Application of the DPSIR model to the Sado Estuary in a GIS context – Social and Economical Pressures

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SUMMARY

Finding the most appropriate tools that help to assess and manage the estuarine environments, allowing their restoration, are one of the main issues in coastal zone management. This paper describes the application of the DPSIR (Driving Forces-Pressures-State-Impact-Response) indicators framework to an estuary in Portugal based on a Geographical Information System (GIS). The work is focused on a preliminary identification and evaluation of the social and economic pressures. Within Sado Estuary, Setúbal sub-watershed was chosen as case study. The indicators are further calculated and discussed for an overall assessment.

KEYWORDS: *Sado estuary, DPSIR Model, Indicators, GIS, Social and economic pressures*

INTRODUCTION

The DPSIR Model, adopted by the European Environmental Agency, is one of the frameworks based on the concept of causality chains for data synthesis, which links environmental information using indicators of different categories (*Driving forces, Pressure, State, Impacts and Responses*) (UNEP/RIVM, 1994; RIVM, 1995) (Figure 1). This model is similar to the PSR framework (OECD, 1993), but with two more categories: *Driving forces* and *Impacts*. The first reports to the "needs" of individuals and institutions that lead to activities that exert pressures on the environment. *Driving forces* are understood as the social needs that require the existence of a given economic activity. The "intensity" of the *Pressure* depends on the nature and extent of the *Driving forces* and also on other factors which shape human interaction with ecological systems. The *Impacts* are related to ecosystems and human health due to *State* modifications. The policy *responses* lead to changes in the DPSIR chain. Greeuw *et al.* (2001), stated that one problem of this framework is that the same item can appear in different components, depending upon which target we are focusing on. Also according to Kelly (1998) the framework fails to capture the complexity of the relationships in complex systems. Nevertheless it is a model largely used and if these drawbacks are taken into account, it could work as a good tool to support the management of ecosystems. Also indicators are an excellent way of representing the environmental components avoiding the measurement of too many parameters. Indicators are often adopted to avoid and reduce the complexity of environmental data. In general, indicators are easily quantified and delineated from already described information in protective goods like environmental compartments and are adequate to assess what is called ecosystem health (Costanza, 1992).

The DPSIR framework can be used as a base for coastal zone environmental management allowing the linkage between environmental and macro-economic models, making it possible to integrate the conservation functions (biodiversity and ecological) with socio-economic development (RIVM, 1995). The application of this causality models in a GIS context has the advantage of allowing the spatial visualization and better integration of the different indicators. Zandbergen (1998) used an integrated approach to link key pressure indicators and GIS maps to visualize complex information what was well received as a decision support tool. The use of these models of causality chains and the selection of the indicators has often been applied in coastal zone management in the last decade. Examples could be: Cooley *et al.* (1996), Ward *et al*. (1998), Chesapeake Bay Program/USEPA (1999), EEA (1999), ME (2001), Casazza *et al.* (2002), Elliott (2002), Jorge *et al.* (2002), Silva and Rodrigues, (2002), Nunneri and Hoffman (2003), Picollo *et al.* (2003), among others. However some of these approaches are only conceptual or little attention is paid to the difficulties of calculating the indicators and their spatial visualization and interpretation for future management of the coastal zones. This fact is of particular importance in the case of social and economic pressures indicators.

This paper illustrates the practical application of the DPSIR model to the Sado Estuary. This estuary, located in the west coast of Portugal is an area where management conflicts are known: although it has a high ecological value, fact that is highlighted by the existence of a Natural Reserve (RNES), it is a very industrialized and populated zone. Therefore, it becomes necessary to build and implement environmental assessment models, which include the construction of methodologies and frameworks that, qualitatively and quantitatively, define the state of coastal area and point out management options.

The main aim of the research project, in which this work is included, is the development of a framework for an estuary environmental data management using the DPSIR Model, including collection, processing and analysis of data, through a GIS. This paper describes the preliminary results of the quantitative analysis of the two model categories *Driving forces* and *Pressures* indicators. One of the Sado's river sub-watersheds was used as example.

METHODOLOGY

Previous Work

The methodological approach of this research project is briefly described in Figure 1. Collection of information about the different conceptual frameworks for indicators (Ramos *et al.,* 2004) and compilation of all kind of data related with the Sado Estuary were the initial tasks. DPSIR model (Figure 1) was them elected as the assessment tool and a preliminary set of indicators for each of its components was selected (Caeiro *et al.*, 2002).

