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The use of DPSIR and SAF for the Management of Eutrophication in the Ria Formosa.

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The use of DPSIR and SAF for the Management of Eutrophication in the Ria Formosa.

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Abbreviations

APRH: Associaçao Português dos Recursos Hidrológicos

AWMS: Agricultural Waste Management System

CPF: Capitania do Porto de Faro

CZSFL: Coastal Zone System Feedback Loop.

DAIN: Dissolved Available Inorganic Nitrogen

DAIP: Dissolved Available Inorganic Phospherous

DIN: Dissolved Inorganic Nitrogen

DITT : Department for Investment Trade and Tourism

DMS: Departamento Maritimo do Sul

DoW: Description of Work

DPSIR: Driver-Pressure-State-Impact-Response

ESE : Ecologic, Social and Economic

HAB: Harmful Algal Bloom

ICZM: Integrated Coastal Zone Management

INAG: Portuguese Water Institute

MADRP: Ministerio da Agricultura, Desinvolvimento Rural e das Pescas.

MESPRD: Ministry of Environment, Spatial Planning and Regional Development

ND: Nitrate Directive

SA: System Appraisal

SAF: Systems Approach Framework

SD: System Design

SF: System Formulation

SO: System Output

SPICOSA: Science and Policy Integration for Coastal System Assessment

SSA: Study Site Applications

VS: Virtual System

UWWTD: Urban Waste Water Directive

UWWTP: Urban Waste Water Treatment Plant

WFD: Water Framework Directive.

WP: Work Package

Resumo

O Driver-Pressure-State-Impact-Response (DPSIR) chegada considera atividades humanas como uma parte essencial da ecossistema e traz ciência natural junta, ciência social e economia em uma estrutura para gerência adaptável. Systems Approach Framework (SAF) abrange o ecológico, componentes sociais e econômicos das zonas costeiras e objetivos estabelecer um diálogo permanente entre cientistas, interessados e criadores de apólice nas zonas costeiras européias para desenvolver ICZM eficaz. O objetivo do estudo presente é achar opções de gerência para eutrophication do Ria Formosa por DPSIR e SAF. O objetivo inclui indicando a possibilidade que as mesmas chegadas também podiam ser adaptadas em qualquer lugar no mundo para corpos diferentes de água. A chegada de DPSIR foi usada para identificar os Motoristas, Pressões, Estado, Impactam e Respostas assim como indicadores ambientais no Ria Formosa. A agricultura e gado, Aquaculture e Pescaria, Turismo e Urbanização eram os motoristas importantes. A pressão era enriquecimento de nutriente. O Estado revelou se em concentração considerável de nutriente, Macro crescimento algáceo, ocorrência de HAB em algumas partes da lagoa e flutuar concentração de oxigénio. O impacte Ecológico era mortalidade alta de amêijoa. A diminuição associada em produtos de aquaculture, perda de trabalho e intoxicação humana devido a HAB pertencem a impactes Socioeconômicos. Respostas anteriores incluem medidas contra nutriente carregar e mortalidade de amêijoa. Respostas adicionais foram recomendados, principalmente para redução de nutriente carregar. Os quatro passos de SAF foram seguidos. Os interessados foram identificados e o assunto de eutrophication foi concordado em. Tendo definido o sistema virtual, o modelo conceitual do Ria Formosa foi feito. Conseqüentemente, a possibilidade de formular o modelo conceitual num modelo numérico representando o ecológico, componentes sociais e econômicos do sistema foi discutido. O ligar dos três componentes num modelo de simulação e corrida que os cenários era, então, discutidos. O processo de deliberação entre os interessados e criadores de apólice, o corpo científico como promotor é destacado. O formato por que o pacote final de saída é disseminado é sugerido. Assim, DPSIR e SAF podem ser usados para a gerência de eutrophication em qualquer parte do mundo com as modificações necessárias por recursos e características de sistema.

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Palavras chaves: **DPSIR, Eutrophication, Ria Formosa, SAF, SPICOSA**.

Abstract

The Driver-Pressure-State-Impact-Response (DPSIR) approach considers human activities as an integral part of the ecosystem and brings together natural science, social science and economics in one framework for adaptive management. Systems Approach Framework (SAF) encompasses the ecological, social and economic components of the coastal zones and aims to establish a permanent dialogue between scientists, stakeholders and policy makers in the European coastal zones for developing effective ICZM. The objective of the present study is to find management options for eutrophication of the Ria Formosa through DPSIR and SAF. The objective includes indicating the possibility that the same approaches could also be adapted anywhere in the world for different water bodies. DPSIR approach was used to identify the Drivers, Pressures, State, Impact and Responses as well as environmental indicators in the Ria Formosa. Agriculture and Livestock, Aquaculture and Fishery, Tourism and Urbanization were the major drivers. The pressure was nutrient enrichment. The State revealed itself in considerable nutrient concentration, Macro algal growth, occurrence of HAB in some parts of the lagoon and fluctuating oxygen concentration. The Ecological impact was high clam mortality. The associated decrease in aquaculture products, job loss and human intoxication due to HAB belong to Socio-economic impacts. Earlier Responses include measures against nutrient loading and clam mortality. Additional Responses have been recommended, mainly for reduction of nutrient loading. The four steps of SAF were followed. The stakeholders were identified and the issue of eutrophication was agreed on. Having defined the virtual system, the conceptual model of the Ria Formosa was made. Consequently, the possibility of formulating the conceptual model into a numerical model representing the ecological, social and economic components of the system was discussed. The linking of the three components in a simulation model and running the scenarios was, then, discussed. The deliberation process among the stakeholders and policy makers, the scientific body as facilitator is highlighted. The format by which the final output package is disseminated is suggested. Thus, DPSIR and SAF can be used for the management of eutrophication in any part of the world with the necessary modifications on the basis of resources and system characteristics.

Key words: **DPSIR, Eutrophication, Ria Formosa, SAF, SPICOSA.**

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1. Introduction

The Driver-Pressure-State-Impact-Response (DPSIR) approach considers human activities as an integral part of the ecosystem and brings together natural science, social science and economics in one framework for adaptive management (Zaldivar et al., 2008). Social and economic developments (Drivers) create a set of Pressures on the environment which produces the State change of the environment with the consequent Impacts affecting human uses; this necessitates Response on the part of the society (Aubry and Elliot, 2006).

Systems Approach Framework (SAF) is a protocol adopted by the Science and Policy Integration for Coastal Systems Assessment (SPICOSA) project. SAF will be used to explore the dynamics of Coastal-Zone Systems and potential consequences of alternative policy scenarios (SPICOSA-DoW, 2009). This approach encompasses the ecological, social and economic components of the coastal zones. SAF, having several steps, ends up by producing outputs that will be communicated to the stakeholders and policy makers. This is in accordance with the objective of SPICOSA to establish a permanent dialogue between scientists and stakeholders (SPICOSA-DoW, 2009). True to the principles of adaptive management, interaction between science and policy creates results in an ever evolving improvement policies for integrated coastal zone management.

These methods can be applied to finding management options for eutrophication. The State of eutrophication of coastal waters produced by Pressure driven by socio-economic activities such as agriculture, aquaculture and fishery, tourism and urbanization with the consequent Impact of water quality deterioration can fit in the DPSIR frame work. The Responses are adoption of solution-seeking policies.

Similarly the SAF approach, making use of its four major steps of System Design, System Formulation, System Appraisal and System Output serves as a useful tool to provide policy makers with alternative policy options for the management of eutrophication.

DPSIR and SAF have common features regarding Drivers and Pressures. With regard to eutrophication, for example, both methods identify them as socio-economic activities and nutrient-loading respectively. However, they have their differences.SAF has several more steps in which the virtual system is defined, stakeholders are mapped and issues are resolved in an iterative manner. The Responses in the DPSIR framework assume the form of recommendations to the policymakers for implementation. But SAF simulates different management scenarios and demonstrate to policy makers what would occur if these management options were taken. Presupposing what kind of policy decision to take is not its objective (SPICOSA-WP3, 2007).

The aim of the present study is to apply DPSIR and SAF for the management of eutrophication in the Ria Formosa. The Ria Formosa is a coastal barrier lagoon (55X6 km) in Southern Portugal (Mudge et al., 1998). The ecosystem receives fresh water inputs, rich in organic and mineral nutrients derived from urban, agricultural and industrial effluents and domestic sewage and is subject to strong anthropogenic pressures due to tourism and shellfish/fish farming (Pereira & Duarte, 2006). According to Newton et al., (2003) there are a number of pressure-producing drivers on the Ria Formosa including urbanization, intensive agriculture, fishing and aquaculture. There is evidence of some undesirable changes occurring in the lagoon system, such as a declining bivalve harvest, attributed to the deterioration in water quality, although a direct link has still to be conclusively established (Newton et al., 2003).

