependent on the stock level. Accordingly, the daily captures of each fleet can assume three thresholds for each species, depending on its biologic level, as shown in Table 13.

Table 13. Captures per trip for different species considering the stock levels.

Species	Coastal fleet			Local fleet		
	High stock	Medium stock	Low stock	High stock	Medium stock	Low stock
Surf clam captures per trip (kg)	154	47	32*	37	7	5*
Donax clam captures per trip (kg)	77*	38	29	107*	54	54
Razor clam captures per trip (kg)	46	9	7	14	1	1
Striped Venus captures per trip (kg)	102	27	10	45	10	1

The values reported on Table 13 correspond to the averages calculated for the years between 2001 and 2008 with high, medium or low stock levels for each species. The values of razor clam species correspond to the averages calculated between 1996 and 2001, as the captures of this species were very low between 2002 and 2008. The criteria used to classify the stock as high, medium and low are as described in section 4.3. The values signalized with an asterisk were estimated, as they could not be obtained as averages of historical data. In these cases it was considered that the captures with low stock are 2/3 of those corresponding to medium stock. The captures with high stock are twice the values observed for medium stock.

In the system dynamics model it was also specified that when the stock level of one species is medium or low, the fishermen will try to compensate the loss of captures of that species by increasing the captures of other species. We assumed that the captures of other species increases by 10% when the stock of one species is medium, and 20% when the stock is low.

The Portuguese legislation imposes two types of limits on daily captures, as presented in Table 10. The first type limits the captures of each species per trip. This legislation is modified every year to be consistent with the maximum captures that are considered biologically sustainable given the stock estimate of each species. The second type imposes a maximum weight of captures for all species (per trip), which is defined according to the vessel GRT.

In the System Dynamics model, the relationship between the quotas and biological stock was represented based on historical records (i.e., Table 10 and Figure 5). The quota concerning the maximum weight of captures per trip was considered to be equal to 275kg for a local vessel and 390kg for a coastal vessel (equal to legislation of 2009). These values assume that a typical costal vessel has a GRT greater than 3.8 tonnes, and a typical local vessel has between 2.8 and 3.8 tonnes.

The annual captures are obtained by multiplying the daily captures by the annual number of fishing trips performed. The annual revenue is the product between weight landed of each species per year and the respective first sale price. The first sale price of each species is defined through the direct observation of real data (see Table 3), depending on the annual weight captured of each species (see Table 7). The annual costs include both fixed and variable components, as described in section 4.1. The number of vessels, both for the coastal and for the local fleet, is assumed to be constant and equal to the values of 2009 (see Table 6).

The variation in the number of fishing trips done by a vessel during one year depends on the profitability per trip. This relationship is specified in the system dynamics model as follows: if the profitability per trip is higher than 100€ for a coastal vessel, or higher than 50€ for a local vessel, the number of fishing trips increases 10%. If the profitability per trip is negative, the number of fishing trips decreases 10% both for a coastal and a local vessel. The number of fishing trips of each fleet is the product between the number of fishing trips performed by one vessel and the number of vessels.

Different scenarios were simulated to explore the behaviour of the system during a period of 6 years. The results obtained with the simulation of a base scenario are first presented. This scenario is used as a reference for the analysis of the other scenarios. The starting values for the stock of target species relate to the year of 2009. The fuel price is assumed to be constant and equal to the average value observed between 2001 and 2008 (0.437€/litre).

The evolution of the abundance of the target species for the base scenario is illustrated in Figure 7 (in g/5 min tow).

The System Dynamics model predicts that the abundance of surf clam and donax clam species will be low in the future. This happens due to the large amounts fished of these two species, even when the respective stock is low (see Table 13). The abundance of razor clam and striped venus increases and stabilizes at a high level, although a slight decrease is noticed in the second year for the striped venus.