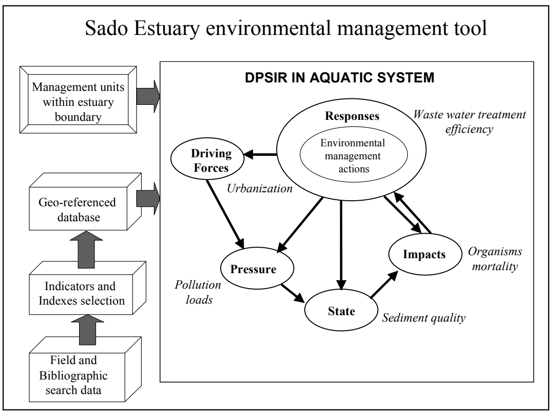

Figure 1: Methodology for estuary environmental management tool. An example of an indicator for each DPSIR indicator is given.

The methodology proposed for the environmental management system applied to Sado Estuary supported on the DPISR framework, is based on identifying, representing and characterizing a series of homogeneous environmental areas inside the estuary (Caeiro *et al.,* 2003a). On each of these management areas, *State* and *Impact* indicators are going to be quantified. These areas are then to be linked with the social and economic pressures measured in the estuary itself and in the terrestrial boundaries of the surrounding areas (*Driving forces* and *Pressures* indicators).

This management system will allow the integration between the biodiversity conservation and human pressure for development. The methodological approach to integrate this information will be the implementation of a GIS.

Driving Forces and Pressures Evaluation

After the selection of the *Driving forces* and *Pressure* indicators the data was collected in different institutions in Portugal or searched in literature, for their quantification. The set of selected indicators that were chosen for the *Driving forces* and *Pressure* categories and source of information are listed in Table 1. An indicator's preliminary calculation and spatial representation was conducted. However, some indicators are not yet calculated or georeferenced due to the current unavailability of the data. The evaluated indicators are highlighted in Table 1.

In terms of pollution loads, it is only available the locations of the urban Wastewater Treatment Plants (WWTP), their type of treatment (primary, secondary or tertiary), the location of the wastewater discharges and a qualitative evaluation of the contaminants discharged. For the urban wastewater discharges and non-point sources it was possible to quantify the pollution loads in terms of Biological Oxygen Demand (BOD), Nitrogen (N), Phosphorous (P) and Total Suspended Solids (SS) loads. In the case of urban point sources the loads were estimated based on bibliographical information concerning emission factors per capita (Tchobanoglous, 1995).

The GIS was developed in *ArcMap 8.1*. It was simultaneously a means to visualize data and a calculation tool for indicators that were related to geographical information. Watershed areas were chosen as the terrestrial units for indicator representation. Setúbal sub-watershed was elected as an example for the calculation of the indicators since the main human pressures of the estuary are located there (Figure 2). The indicators were overlaid within the coastal area shoreline (Caeiro *et al.,* 2003b).

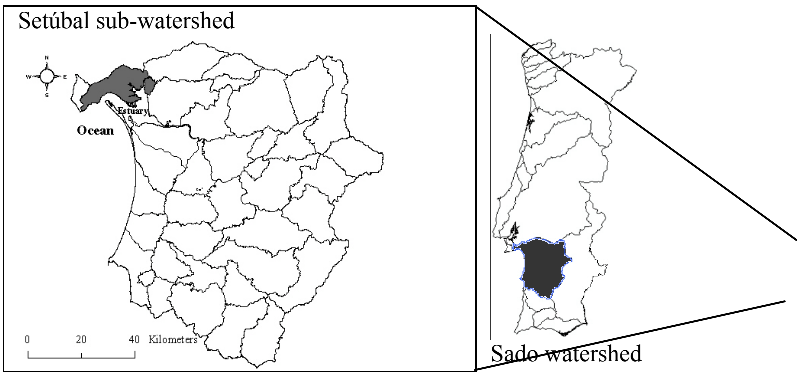

Figure 2: Sado watershed. Adapted from INAG (2001).

A Standard approach, i.e. normalization factors, was used to express the results of the environmental indicators. For example, total sub-watershed area, total estuary area or coastline length were used as denominators. This normalization allows the indicators comparison, including with other costal zones and also allows a better evaluation of the level of their magnitude. The estuary area considered was the main bay until the entrances of the Águas de Moura and Alcácer Channels (about 110 km^2). When available, a temporal evolution of the indicators was performed.