The assessment based on the European Environmental Agency criteria of nutrient concentrations indicated that the situation in the lagoon is “poor” to “bad”; in contrast, the USA National Eutrophication Estuarine Assessment, based on symptoms, such as high chlorophyll and low oxygen saturation, indicated that the lagoon is near pristine (Newton & Icely, 2006). Using simple screening model Newton and Icely (2006) showed that the nutrient input in the Ria Formosa is high but the large tidal exchange flushes most of the system daily, resulting in relatively low chlorophyll-a concentration. Filter feeders are also considered to check on phytoplankton (Ferreira et al., 2009). On the other hand; Mudge et al., (2007) indicated that the inner lagoons may not be effectively flushed as the highest residence time calculated was 7 days.

Application of the two methods is considered to be a useful exercise to manage eutrophication not only in the Ria Formosa but also elsewhere.

1.1. Research question:

The research question is: can DPSIR and SAF be used to manage eutrophication in the Ria Formosa?

1.2. Objective:

The objective of the present study is to find management options for the eutrophication of the Ria Formosa lagoon using the DPSIR and SAF approaches. By doing this, an attempt will be made to indicate that these approaches may be employed anywhere with the necessary modifications depending on resources and system characteristics.

1.2.1. Aims:

- Description of the various socio-economic drivers leading to eutrophication.
- Description of pressures related to the identified drivers.
- Description of ecological, economic and social impacts resulting from State change.
- Recommendation of appropriate Responses.
- Identification of various environmental indicators of Pressures and State.
- Identification of Stakeholders relevant to eutrophication.
- Definition of the virtual system.
- Demonstrating the steps of SAF for eutrophication management in the Ria Formosa.

2. Literature Review

2.1. Drivers-Pressure-State-Impact-Response (DPSIR)

2.1.1. Emergence and uses of DPSIR frame work.

Several authors (e.g. Klotz, 2007, Svarstad et al., 2008) consider the works of *Statistics Canada*, which developed Stress-Response (S-R) framework in 1979, as the pioneer of the PSR and subsequently the DPSIR frameworks (Fig. 2-1). OECD employed the PSR framework for the evaluation of environmental performance, eutrophication among others, using the core set of selected indicators (OECD, 1993). DPSIR was first elaborated in the EEA-sponsored *Dobris Assessment* of Europe’s environment (Air, Water, and Soil) and adopted an environmental programme in Europe (EEA, 1995).

Therefore, this approach can be employed for assessment of different aspects of both the aquatic and terrestrial ecosystems. For example, it has been used: for evaluation of development and sustainability in coastal areas (Bidone et al., 2003); in Water Frame Work Directive for protection of ground water, inland surface waters, estuaries and coastal waters (Borja et al., 2006); for the risks in biodiversity (Maxim et al., 2009); and for assessment of impacts of development activities on environment and society. Two features that contributed to its wide use are; first it structures the indicators with reference to the political objectives related to the environmental problem addressed; and second, it focuses on supposed causal relationships in a clear way that appeals to policy actors (Smeets & Wetterings, 1999).

The DPSIR framework allows the description of environmental problems by defining the relationships between anthropogenic activities and the environment (Pacheco et al., 2007). The framework provides a better context in which to integrate different types of indicators, enabling the possibility of taking into account not only environmental but also socio-economic impacts that result from changes in the state of coastal systems (WR,2002, Cited in: Pacheco et al., 2007).

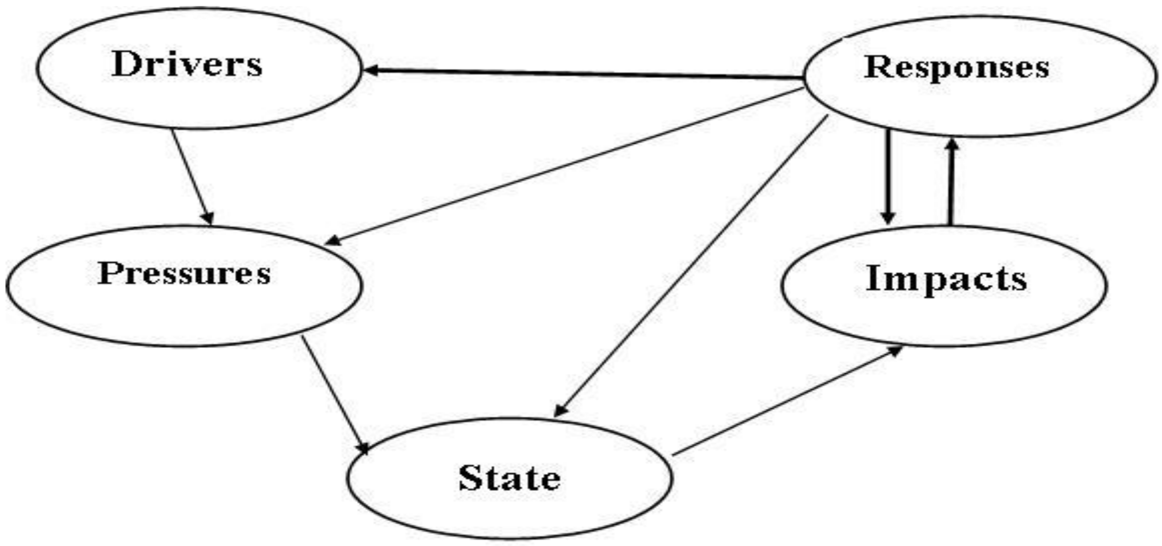


Figure 2-1: DPSIR framework (Smeets & Weterings, 1999).

OECD (1993) explains that using indicators to represent the elements of the chain simplifies the information conveyed to broad groups of stakeholders and the general public, providing clear messages, thus enhancing the transparency of decision-making. Indicators can also be used to assess the effectiveness of the actions and policies implemented, by measuring progress towards environmental targets (OECD, 1993).

As DPSIR might be poorly understood by decision makers, it should be used without obviously refering to the term. Despite the wide utilization of the framework, Carr et al., (2007) mention several critiques of DPSIR as stemming from misunderstanding of its purpose: First, it creates a set of stable indicators that serve as a basis for analysis, not taking into account the changing dynamics of the system; second it does not capture trends except by repeating the study of the same indicators at a regular intervals; third, DPSIR does not illustrate clear cause-effect relations for environmental problems; and finally it suggests linear unidirectional causal chains in the context of complex environmental problems. Carr et al., (2007), however have critiques of their own regarding the flaws in DPSIR. They argue that the framework implicitly creates a hierarchy and privileges. The Response component starts with national governments and international organizations followed by environment ministries and NGOs as the privileged actors that are considered capable of influencing Drivers, Pressures and the State. This undermines the role played by the local Response that can influence not only the impacts but also the pressures and even the drivers. Moreover, although the didactic clarity is appealing, the apparent simplicity can be misguiding, ignoring the possible synergistic relations existing between the DPSIR components: for example a specific Impact can be caused by several State conditions and by Responses to other Impacts (Maxim et al., 2009). Svarstad et al., (2008) criticize the DPSIR framework for its shortcomings in establishing good communication between researchers, on the one hand, and stakeholders and policy makers on the other. They further argue that it lacks efforts to find a satisfactory way of dealing with the multiplicity of attitudes and definitions of issues by stakeholders and the general public.

2.1.2. DPSIR approach in Eutrophication management

The DPSIR approach with the necessary adaptations to specific cases can be used for assessment of the eutrophication water bodies. In the process, the socio economic drivers, the pressures that produce the state change in the aquatic environments, the socio-economic and ecological impacts felt both by the society and the ecosystem can be identified. Appropriate policy Responses can, then be envisaged, formulated and implemented. For example, in conjunction with other methods of quantification of nutrient loads and concentrations, appropriate management options for reducing the input can be recommended through DPSIR.

DPSIR links causes of environmental change to influences that trigger societal Responses. For instance, Aliaume et al., (2007) describe the causal relations in eutrophication as follows: Economic Drivers, such as for example, agriculture generates Pressure like nutrient emission that ultimately changes the environmental State resulting in hypoxia (oxygen deficit) and anoxia (oxygen loss) which in turn cause loss of habitat and biodiversity. Such environmental changes will consequently have an impact on human activities and welfare, for example through losses of aquaculture productivity, or health impacts on coastal populations. As a Response, this instigates the government institutions to take suitable measures in order to reduce Pressures, to ameliorate the environmental state and hence to reduce Impacts on human populations and activities.