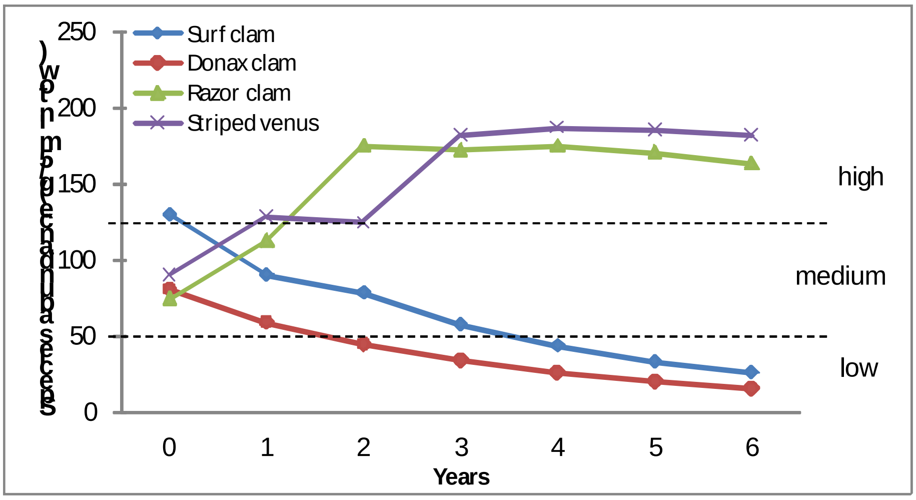

Figure 7. Abundance of target species (g/5 min tow) in the base scenario.

The annual weight captured by each fleet is shown in Figure 8.

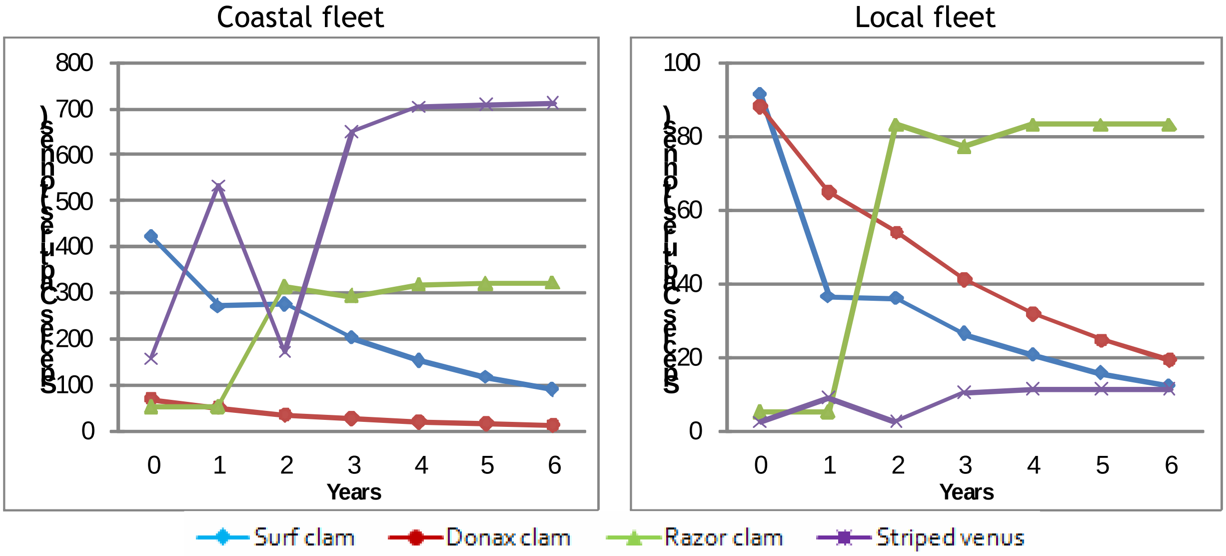

Figure 8. Captures of target species (tonnes) in the base scenario.

The captures for both fleets depend on the stock estimated for each year, which is illustrated in Figure 7. Accordingly, the captures of surf clam and donax clam decrease systematically, since their stock decreases as well. The increase noticed in the striped venus captures in the first year is induced by the change in its abundance level from medium to high. However, the captures of this species decrease in the second year as its abundance changed back to a medium level. Similarly, the peak verified in razor clam captures in the second year results from a variation in the respective abundance level from medium to high. Since year 3 the captures of striped venus stabilize in high values, and they are intensified by the extra effort that both fleets perform to compensate the low levels of surf clam and donax clam. The extra effort for the razor clam is not so pronounced because the weight captured of this species tends to be relatively low, even when the abundance level is high, as specified in Table 13.