Table 3: Selected indicators, unit, GIS representation and source of information.

Driving Force Category	Unit	GIS Representation	Source of Information
Urban areas near the estuary	km^2	Area	Portuguese Geographical Institute IGEO (2003)
Industry types[1]	number of installations per industry type	Point	Technical/scientific data Correia and Florêncio (2002)
Dunghills/ sanitary landfills	km^2	Area	National Waste Institute (INR)
Rice-fields	km^2	Area	IGEO (2003)
Saltpans[2]	km^2	Area	RNES, Technical/scientific data: Painho *et al.* (1996) and Dias (1994)
Aquacultures[2]	km^2	Area	RNES, Technical/scientific data: Painho *et al.* (1996) and Dias (1994)
Fishing[3]	number of fishing ships per harbour. $year^{-1}$	Point	Ministry of Agriculture and Fishery (MAP)
Ships traffic	number of ships per harbour. $year^{-1}$	Point	Setubal and Sesimbra Administrative Port APSS (2003a)
Harbours	number	Point	APSS (2003a), IGEO (2003)
Tourism areas	km^2	Area	Statistics National Institute (INE)
Pressure Indicator	**Unit**	**GIS Representation**	**Source of Information**
Population density	$inhab.km^{-2}$	Area	INE, 2003
Toxic substances spill	number of spills occurrence. $year^{-1}$	Point	Maritime Police
Pesticides in rice-fields	$t.ha^{-1}.year^{-1}$	Area	Technical / scientific papers
Fertilizers in rice-fields	$t.ha^{-1}.year^{-1}$	Area	Technical / scientific papers
Commercial species captured (fish and bait)[4]	t fresh $weight.year^{-1}$	Area	MAP
Dredging[5]	$m^3.year^{-1}$	Point	APSS (2003b)
Dredged material disposal[5]	$m^3.year^{-1}$	Point	APSS (2003b)
Urban wastewater discharges without suitable treatment	$m^3.year^{-1}$ or t contaminant. $year^{-1}$	Point	Water Institute: INAG, (2001) Technical/scientific data: Correia and Florêncio (2002).
Industrial wastewater discharges without suitable treatment	$m^3.year^{-1}$or t contaminant. $year^{-1}$	Point	Technical/scientific data: Correia and Florêncio (2002) AQUA/FCT/UNL (1997)
Solid waste disposal	$t.year^{-1}$	Area	INR
Solid industrial waste disposal	$t.year^{-1}$	Area	INR
Non source pollution (water runoff)[4]	$t.year^{-1}$	Area	Technical/scientific data: INAG (2001).

[1]Only number of industries is available; [2]Not available geographically which areas are saltpans or aquaculture;[3] All the existent fishing dock were considered and not only the ones at Setúbal watershed [4]Only the fish data is available; [5]Spatial data is not available.

The different indicators of *Driving forces* and *Pressures* categories were visualised and evaluated together for a better integrated assessment of the human activities and related pressures in the estuary. Not all the *Driving forces* indicators have one-to-one linkages with the *Pressures* indicators. An integrated approach should be adopted relating different indicators as clusters with multiple aspects that interact with each other (Ramos *et al.,* 2004).

RESULTS AND DISCUSSION

The qualitative evaluation of the effluent discharges is shown in *Figure 3*. The main Setúbal's sub-watershed urban, agriculture and industrialized pressures in the estuary are shown in Figure 4. In an easy way it is possible to conclude that high pressures exist in the North Channel of the estuary. The urban use has an area of approximately 10.3 km^2, corresponding to 4.5 % of the sub-watershed total area, distributed by 11 villages. This sub-watershed has many urban areas since the main city (Setúbal) is located in it. As can be noticed from Figure 4 the population density is higher near the estuary boundary.

A large and intense number of urban and industrial effluents are discharged inside the estuary. In the zone of higher population density (Setúbal City) the major sewage disposals are urban. The presences of industries are followed by industrial sewages that discharge their effluent on the estuary. Near Lisnave shipyard, Tanquisado and Eurominas industries there are also storm water effluents. On some of these effluents it is possible that runoff results not only from rainfall but also from contaminated water associated with the industrial activities. It was not possible to assess, with the necessary accuracy, if each industrial effluent discharge has suitable treatment, where each urban WWTP discharges their effluents, what are their capacities and what are the treated wastewater characteristics. Only the wastewater treatment plant near Setúbal has tertiary treatment, and started to operate only recently. Some of the industries will be connected to this plant (like SAPEC – fertilizers and pesticides and Maurifermentos - ferments) which, at the moment, don't have a suitable wastewater treatment. Lisnave shipyard and the power plant industry have their one WWTP but it was not possible to know the efficiency of their treatment. Industrial complex of Mitrena – (olive oil packaging, plastic manufacturing, cereal storage and reused paper industries) has a WWTP but it is not working properly (APSS – personal communication).