2.1.2.1. Drivers

Borja et al., (2006) described Driving Forces as the economic and social policies of governments, and economic and social goals of those involved in industry. On the other hand, MEA (2003) defines Drivers as being not only anthropogenic, but also natural. Both ways, Drivers are those components triggering Pressures on the system.

Changes in life style produce Drivers such as increased urbanization of coastal areas for permanent residency and tourism (Zaldivar et al., 2008). Zaldivar et al., (2008) further state that tourist development, aquaculture and golf are examples of newly created drivers and the latter, in its use of fertilizers, is similar to intensive agriculture. Zaldivar et al., (2008) further states that tourist development, aquaculture and golf are examples of newly created Drivers and the latter, in its use of fertilizers, is similar to intensive agriculture. Changes in land use have also created additional new Drivers such as land clearing, reclamation of wetlands, and damming (Zaldivar et al., 2008). According to the same authors, port development and shipping activities which might be stimulated by marine policy belong to yet another set of Drivers.

2.1.2.2. Pressures

Pressures are the ways Drivers are actually expressed, and the specific ways that ecosystems and their components are perturbed (Borja et al., 2006). Similarly, Pressures are anthropogenic factors inducing environmental changes which are usually unwanted and seen as negative (Maxim et al., 2009).

Pressures arising from the above mentioned Drivers are mainly high nutrient load. Nutrients originate in agricultural runoff, domestic sewage, detergents and animal manures. Loss of riparian vegetation and loss of dentrification capacity are Pressures resulting from changes in land use including port development and shipping activities (Zaldivar et al., 2008). Further, the latter activities additionally create high release of N and P, as well as changes in the residence and flushing times of the water bodies.

According to Zaldivar et al., (2008) fish aquaculture practiced in ponds, reclaimed from a wetland, produces a Pressure from dentrification loss. Moreover, the same authors explain that the sterilization of the ponds with bleach followed by neutralization with thiosulfate disrupts the biogeochemical cycle leading to a disturbance in nutrient cycle. The fish food and excreta are other factors leading to high input of organic matter.

2.1.2.3. State

State is the condition of the environment which is not static but that reflects the current environmental trends (Carr et al., 2007). The change in State is a result of Pressures.

The State of a system can be measured making use of quantifiable environmental indicators. For example; eutrophication which is the expected consequence of the Pressures is quantified through chlorophyll-a measurement and phytoplankton cell count. Moreover the concentration of nutrients and the level of oxygen in the system are State metrics that indicate the eutrophication status of the system.

For instance, Scavia and Bricker (2006) have used six indicators to determine the various stages of eutrophicaton: Chlorophyll-a, epiphytes and macro algae for detection of primary symptoms; Dissolved oxygen (DO), loss of submerged aquatic vegetation and occurrence of harmful algal blooms for detection of secondary or well-developed eutrophication.

2.1.2.4. Impact

Impacts are the effects produced on the ecosystem and the society as a result of a change in the State of the system. They have various forms and sizes depending on the nature and extent of the State change. Deterioration of water quality for drinking and bathing purposes produce economic Impacts. These economic Impacts are produced because the former necessitates construction of expensive water treatment plants and the latter may undermine touristic revenues due to poor quality bathing water. The occurrence of toxic algal blooms produces ecological Impact of loss of biodiversity. A decrease in transparency of water and low oxygen availability likewise, create Impacts of low productivity and demise of aquatic organisms. The effect on public health due to algal blooms and loss of jobs resulting from collapse of fishery serve as examples of social Impacts.

2.1.2.5. Responses

Responses are actions by the society to mitigate or remove the unwanted results produced initially by the Drivers. As figure 2-1 indicates, the Responses could be to all four components of the system or restricted to only one of them. The Responses are usually expressed as policy reactions made by government or international institutions. However, as some critics of DPSIR indicated (Carr et al., 2007), locally manifested individual and group Responses at different levels of the system are possible.

The common Responses with respect to eutrophication are reduction of nutrient load into water bodies, construction of Urban Waste Water Treatment Plants (UWWTPs) and connecting households to sewer systems. Policy Responses to reduce the pressure of pollutant load include economic instruments (polluters pay principle) and drafting policy (e.g. European Nitrate Directive).

2.2. DPSIR in the context of the Ria Formosa.

There are many conflicting interests over management such as fishing, aquaculture, tourism, salt production, harbor activities, urban development and conservation (Cristina et al., 2008). Cristina et al., (2008) further explain that several institutions ,for example, the natural park authority, municipalities and the Portuguese navy are stakeholders involved in the decision making process concerning the area. Therefore in such a complex system, DPSIR provides the means to manage the coastal ecosystem by analyzing cause-effect relationships and recommending the required policy Responses.

Though there are a number of issues to be addressed as highlighted above, the issue of Eutrophication was chosen to serve as an example of using the DPSIR framework. The deliberative process of choosing an issue was not followed due to the time constraints of the present study.

The Drivers identified in the Ria Formosa relevant to eutrophication, are socio-economic activities producing the Pressures of high nutrient and pollutant input into the lagoon. This has created a State change with respect to nutrient concentration, macroalgal growth and oxygen fluctuation; all symptoms of eutrophication. The resulting Impacts are, then, exemplified by deterioration of water quality, bivalve mortality and negative economic and health effects on the communities. Using environmental quality indicators like the level of oxygen and chlorophyll-a, the degree of State change can be quantified. Once the chain reaction of causes and effects up to the Impact stage is identified the next step would be finding Responses to mitigate the Impact by reacting to any one of the components. Thus, through DPSIR scheme different policy Responses can be recommended for management of eutrophication in the Ria Formosa.

2.3. Systems Approach Framework (SAF)

2.3.1. Science and Policy Integration for Coastal Systems Assessment (SPICOSA)

SPICOSA is a project developed under the European Sixth Framework Programme Priority. Its objectives are briefly described as follows in SPICOSA-DoW,(2009) : *The overall objective of SPICOSA is to develop a self-evolving, holistic research approach for integrated assessment of Coastal Systems so that the best available scientific knowledge can be mobilized to support deliberative and decision-making processes aimed at improving the sustainability of Coastal Systems by implementing Integrated Coastal Zone Management (ICZM) policies. Based on a systems approach, a* *multidisciplinary assessment framework will be developed with a balanced consideration of the Ecological, Social and Economic sectors (ESE) of Coastal Systems. The SAF and its tools will be implemented in eighteen coastal Study Site Applications, which range from Norway to Portugal to Turkey and to Romania*.

Achieving this objective will require a restructuring of the science and methodology needed to understand and to quantify the response of the coastal ecosystems, together with their consequences to their social and economic services, when these ecosystems are subjected to changing environmental and anthropogenic conditions (SPICOSA-DoW, 2009).

2.3.2. Systems Approach

The Greek word *Synistanai* meaning *to bring together or combine* is the basis for the term *System*. A system is not confined only to the physical world but also belongs to the human society and has emergent properties, spatial and temporal boundaries as well as an internal state, which can change in time as a response to internal dynamics or to external influences (SPICOSA-WP3, 2007). It also has a hierarchy of levels of organization in which emergent properties at one level contribute to relationships at a higher-level. System may be closed or open. A *closed system* is one where interactions occur only among the system components and not with the environment whereas an *open system* is one that receives input from the environment and/or releases output to the environment (Wallonick, 1993).

Choosing the framework of system approach is often considered as a powerful procedure which allows combining multidisciplinary knowledge to describe complex systems (SPICOSA-WP4, 2009). The systems approach integrates the analytic and the synthetic method, encompassing both holism and reductionism (Heylighen, 1998).

Systems theory proposed by the biologist Ludwig von Bertalanffy is a reaction to reductionism seen in physical sciences and an attempt to revive the unity of science; so instead of reducing an entity to the properties of its parts, it focuses on the arrangement of and relations between the parts which connect them into a whole (Heylighen, 1998).

The key features of physical and human systems can be abstracted into conceptual or mathematical models, which can be used by humans to manage the real system for a defined purpose, as the project SPICOSA is currently doing with the ecological and social systems.

Two systems approaches are recognized; hard and soft. Hard systems approach takes the world as a set of interacting systems that can be described by laws of mathematics and susceptible to mathematical modelling; whereas soft systems approach argues that system should not be used to describe the complex and problematic world but rather be applied to the process of dealing with the world through a learning system (SPICOSA-WP3, 2007).Connecting the two methods has been done by the SPICOSA with hard method describing the coastal zone and the soft method integrating the ecological and social aspects of coastal zones.