The base scenario results concerning the profitability per trip of both fleets are detailed in Figure 9. Regarding the profitability per trip of the costal vessels, an increase is verified in year 1 due to the increase of striped venus captures, which compensates the loss in surf clam captures. In year 2 a decrease is noticed due to the reduction of striped venus captures, which is partially compensated by the increase in razor clam captures. In year 3, it is verified a recover only due to the striped venus captures, since the captures of the other three species decrease. The slight reduction observed after year 4 is mainly induced by the decrease in the surf clam captures.

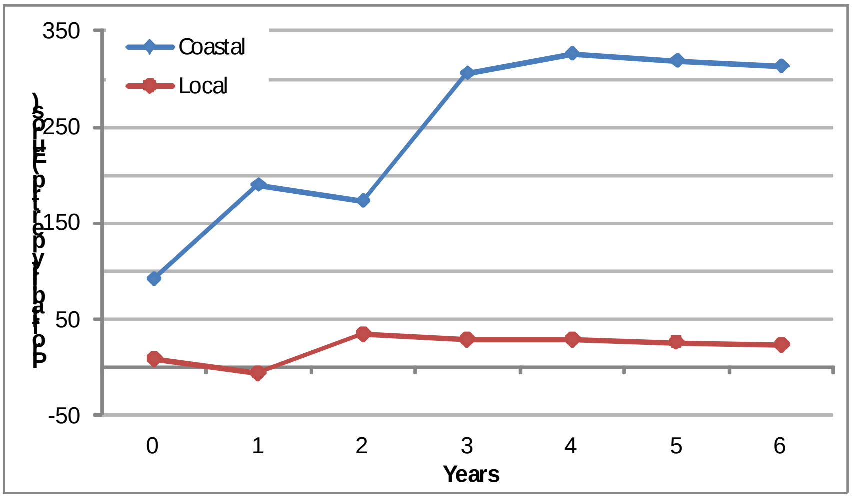

Figure 9. Profitability per trip (Euros) in the base scenario.

Concerning the local profitability per trip, negative results are observed in year 1 since the captures of surf clam and donax clam decreased significantly, and the increase in striped venus captures was not sufficient to compensate that loss. The profitability of local fleet recovers to positive values after year 2, mainly due to the increase of razor clam captures. In this year the razor clam reached a high level of abundance and the donax clam, which is the most significant species for local fleet, reached a low level of abundance. Since year 3, the captures from razor clam and striped venus compensate the loss of capture from donax clam and surf clam, allowing the local fleet to reach reasonable profits.

The second scenario studied prohibits the captures for species with low stock level. The results for the evolution of the stock of each species are shown in Figure 10.

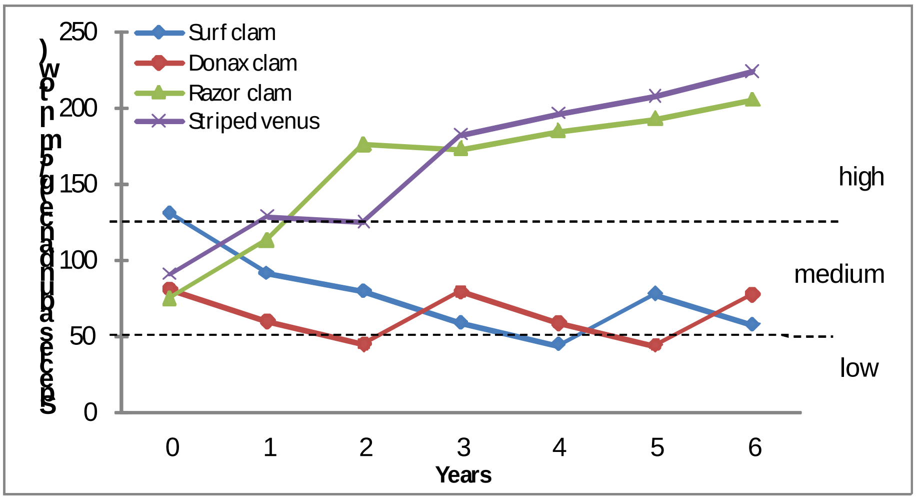

Figure 10. Abundance of target species (g/5 min tow) in scenario 2.