The main contaminants agents discharged in the urban effluents are Fats, Oils and Grease (FOG) and Nutrients, Chemical Oxigen Demand (COD), Biological Oxigen Demand (BOD) and SS. The effluents discharged near Eurominas and Lisnave have more complex contaminants like metals, Polychlorinated Biphenyls (PCB), Tributyl-tin (TBT) and Polyaromatic Hydrocarbon (PAH) (Fig. 3). Most of this contaminants are persistent and toxic to the marine biota (Laws, 1993). Since along the North Channel the hydrodynamics is low, and the more complex contaminants are discharged in Shipyard and Eurominas area, it is expected a more intense impact in that estuarine area.

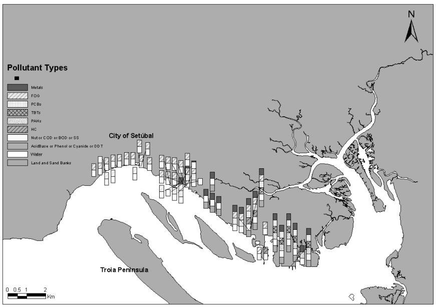

Figure 3: Main pollutant types in each effluent discharge in Sado Estuary.

The major sources of nutrients (N e P) in the estuary are non point sources, mostly due to agricultural activities (Figure 6). Nitrogen load is high when compared with Phosphorus. N is expected to be higher than P in urban runoff, raw sewage and rainfall (Laws, 1993). Analyzing BOD and SS, the major input is due to point sources (non-point BOD and SS are only 15 % and 32 % of total sources). Nevertheless special care must be taken when comparing these two pollution sources, since they were calculated based on different methods and sources. It was not possible to represent spatially this data but non-point sources are expected to come mainly from Águas de Moura Channel.

Salt exploitation's usually organized by groups of salt-pans (Dias, 1994) (Figure 4). The sum of the area of this *Driving Force* is 8.36 km^2 corresponding to a total of 19 groups and 3.7 % of the sub- watershed area. This indicator should also be seen as a positive *pressure* once the maintenance of salt-pans is a sign of conservation and biodiversity. Aquacultures are frequently implemented in old salt-pans (Dias, 1994). This fact can cause difficulties in the spatial representation of this indicator (negative pressure), which needs to be distinguished from the previous indicator (positive pressure).

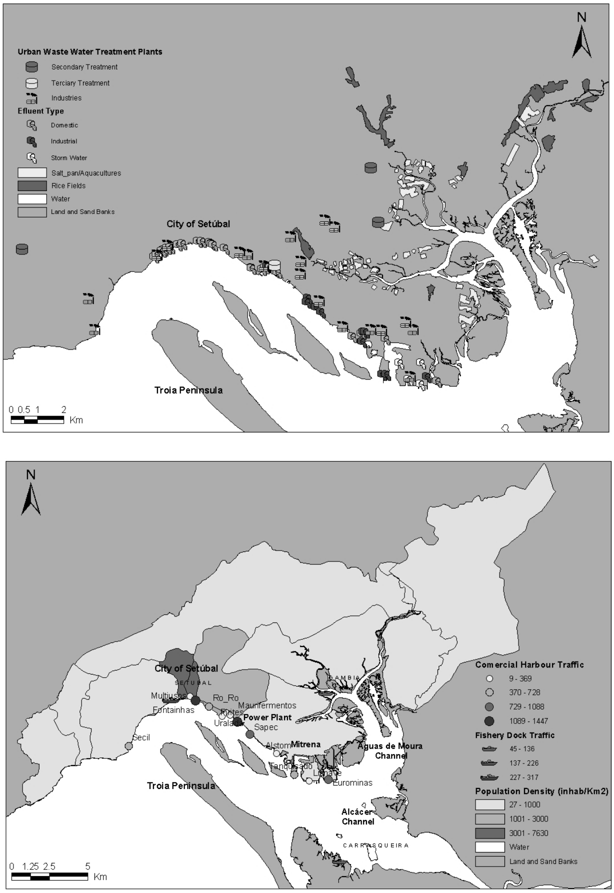

Figure 4: Urban, agriculture and industrial indicators in the Setúbal sub-watershed. Industrial effluents include industrial, storm water and/or domestic wastewater. Domestic effluents include domestic and/or storm water. Average traffic of ships, from 1999 to 2003, in the main commercial harbours and average traffic of fishing ships, from 1998 to 2002, in the fishing docks.