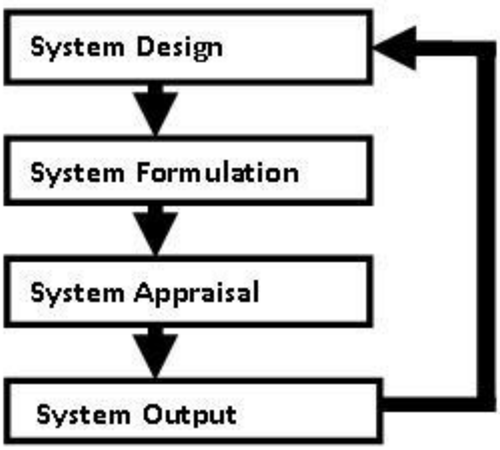


Figure 2-2: Steps used by the project to evaluate Systems Approach to coastal zone management (SPICOSA-DoW, 2009).

2.3.3. System Design (SD)

SPICOSA-WP3 (2007) defines System Design as a the first step in Systems Approach Framework which deals with the identification of an environmental problem in the coastal zone, and the designing of a conceptual model to deal with this problem, taking account of ecological, social and economic factors.

The process has several sub-tasks as enumerated below (SPICOSA-WP3, 2007):

- **Issue resolution**: After identifying the key stakeholders and relevant economic activities, a particular issue is chosen to address at the study site. Then objectives are set by which the resolution of this Issue and the successful management of the system relevant to this Issue can be assessed.
- **System definition**: Following the identification of the scale and extent of things affected by the issue, system boundaries are defined. Key relevant ecosystem features within and at the boundaries, and the key social and political features relevant to the issue are identified.
- **Conceptual model**: A conceptual model of the System is constructed in relation to the issue, showing the relationships between the main ecosystem, social and economic components identified in the previous step.

Acquiring the existing relevant data and provision to other data requirements, and problem scaling are the last two sub-tasks. The latter involves checking the feasibility, on the basis of resources, of the system description. It is recommended to reconceptualise and simplify the system if necessary.

2.3.4. System Formulation (SF)

The System formulation (SF) step involves in systematically organizing, quantifying and analysing the Virtual System (VS) as needed to implement the Policy Issues. Essentially, the SF step defines how to represent the functionality of the VS for simulation/interpretation by selecting the most relevant inputs, processes, and internal interactions and by assembling these into functional components that can be independently modelled and calibrated (SPICOSA-WP4, 2009).

System formulation step receives three important outputs from the System design step. They are: definition of the virtual system, information on how and what to be quantified and the type of input needed to evaluate the virtual system (SPICOSA-WP4, 2009).

In system formulation step, Environmental,Social and Economic (ESE) models are constructed using various symbols, feedback loops and stock/flow diagrams. The formulation of the model is explained with existing examples which illustrate the modelling strategy .Various modeling software (STELLA, EXTEND) are chosen. The overall aim of this step, then, is to give methodological guidelines in qualitative and quantitative assessment of VS in each SSA.

2.3.5. System Appraisal (SA)

The System Appraisal (SA) step explains how to carry out the simulation and validation of a system model including ecological, economic and sociological components, and how to interpret the results of the model concerning the Coastal Zone Response to selected Policy Issues (SPICOSA-WP5, 2009)

Using as a basis the assessment methodologies such as ecological ,social and economic (ESE) assessment plans and information about the input data obtained from the formulation step, SA step runs the simulation model and conducts the interpretative analysis relative to the policy issues; thereby providing scientific and descriptive supplements to the model outputs (SPICOSA-WP5, 2009).

2.3.6. System Output (SO)

In the System Output step the results that have been received out of the SA step will be shown to the stakeholders / policy makers / decision makers who have initially decided upon the policy issue to be inserted into the SAF. In stakeholders' forum, results produced in the prior steps will be presented; findings will be explained with plain language for non-scientists with the objectives of deliberating with the stakeholders (SPICOSA- WP6, 2009).

SPICOSA-WP6 (2009) further states that it will be crucial that the Output Step recapitulates the SAF process for transparency when holding the science-policy consultations. This will include explanations about uncertainties (general and about individual scenarios and their assumptions), about long term benefits, tradeoffs, data gaps etc. Moreover, the Output Step will give suggestions on how to prepare the science-policy consultations, what needs to be considered when approaching the bigger stakeholder audience and what presentation formats can be used.

2.4. Eutrophication

2.4.1. What is eutrophication?

From the time eutrophication has been recognized as an undesirable phenomenon in water bodies, a number of definitions have been suggested. It has been defined as a process, a trophic state and an effect of increased nutrient input on a water body. Some have divided eutrophication into two categories- natural and cultural (Anthropogenic). Thus, stimulation of algal growth through enrichment of waters by nutrients (Richardson, 1989), accumulation of carbon (Rabalais et al, 2009), increase in the supply of organic matter (Nixon, 1995), the accelerated production of organic matter, particularly algae, in a water body (Bricker et al., 2003), enhanced primary production due to human-induced excess supply of nutrients (EEA, 2001) are some examples of the various definitions given to eutrophication.

The Council of the European Communities in its Urban Waste Water Directive (1991) defines Eutrophication as the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an **accelerated growth of algae and higher forms of plant life** to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned.

Despite their differences, all agree on the excessive growth of algae caused by supply of nutrients leading to the deterioration of water quality. So it leads to a conclusion that eutrophication is a phenomenon (that persists as long as nutrient supply is present), of excessive algal growth above the background level which results from increased supply of nutrients and causes loss of water quality through oxygen depletion and decreased water clarity.

Figure 2-3: Algal bloom in area or restricted exchange**.**

2.4.2. Consequences of eutrophication

Eutrophication has been producing negative impacts both on the aquatic ecosystem and the society. Its effects range from changes in the structure and function of the aquatic ecosystem to socio-economic disruption as expressed by collapse of fisheries, decreased tourism and bad human health. For example, Cloern (2001) states that benthic and submerged vascular plants decline as a result of decreased transparency affecting the availability of light, and other stressors such as enhanced epiphytic growth; moreover, some species of algal blooms produce toxins that can impair the growth and reproduction of invertebrates and can be lethal to fish and threats to human health. For example, when fish with high concentration of these toxins are consumed, neurological and gastrointestinal is poisoning may occure. While hypoxic and anoxic environments have existed through geological time, their occurrence in shallow coastal and estuarine areas appears to be increasing, most likely accelerated by human activities leading to loss of biodiversity through migration and death of species (Cloern, 2001). Additionally, the impacts include alteration of food webs; degradation and loss of sea grass beds, kelp beds and coral reefs (Scavia & Bricker, 2006) with the associated loss of ecosystem goods and services.

2.4.3. Eutrophication in the Ria Formosa

Sewage and agriculture are the major sources of nutrients in the Ria Formosa with nitrogen more enriched than phosphorous, and silicon concentration exceeds nitrogen in winter and vice versa in summer (Newton, 1995; cited in Newton & Icely, 2006). Tett et al., (2003) estimated dissolved available inorganic nitrogen (DAIN), dissolved available inorganic phosphorous (DAIP), and dissolved silica (DSi) to be 38μM, 1.5 μM and 35 μM respectively. Nitrate and phosphate are imported from the adjoining coastal area to the lagoon during the spring (>60%), and silicates are permanently exported out of it (Falcão & Vale, 2003). Falcão and Vale (2003) further clarified while silicates at low tide exceeded values at high tide throughout the year, nitrates and phosphates exhibited a clear-cut seasonal variation at high spring tide, with maxima in the period of low temperatures (early spring), indicative of their import from the adjacent coastal zone.

Moreover, nutrient dynamics exhibited spatial variations. Newton et al., (2003) showed that the concentration of dissolved available inorganic nitrogen, phosphate and silicate is much higher in the eastern lagoon where the population density is lower and the proportion of agricultural land is greater than in the western lagoon, , probably indicating the importance of agriculture than sewage. The particularly high concentrations of nutrients in the eastern lagoon during winter months can be attributed, in part to freshwater runoff (Newton et al., 2003). In addition to the coastal waters, the sediment is a source of nutrients to the lagoon (Falcão & Vale, 2003, Newton & Icely, 2006).

It appears that the productivity of the lagoon checks on the abundance of nutrients in it. For example, the lower nutrient values at low tide and the increase in chlorophyll *a* (upto 2 μg g^{-1}) point to a rapid biological consumption of the imported nutrients (Falcão & Vale, 2003). Thus algal blooms in the lagoon periodically reduce nutrient availability and inflowing coastal water becomes a nutrient source (Newton & Icely, 2006).