Comparing the results obtained in the base scenario and in the scenario 2, the main differences observed are related to the stock of the species donax clam and surf clam. In the base scenario, the stock of donax clam would reach a low level in year 2, and after that would not recover to a medium level in the period analysed. In scenario 2, the captures of this species would be prohibited in this year, so the species would recover in the next year, and remain with a medium stock level for 2 consecutive years. This pattern would be repeated afterwards, as in year 5 the stock would again be low, but recover in the next year due to the quota restriction. Similarly, the surf clam species would reach a low level in year 4, but would recover in the subsequent year, which did not occur in the base scenario.

These quota restrictions also have an impact in striped venus and razor clam species, which show a slight increase of stock in years 5 and 6 compared with base scenario. Since the stock of donax clam and surf clam is not low for both species from year 4 onwards, the extra fishing effort to the other species will not be so marked, so their biological stock can steadily increase.

Figure 11 shows the profitability per trip of both fleets. It includes the lines of the base scenario as a reference. The simulation was run for a longer time period, to explore the economic impact of quota restrictions in the long run.

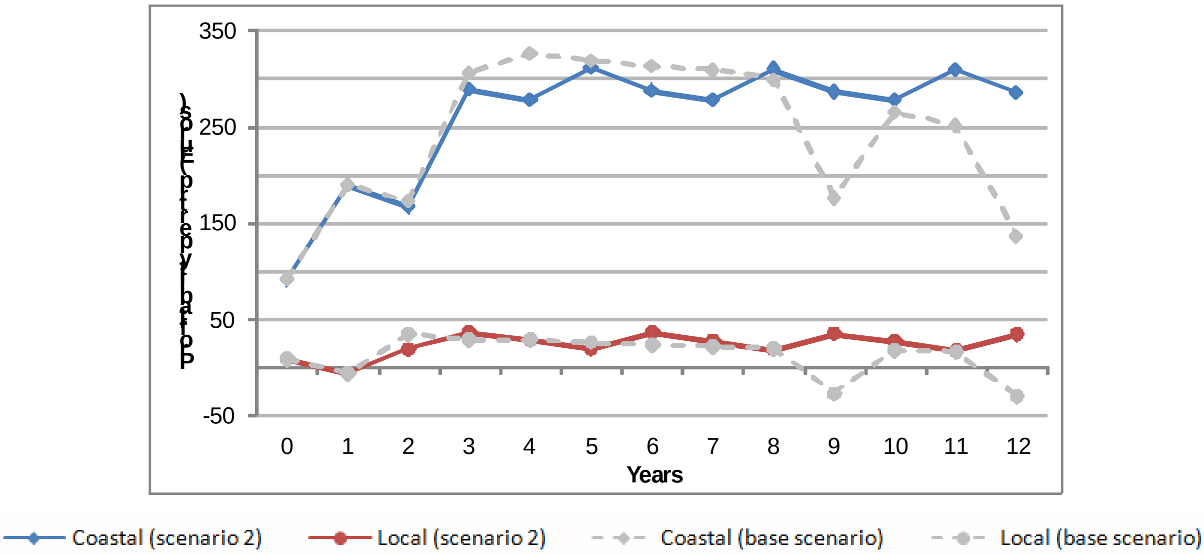

Figure 11. Profitability per trip (Euros) in scenario 2.

The profitability per trip decreased in the years when a species was prohibited. In particular, the profitability per coastal trip decreased considerably with the interdiction of surf clam captures in year 4, and the profitability per local trip decreased with the interdiction of donax clam captures, in years 2 and 5. However, the quota restrictions allowed an increase in profitability for the local fleet in the years immediately after the interdictions (years 3 and 6). For the coastal fleet, the biological sustainability of the species is not accompanied by an increase in profitability in the short run (note that in the first 8 years the profitability of this fleet in scenario 2 is always lower than in the base scenario). However, the results obtained in the final years of the simulation period show that both fleets would benefit from the quotas restrictions in the long run. The profitability of coastal fleet would reach stable values in the long run, unlike the decreasing and unstable pattern observed in the base scenario. The local fleet would also achieve more stable profitability values compared with the base scenario.