Some old groups of salt-pan areas disappeared to give place to aquacultures, in some cases with larger areas (Figure 5). This replacements and new installations are one of the great concerns of the Natural Reserve since some of these aquacultures use no authorized intensive culture systems that can cause extra organic loads into the estuary. The use of anti-fouling, pesticides, fertilizers, pharmaceutical products and introduction of new species are also aquaculture activities that can cause other important impacts (Amaral, 2000).

The rice-fields area in Setúbal's sub-watershed is 4.18 km^2, corresponding to only 1.8% of the sub-watershed area (Figure 4). The major rice-fields are located on the right side of the sub-watershed up Águas de Moura Channel near the salt-pans. This *Driving force* is responsible for loading pesticides and fertilizes into the estuary coming from this channel. According to Pereira (2003), pesticides like Endolsulfan, Lindane, Molinate, Propanil, MCPA and Clorphenvinphos are used by rice-field farmers in Sado watershed. In particular, Endolsulfan, Chlorphenvinphos and Molinate have high potential to cause adverse toxic effects to the biota community in Sado river. Also two of WWTP that are located near Águas de Moura Channel should discharge their effluents into this channel (Figure 4).

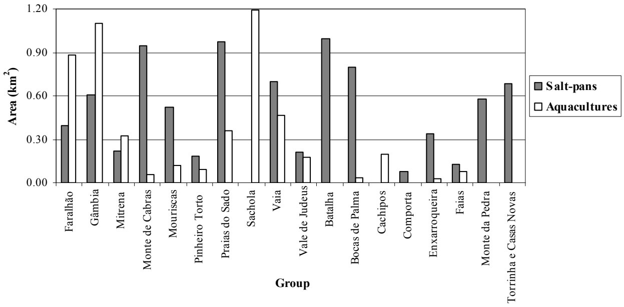

Figure 5: Groups of Salt-pans/aquacultures and their areas in the Sado Estuary.

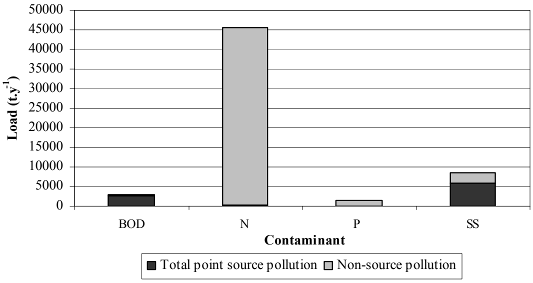

Figure 6: Loads of BOD, N, P and SS from point and non-point sources in the Setúbal sub-watershed.

The Port of Setúbal represents about 10% of the National port and maritime sector activity (APSS 2003a). The major existing harbours of the estuary are located on Setúbal's sub-watershed. This study area has about 20 harbours, most of them industrial. The area occupied by these structures has approximately 0.90 km^2, which represents approximately half of the coastal line occupied by the sub-watershed, and about 2 harbours per km of coastline. The traffic of ships per commercial harbour, during the period 1998-2003, is shown in Figures 3 and 7. The higher number of ships in the year 2003 may have caused an increase of pressure in the estuary (about 60 ships per km^2 of estuary area per year), although not too much when compared with earlier years like 1999. Pirites and Fontaínhas, followed by Eurominas and Sapec, are the harbours with higher traffic, so the most intense impact in the estuary, due to this pressure, is expected in those locations. Pirites is an industrial harbour where the main cargo types are Cooper concentrates and fuel-oil; Fontaínhas is a marina and recreation boating and Eurominas is an industrial harbour where the main cargo type is coal and clinker (APSS, 2003a). Eurominas industry, although deactivated, is mainly used for harbour activities, what can explain the decrease in harbour activities in the last years. Sapec is also an industrial harbour where the main cargo is petroleum coke, coal, clinker and cereals. Several pollutants can be associated with these human activities like BOD, COD, suspended solids, petroleum hydrocarbons, solvents, metals and FOGs (USEPA, 2001).