3. Materials and Methods

3.1. Study area (The Ria Formosa)

The Ria Formosa lies in the geographic coordinates of 37^0N, 8^0W to 37^0N, $7^0$32’W,extending for 55 km in the southern coast of Portugal (Fig. 3-1). It is a shallow mesotidal lagoon with natural biogeochemical cycles essentially regulated by tidal exchanges at the seawater boundaries and at the sediment interface (Newton et al., 2003). The lagoon is a true barrier island system, comprising mainland, backbarrier lagoons, inlet deltas, barrier islands, barrier platforms and shoreface (Gamito, 1997). Different authors give different figures on the area and volume of water of the Ria Formosa. It covers an area of 163 km^2 (Gamito, 1997), 58 km^2 (Tett et al, 2003), 100 km^2 (Newton & Icely, 2006, Duarte et al., 2008), 49 km^2 (Ferreira et al, 2009). Similarly, the volume of water was estimated to be 31M m^3 (Edwards et al., 2005), 88 M m^3 (Tett et al,2003), 92 M m^3 (Ferreira et al, 2009). These discrepancies could be attributed to seasonal variations of the lagoon which coincided with the times of measurements. The Ria Formosa is of sufficient ecological importance that it has been recognized as a National Park, as well as a Ramsar and Natura 2000 site (Loureiro et al., 2005).

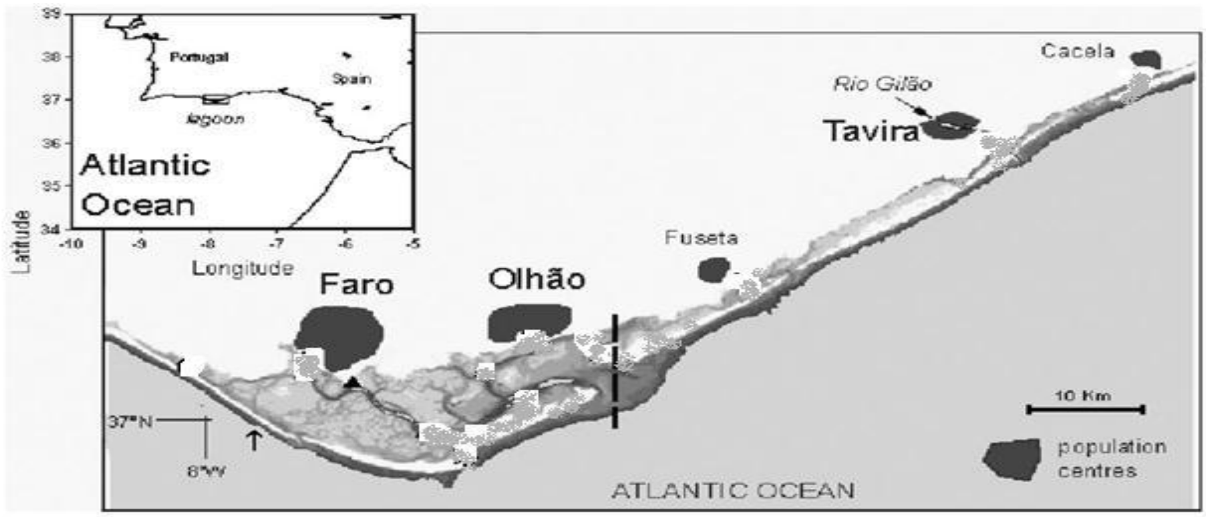


Figure 3-1: The Ria Formosa Lagoon (Adapted from Newton et al., 2003).

Newton and Mudge (2003) indicated that freshwater is supplied to the Ria Formosa by five small rivers and 14 streams most of which dry out completely in summer; and the mean annual rainfall in the basin is 634 mm and is often concentrated into only a few winter days. It has an estimated volume of $88Mm^3$ of water with fresh water inflow of $0.22Mm^3/d$ and a maximum and mean depth of 19m and 1.5m respectively (Tett et al., 2003).The lagoon is characterized by semi-diurnal tidal regime with a tidal range of 1.35m at neap and 3m at spring tides respectively (Newton & Mudge,2003). Consequently, there is an exchange of about 50-75% of the lagoon water with the ocean each tidal cycle (Tett et al., 2003).

The water salinity can reach about 36.5 with temperature of $27^{O}C$ (Newton & Mudge, 2003). The evaporation of water from the shallow inner regions coupled with the small and seasonal freshwater input (negligible run off in summer) leads to greater salinities in the lagoon compared to the external ocean waters (Mudge et al., 1998). The hot and dry summer weather heats the water and increases its temperature ($25^{0}C$), evaporation and salinity, whereas in the cooler winter the rainfall dilutes the lagoon with freshwater so that the water temperature and salinity decrease (Newton and Mudge, 2003).

It has several inlets which showed variability through time. For example, Newton and Mudge (2003) stated that there are seven inlets two of which are artificially consolidated that allow exchanges of water with the Atlantic Ocean. The restriction of the exchange of water to the seven inlets makes the lagoon a region of restricted exchange (Newton and Mudge, 2003). The most recent work by Dias et al., (2009) indicates that there are six tidal inlets, which restricts its exchange even more.

Sediment dynamics is an important environmental factor in aquatic ecosystem. It is associated with the transparency of the water which affects the light penetration and hence photosynthetic activity. Sediment is also associated with pollutant and nutrient dynamics. For example, as salinity increases the nutrient adsorption on the sediment decreases (Carrit and Goodgal 1954, cited; Murray et al., 2006) hence releasing sediment-bound phosphorous (P) in to seawater ; therefore in estuaries or coastal lagoons, where salinity is altered by fresh water inputs or high evaporation, the proportion of sediment-bound P will change accordingly (Murray et al.,2006). Furthermore, Murray et al., (2006) showed that in the Ria Formosa, sediment pore water concentrations of nutrients exceeded seawater concentrations, and sediments were sources of inorganic nutrients to the overlying seawater. Sediments contribute to the preservation of coastal salt marshes. Fassetta et al., (2006) for instance, have indicated that, the sedimentary balance of lagoon marshes was altered by human activities and many marshes in the Ria Formosa do not receive sufficient sedimentary inputs to support their growth.

The Ria Formosa is known to be a highly productive ecosystem. Its different habitats support a rich diversity of flora and fauna (Newton & Mudge,2003).The lagoon has a long tradition of bivalve farming, where 80% of Portugal's mollusc fisheries is harvested, especially *R.deucussatus* and other significant species like *Ruditapes romboids* (Coelho et al., 2002). Beside the fact that many fish species are taken within the lagoon, it is an important nursery for species caught in the surrounding coastal waters (Newton & Mudge, 2005). As the Ria Formosa is a Ramsar and Natura 2000 site, it has an important population of water birds. Beach-nesting *Charadrius alexandrinus* and *Sterna albifrons* as well as wintering waders and duck numbering as high as 20,000 on a regular basis are notable examples (BI, 2009).The lagoon is included in special birds protection area (Loureiro et al., 2006).

The combination of hydro-graphic factors and the nature of the substrates (predominantly sand and clay) constitute ideal conditions for the development of benthic communities (Austen et al., 1989: cited in Coelho et al., 2002). The macrobenthic species are dominated by bivalves *Abra segmentum*, *Cerastoderma* spp and *Loripes lacteus*, the gastropods *Bittium reticulatum* and *Cerithium vulgatum*, the polychaetes *Hediste diversicolor*, *Heteromastus filiformis* and *Streblospio* spp, the crustaceans *Apseudes latreillii*, *Corophium* spp, and *Microdeutopus* spp (Cristina et al.,2008).

3.1.1. Socio-economic activities

The resident population around the Ria Formosa in the three population centres of Faro, Olhão and Tavira was 124,000 in 2001(Duarte et al., 2006) with some increase currently. According to Mudge and Bebiano (1997) the population increases three fold in summer. The population centres along the barrier island system too, have extremely variable annual population depending on the type of economic activity such as tourism, fishing, commerce and shellfish farming (Duarte et al., 2006). The population dynamics is strongly associated with the demand for waste water treatment.

Other economic activities in the Ria Formosa include salt extraction, sand mining and intense agriculture. The shallow soft bottom of the lagoon provides a suitable habitat for clams, which live in the mud (Cristina et al.,2008) and approximately 95% of the total production of the clam *Ruditapes decussatus* originates in the Ria Formosa and involves approximately 10 000 people (Chicharo et al., 2008). According to Ferreira et al., (2009) clam cultivation provides a yield of about 8000 tons of total fresh weight (TFW) per year.

aosabordamare.blogs.sapo.pt/2009/02/01/

http://www.portugalvirtual.pt/_tourism/algarve/

Figure 3-2: Economic activities in the Ria Formosa

3.1.2. Ecological/Environmental conditions

Several authors have indicated that a substantial load of anthropogenic material derived from domestic sewage, agriculture and aquaculture enter directly into the lagoon, causing eutrophication in the system. The consequent oxygen depletion then produces ecological disturbances. For instance, Mudge et al., (2007) stated that due to direct discharge of sewage in to the Ria Formosa, which has a longest residence time of up to 12 days, oxygen consumption rate at neap tide was found to be 18% per day .This may have contributed to water quality deterioration in summer months, which caused clam mortality.