A third scenario was simulated, considering an increase in the fuel price of 0,50€/litre and an increase in the first sale price of 0,50€/kg, for all species. The results considering the abundance level and the captures performed are quite similar to those reached in the base scenario. Significant variations were noticed only for the economic indicators. The profitability per trip obtained for both fleets is presented in Figure 12, which includes the lines of the base scenario as a reference.

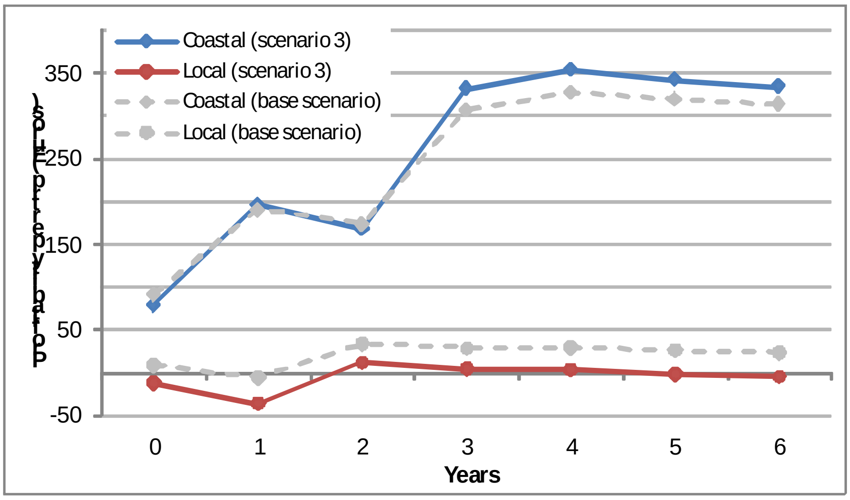

Figure 12. Profitability per trip of coastal and local fleets (Euros) in scenario 3.

The results of scenario 3 indicate that, for the coastal fleet, the increase of 0,50€/kg in first sale price would be sufficient to cover an increase in fuel price of 0,5€/litre. In the first three years, the profitability results obtained in scenario 3 do not present significant differences from those obtained in the base scenario. After year 3, the profitability per trip of the coastal fleet is higher in scenario 3 than in the base scenario.

Regarding the profitability per trip of the local vessels, the results obtained in scenario 3 are significantly lower than the results observed in the base scenario. The raise in first sale price of 0.50€/kg is not sufficient for this fleet to cover the raise in fuel price. The weight captured by the local fleet is much lower than the weight captured by the coastal fleet, which makes it more difficult for this fleet to absorb an increase in the price of raw materials.

6. Conclusions

In this paper the DPSIR framework was explored to describe artisanal fisheries. The DPSIR framework gives a multidisciplinary perspective of the system under analysis, using indicators that describe social, economic and ecologic dimensions. These indicators can also be used to explore potential cause effect relationships between the variables considered. With this methodology, stakeholders have access to structured information, which can support management decisions.

Following the DPSIR methodology, a set of indicators was proposed and applied to dredge fisheries in Algarve. The data collected enabled the description of the fishery analysed for the period between 2001 and 2009, although a significant number of indicators could not be reported due to the lack of data.

A System Dynamics model was developed to illustrate how the DPSIR indicators can be used to guide managerial decisions. This framework tries to promote the sustainable exploitation of artisanal fisheries. The model presented can be used to foresee the impacts of certain scenarios on artisanal fisheries.

Future research may try to incorporate new items in the system dynamics model, such as the influence of tides and water temperature.
The enhancement of the artisanal fisheries sustainability may depend on the existence of structured information, which is the base for management decisions. The set of DPSIR indicators proposed in this study is a contribution for the achievement of such objective.

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