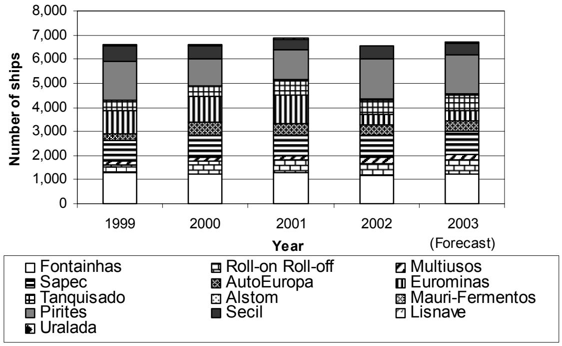

Figure 7: Traffic of ships in the main harbours from 1999 to 2003. Eurominas and Auto-Europa correspond to data for more than one harbour that for simplification reasons was joined.

The fishing dock with higher traffic is Setúbal, compared to the other two (Gâmbia and Carrasqueira) (Figure 4). There was a decrease in the number of boats along 1998 and 2002 years in Setúbal dock, but an increase in the other docks in the year of 2002, although not significant in an overall analysis of this indicator (Figure 8). In this last year the fishing boats represented only 6% of the total traffic of ships in the estuary. As can be noticed from Fig. 8, the number of boats and the caught fish yield distinct patterns. Since 1998 the number of boats has been decreasing and until 2000 the fish catches has increased. This could be related with better catching techniques, higher number of working hours and larger capacity of the fishing boats or others. From 2000 to 2002 both number of boats and caught fish decreased. These latter facts could be related with European Union fishing policies. Nevertheless there is no other information available like number of working hours, fishing fleet characteristics, fish stocks and more complete temporal series that could help in a better interpretation of this data.

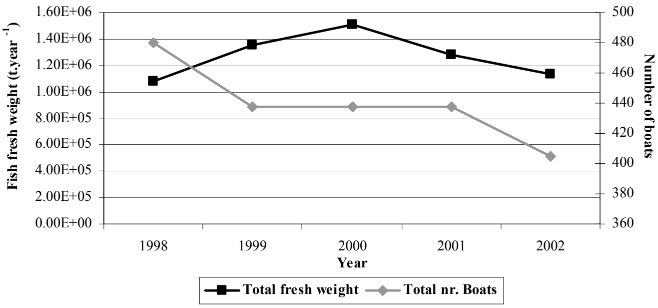

Figure 8: Fish fresh weight caught and number of fishing boats from 1998-2003 (average of the 3 docks).

To evaluate the *pressure* indicator, caught fishing species with commercial value, the data of the 3 fishing docks were also analysed together since the fish discharged in each dock is not related with the proximity of the catchments area to the dock but with the sale market of each harbour (Figure 8). A slight decrease has been noticed in the weight of each captured species along the analysed period (from 1998 to 2003) (Figure 9). Ray, sea bream, black bream and grey mullet are the most relevant species captured in the estuary, in terms of fresh weight. These species are abundant in the Portuguese coast, in particular sea bream, which uses the estuary for nursery (Sobral and Gomes, 1997). Among the marine species discharged, sardine and horse-mackerel assume the major relevance, even when comparing with the estuarine species. Both these marine fishes have high commercial interest due to traditional Portuguese gastronomy. Several studies showed that some of these species with commercial value have been affected by the human activities in the estuary (Antunes and Cunha, 1995; Cunha, 1995). Small shed is a vulnerable species according to vertebrate red book of Portugal and eel is considered a commercially threatened species. Prove of this is their low levels of capture (Fig. 9). Toadfish is a resident species of Sado estuary being highly vulnerable to changes in its habitat. Setúbal's inhabitants highly appreciate this fish in their food diets (Sobral and Gomes, 1997). For a better evaluation of the fish resources *pressure* and their *state* on the estuary, the fish catches should be related with the fish stock. Nevertheless there is a research need in this field, since stock data is available for a very few species and only at a national level.