Population pressure associated with tourism has contributed a great deal for eutrophication in that it increased the load on UWWTPs. The population increase in the summer tourist months makes domestic sewage an important source of ammonium and phosphate particularly near the towns of Faro and Olhão (Newton & Mudge, 2005). Similarly, the intensive farming in the hinterland of the lagoon with the use of ammonium nitrate, urea and phosphate fertilisers (Newton & Mudge, 2005) carried in the agricultural runoff is an important source of nutrients to the lagoon (Newton et al., 2003). Urbanisation and several golf courses bordering the lagoon pose an ever increasing stress upon the lagoon system (Cristina et al., 2008).

3.2. DPSIR

The DPSIR frame work was used to describe the Drivers, Pressures and Impacts that produced a change in the State of the system. The major socio-economic activities (Drivers), Pressures, State and Impacts in the Ria Formosa were described. Then the appropriate policies Responses to one or more components of the framework were suggested in the form of recommendations. Moreover various environmental indicators were identified and listed.

3.3. SAF

The four steps of SAF, namely System design, System formulation, System appraisal and System output were followed. In the first step, the major socio-economic activities and stakeholders were identified. The policy issue of eutrophication in the Ria Formosa was agreed upon. Scenarios were formulated and environmental indicators were chosen. Then the conceptual model was constructed. The next three steps were discussed and model components were demonstrated to show the possibility of using SAF for the management of eutrophication.

4. Results

4.1. Driver-Pressure-State-Impact-Response (DPSIR)

4.1.1. Socio-Economic activities (Drivers)

For the definition of the driving-forces that lead to environmental pressures, it is important to identify the corresponding major stakeholders too, their values and interests, and also the possible conflicts between them. In the Ria Formosa, agricultural and aquaculture farmers, fishermen, local inhabitants and tourists are identified as major stakeholders on individual basis. Different government, educational and private institutions associated with the socio-economic and research activities are the other institutional stakeholders. Some examples are National Park authorities, Agriculture and Fishery department, Port authorities, Real estate developers, Tourist operators and resorts. Each stakeholder has its own world views sometimes in conflict with one another.

As an example, the primary aim of the agricultural farmers is maximization of production, which necessitates the use of fertilizers. Nutrients washed off to the water body could produce excessive algal growth causing ecological degradation. This degradation reveals itself in reduced water clarity, oxygen depletion, probable occurrence of harmful algal blooms (HAB) and the consequent loss of biodiversity. Fishermen will be affected as their catch is reduced. Tourist operators could, similarly, be affected as tourists may not want to visit or bath in a water body with excessive algal growth. The expansion of golf courses by tourist operators produces the same effect as agriculture.

As a second example, the government has interests and responsibilities to upgrade the overall living standards of the population. Among these, urbanization holds an important place. Development of infrastructure with tons of sediments from construction sites, increased sewage, both treated and untreated, contributes its share to the deterioration of the aquatic ecosystem. The resulting eutrophication produces ecological, economical and social negative consequences leading to a web of conflicts among the stake holders. While ecological consequences are obvious, the economic losses are expressed as increased cost for construction of urban waste water treatment plants by governments (Nobre, 2009), loss of income by the fishermen and loss of revenue by the tourist operators. The social effects are loss of jobs (Zaldivar et al., 2008), poor health and decreased productivity of the society.

These conflicting interests can be mitigated if the stakeholders find some common platform for mediation and conflict resolution. For example, agricultural and aquaculture farmers can cooperate so that both stakeholders come out as winners. Cultured bivalves provide a means of top-down control of eutrophication symptoms associated with excessive loading of nutrients to the coastal zone (Ferreira et al., 2009). Ferreira et al., (2009) in their Farm Agricultural Resource Management (FARM) model show that in the Ria Formosa, a net total of about 28.5 ton/y of nitrogen and 22.5 ton/y of carbon as phytoplankton are removed from the water through filtration of algae and detritus. These authors suggest that the shellfish aquaculture can sell nitrogen credits to agriculture and finfish farming with the objective of offsetting nitrogen emissions, in exactly the same way as is currently traded for carbon.

Agriculture/livestock, aquaculture/fishery, tourism and urbanization have been identified as major socio-economic drivers in the Ria Formosa. These activities can be managed well so that the human welfare is maximized while maintaining the sustainability of coastal systems. This can be achieved by adopting Integrated Coastal

Zone Management that involves the relevant stakeholders and makes use of the best available scientific knowledge for management.

4.1.1.1. Agriculture/Livestock

The Algarve has 68.5%, 1.7% and 29.8% of utilized agricultural areas in mountainous, agriculturally less favoured and not less-favoured areas of Portugal respectively (MADRP, 2007). The Ria Formosa lies in one of the not less-favoured areas (Fig.4-1). The region has in the Natura 2000 area 23% of agriculture, 34% of forest, and 33.2% of natural vegetation, which makes the Algarve contain 30% of heterogeneous agriculture (MADRP, 2007). MADRP (2007) further elaborates that it contributed to the economy of the country by absorbing about 4.1% of the economically active population in 2001.

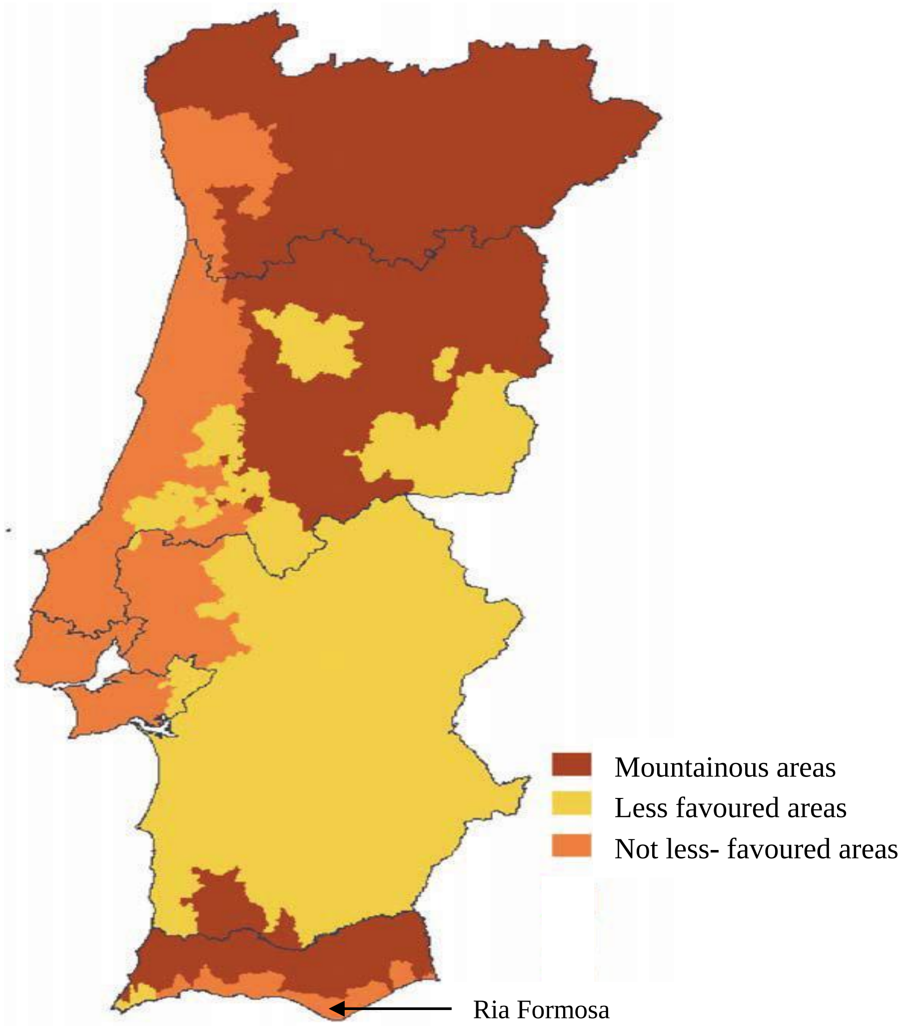


Figure 4-1: Land use showing mountainous, less favoured and not less-favoured areas for agriculture (MADRP, 2007).

The total utilized agricultural area in Algarve is 102,765 ha, out of which arable land and permanent cultivation constitute 40,745 ha and 41,475 ha respectively: the rest is composed of pastures (19,616 ha) and family plots (924 ha) (INE, 2007). 68.5%, 29.8% and 1.7% of Algarve lies in mountainous, not less-favoured and less-favoured areas respectively and corresponding proportion of farms (64.3%, 35.1% and 0.6% respectively) are found in the three different categories of agricultural areas (MADRP, 2007).

Different kinds of cereals (wheat, maize, barley, oats etc..) ,potatoes , beans and fruits (Orange, apple, pear, peach etc..), as well as apricots and olive are produced in Algarve region (INE,2004). The intensive horticultural farms are especially important to the Ria Formosa.

According to 2002 statistics, 224,515 metric tons of fertilizers excluding traditional animal and plant manures are used in Portugal; this gives a per capita consumption of 19,965 metric tons per one million population and an average consumption per hectare of about 84.3 Kg. (NM, 2002).

With a 30% of the region used for heterogeneous agriculture, Algarve use a considerable amount of fertilizer. According to Newton and Mudge (2005) the hinterland of the Ria Formosa is intensively farmed with the use of ammonium nitrate, urea and phosphate fertilisers. The seasonal rainfall with the resulting agricultural runoff during autumn rainy months contributes a particularly high input, and in spring when rainfall occurs, additional load of fertilizer is drained into the lagoon after springtime fertilizer applications (Newton & Mudge, 2005).

The Ria Formosa catchment, as it is in agriculturally favoured area of the Algarve has an important agricultural component. Horticultured farms (Fig 4-2) contribute to the nutrient enrichment of the Ancao Basin in the western end of the Ria Formosa. For instance several significant inputs of nutrients; nitrate, nitrite, and ammonium originating from the horticultural company have been measured in the Esteiro de Maria Nova, which is part of the Ancao Basin (Wayland et al., 2008). Similarly, two intensely farmed areas, Campina de Faro and Campina da Luz, located north of the lagoon are overly nitrate- contaminated (Leote et al., 2008). The Campina de Faro is the most intensively farmed area of the Algarve, and even in rapid urbanization of this area some zones are reserved for agriculture (Newton & Mudge, 2005). Moreover, the eastern part of the lagoon is intensively used for agriculture too. In response to a situation where phosphorus seemed a limiting nutrient (based on a Redfield ratio of N: P), which is unusual in a shallow marine water in contact with large area of sediment, Newton et al., (2003) suggested that there is a large excess of nitrogen in the system, particularly in the eastern lagoon, an area where there is a lot of intensive agriculture.

Figure 4-2: The Vitacress intensive agriculture in the Ria Formosa (Photo: B. Fragoso).

Irrigation of four golf courses , namely, Quinta do Lago, Quinta do Lago- Ria Formosa, Quinta do Lago-Sao Lorenz and Quinta do Lago-Pinheiros Altos was planned using a desalinized sea water and the desalinization unit located in Loulé municipality was expected to start in 2006 (Koundri et al., 2006). Golf courses are considered equivalent to intensive agriculture. A significant amount of phosphate enrichment of the the Ria Formosa lagoon is associated with the golf complex (Wayland et al., 2008).

Figure 4-3: Quinta do Lago Golf course (http://premier-direct.com/riafmosa.htm)

Portugal's share of cattle, pigs and sheep (and goats) in the European Union is 10.2% , 8.4% 2.3% respectively (MADRP, 2007). In year 2007, 1,924,660 metric tons of cow milk ,96154 metric tons of sheep milk and 119,119 metric tons of hen's eggs have been produced (FAOSTAT,2007). Livestock rearing is an important agricultural activity in Algarve. There were about 10,000 heads of cattle, 73,000 heads of sheep, 21,000 heads of goats and 54,000 heads of pigs (MADRP, 2007). However, according to MADRP (2007), the livestock density index has decreased by half from 0.4 in 1999 to 0.2 in 2005. The consequent statistics from 2006 to 2008, likewise, shows a slightly decreasing trend except for the cattle (Fig. 4-4).

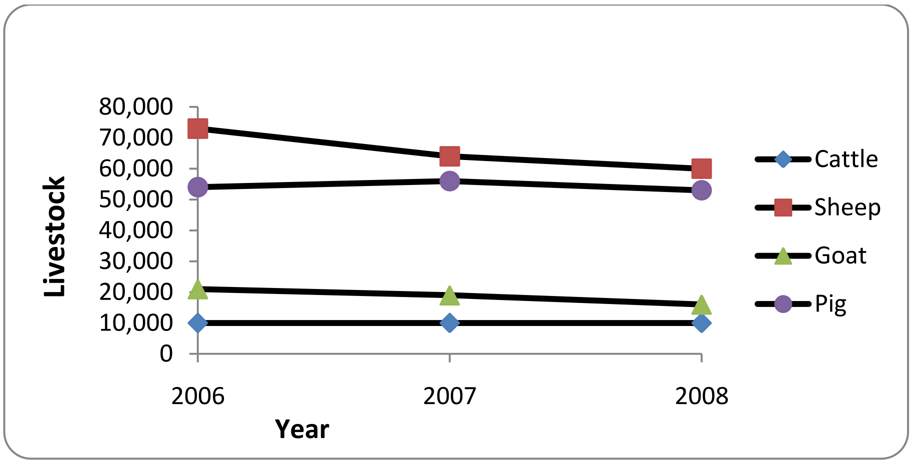


Figure 4-4: Livestock in Algarve (INE, 2008).

4.1.1.2. Aquaculture/Fishery

Fishery's output in Portugal, in the year 2005 was 218,246 tons and 6484-6695 tons from fish catch and aquaculture respectively, and the fishing fleet numbered 9155 (MADRP, 2007). MADRP (2007) further shows that despite a slight decrease in finfish production, fishery's output, in general, has shown an increasing trend from 94.4 % to 95.2 % between 1995 and 2005. The larger share belongs to finfish, ranging from 71.2 % to 72.5% and that of shellfish and invertebrates is between 4.6 % and 12.3 % (MADRP, 2007).

Aquaculture and fishery are among the most important socio-economic activities around the Ria Formosa. The Ria Formosa has a considerable wealth of species of fish. Ribeiro et al., (2008) showed that within the space of 22 years (1980-2002), 57 taxa of 24 families of fish have been identified in the lagoon. Of these, 10 species that were present in 1980s seem to be replaced with 12 new species (Ribeiro et al., 2008).This ecosystem is considered a nursery for a large number of coastal species, and its extensive intertidal areas are being used for clam and aquaculture ponds.

Table 4-1: Fishery's output in Portugal (Source, MADRP, 2007)

	1995-1999	2000-2005	Difference
Fish	72.5 %	71.2 %	-1.3
Crustacean	4.6 %	5.3 %	0.7
Cephalopods	12.1 %	12.3 %	0.2
Bivalves	4.8 %	6.2 %	1.4

As mentioned earlier, 80% of Portugal's bivalve fishery is harvested in this lagoon. Other authors make the percentage even higher. For instance, Newton et al., (2003) stated that saltpans and aquaculture ponds occupy about 1000 ha of the lagoon and in 1989 around 7000 tons of clams were harvested from the sand flats of the lagoon, supplying 90% of the Portuguese market. However, the production declined to 2000 tons by 1990 (Dinis, 1992, Cited in: Newton et al., 2003) presumably owing to the deterioration of water quality. Bebiano (1995), on the other hand, indicating the total area of the lagoon used for extensive clam culture (e.g. cross carpet shell Ve*nerupis decussata*, banded carpet shell *Venerupis rhomboides*, the thick trough shell *Spisula solida*, the common cockle *Cerastodemaa edule*, the oyster *Crassostrea angulata* and the mussel *Mytilus galloprovincialis*) as 10,000 ha, gives an elevated figure of production of 10,000 tons in 1988, which declined to 3000 tons in the following six years. Figure 4-5 diagrammatically summarises the figures enumerated above.

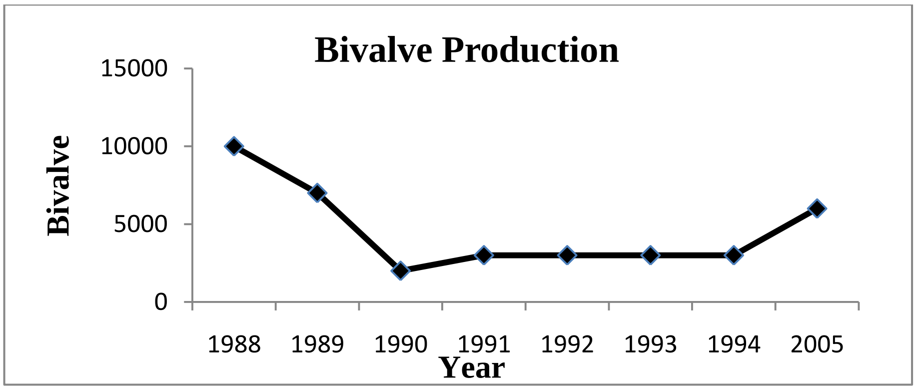


Figure 4-5: Bivalve production 1988-2005

According to Hubert et al., (2006), extensive multi-species fish farming is also a traditional activity being undertaken in ancient saltpan reservoirs. Semi-intensive fish farming of sea bass (*Dicentrarchus labrax*) and gildhead sea bream (*Sparus aurata*) has been developing for the past 20 years; and it has also been undertaken in ancient saltpans or in concrete tanks (Hubert et al., 2006).