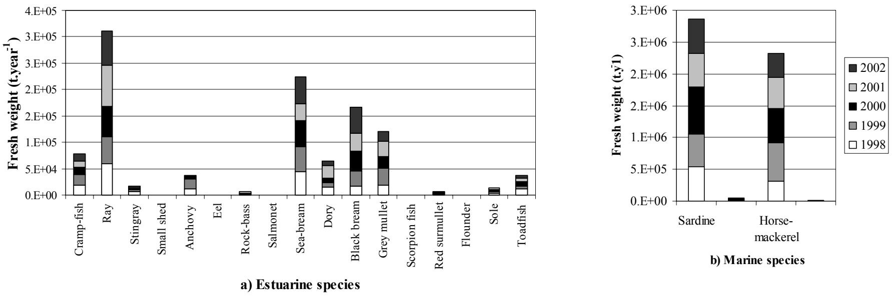

Figure 9: Most important commercial fish species a) estuarine and b) marine) captured in the Sado Estuary and their fresh weight discharged in the period from 1998 to 2002.

According to APSS (2003b), in the year 2004 maintenance dredging operations will be carried out with an average total volume of 919.186 m^3 dredged material. These dredging operations will be done in North Channel (from Fontaínhas to Alston harbours), entrance of the estuary (connection between sea and estuary) and South Channel (from Eurominas to Tanquisado). These dredging operations are related with maintenance of the navigation channels and will correspond to about 8 m per km^2 of estuary area. This dredged material will be disposed in Setúbal Canyon, an area outside the estuary with high hydrodynamics. Therefore, it is assumed that this activity will not exert pressure on the study system.

CONCLUSION

In this paper indicators belonging to the DPSIR *Driving forces* and *Pressures* categories were assessed using a GIS. GIS is a useful tool for this kind of data synthesis models since it facilitates the visualization and computation of indicator results. Although only some preliminary results of the indicators were calculated and visualized with the GIS, it already allowed discussing the indicator's information and limitations. Zandbergen (1998) stressed that spatial trends in selected indicators can be illustrated effectively using GIS, which helps to identify particular regions within the watershed which should receive a higher priority for management. This preliminary quantification was a difficult task due to data unavailability. Much of the data, like the pollution loads evaluation, were only possible in a qualitative way. Although several plans and inventories were developed or are in development, most of them performed due to EU obligations, their data is not easily accessible, even for academic purposes. The *Driving forces* and *Pressures* indicators assessment in the Setúbal sub-watershed lead to the following conclusions: i) existence of clustered populated areas near the city of Setúbal and estuary boundary; ii) existence of a dense number of ports most of them industrial in the North Channel, in which the main cargo movements are a potential source of pollution, like petroleum derivates; iii) existence of industrial, urban and storm water effluents, most of them discharging wastewater without suitable treatment with a diverse type of contaminants; iv) agriculture and aquaculture activities, sources of non-point pollution loads coming from Águas the Moura Channel. Due to these diverse pressures, a strong environmental impact is expected in the North Channel of the Sado Estuary, particularly near Lisnave and Eurominas industries. In this area the type of contaminants discharged are diverse and more persistent, the hydrodynamics is lower, and additional contamination coming from Águas de Moura Channel can settle due to residual flow (hydrodynamics according to Neves, 1985). Spatial pattern evaluation of the fishing communities is not possible due to lack of data or difficulty in defining specific fish habitats inside the estuary. Nevertheless fishing activities are also an important pressure on the estuary, where for example some vulnerable or endangerous species are included in the commercial caught species. In contrast pollution on the estuary can cause a decrease in the quality of these resources and thus on the fishing economy. The new wastewater treatment plant will treat wastewater whose loads correspond to 300000 inhabitants' equivalent, including industrial and domestic effluents. In this way, it is expected that some of these pressures although high at the moment decrease in the next years.

No considerable advantages were noticed in the division of *Driving forces* and *Pressures* categories, after their quantification and spatial representation. The *Driving forces* indicators help to represent and list the human activities that are responsible by the *Pressures* and in some cases due to the lack of data some *Pressures* were only evaluated as *Driving forces*. Also the indicators belonging to this category allow the distinction between positive or negative impacts on sustainable development, as is often the case with social and economic and institutional indicators (UN, 1996; UN, 2001). Nevertheless the gain in precision does not compensate the use of that category. We think that in future developments only the *Pressure* indicators need to be quantified although considering encompassing the human activities, processes and patterns that impact on sustainable development.

Further work includes more detailed spatial analysis of those categories and the integration in the GIS of the remaining DPSIR indicators, and the different possible links between them. This will allow the assessment of environmental conditions, a better integration with existing projects, programs, plans and policies, and the design of specific restoration/management actions for Sado Estuary.

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