Despite the differences in figures for shellfish production in the Ria Formosa, the lagoon is important for aquaculture. The income it generates supports about 5000 families by providing an employment to some 10,000 people, as mentioned earlier.

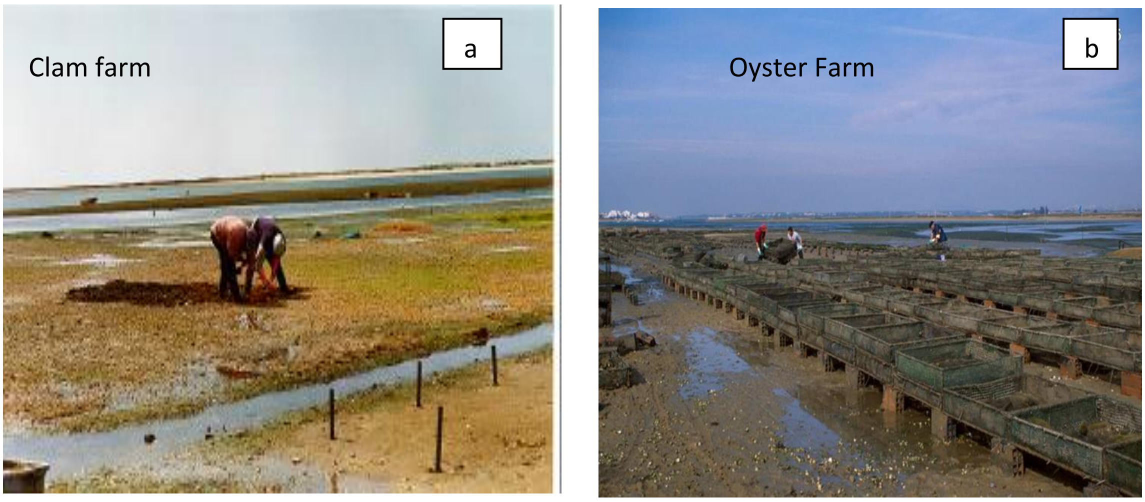


Figure 4-6: Aquaculture in the Ria Formosa (Photo: Ana Manijua).

In conjunction with aquaculture, artisanal fishery is practiced in the Ria Formosa. As the work of Vasconcelos et al., (2008) highlights, the target species are muricid gastropods , because the banded murex (H*exaplex trunculus*) and the purple dye murex (*Bolinus brandaris*) are greatly appreciated seafood with high commercial value on the market (reaching values of around 10-15 €/kg and 20 €/kg, respectively). In addition to hand harvesting in inter-tidal areas, they are traditionally caught with an artisanal fishing gear, locally known as the "wallet-line" (Vasconcelos et al., 2008), an illegal fishing gear according to the regulations for the fishery in the lagoon (D.R., 1990, Cited In: Vasconcelos et al., 2008).

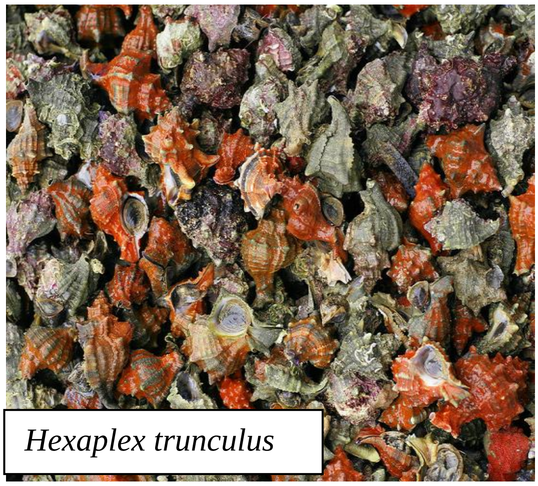


Figure 4-7: Muricid Gastropods harvested in the Ria Formosa. (http://www.george-shells.com/murex6/brandaris_long_3s708.jpg

While *Ruditapes decussatus* is the main species harvested in the Ria Formosa (Chicharo et al, 2008, Nobre, 2009), other clam species such as *Venerupis decussatus, Venerupis rombiods and Spisula solida* are also found in the lagoon.

4.1.1.3. Tourism

The Algarve region is one of the most tourist-frequented areas in Portugal. Large-scale tourist industry development in this region began in the 1980s and has consisted mostly in the commercial exploration of the sea-sun binomial, held in particularly high regard by Northern European tourism operators (Estevens & Barroqueiro,2004). But its popularity dates back to 1960s due to its reputation as an upmarket alternative to the Mediterranean coast (Petrov et al., 2009).

The size of the population in the major touristic centres grows dramatically during tourist seasons. According to Mudge and Bebianno (1997), the population of the area triples from approximately 150,000 inhabitants to 450,000 during the summer months. This assumption is consistent with Portuguese National Statistics Institute (INE).

According to INE (2008) the number of tourists in Algarve was 146,900, 49,100 and 43,200 for one night stay, for one to four nights stay and for four and more days stays respectively. This makes the total tourist population in 2008 about 239,200.

From the south western tip of Sagress to the north western tip of Margem do Guadiana, the beautiful beaches of Lagos, Albufeira, Olhão and Tavira to mention but a few and the beautiful isles (eg., Barreta, Cultra, Armona and Tavira) in the Ria Formosa Nature Reserve are major tourist attractions in this region. The nature reserve plays an important part in the conservation of many varieties of fish, flora and birds. The park has been involved in preserving the cultural heritage of the area; for example, the tidal mill and Roman salting tanks. Besides the natural beauty of the landscape with associated fauna and flora such as birds, aquatic animals and vegetation, there are a number of Golf courses and water sport facilities that increased the amenability of the region for tourism.

Moreover, the medieval walls, monuments, cathedrals, museums, the Roman ruins and the remnants of the 10th century Moorish castles reminiscent of the Arab occupation of Portugal contribute a great deal to the tourist flux in to the region

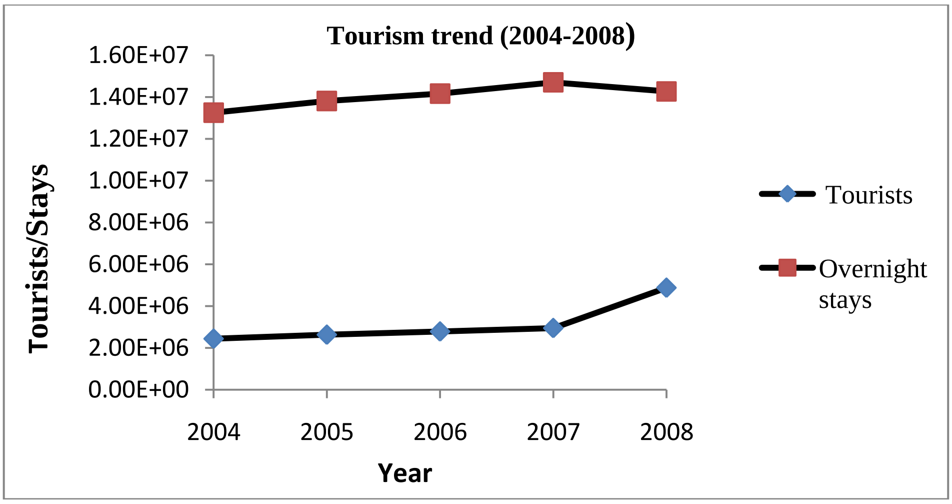


Figure 4-8: Tourism trend in Algarve region (INE, 2004-08)

Figure 4-9: Beaches in Lagos (http://www.portugalvirtual.pt/_tourism/algarve/)

Figure 4-10: Beaches in Albufeira (http://www.portugalvirtual.pt/_tourism/algarve/)

The Ria Formosa holds an important place in Algarve as a valuable resource of tourism (Newton et al., 2003). The area of land used in the Ria Formosa for tourism is second only to urban development (Tett et al., 2003). The major population centres are Faro, Olhao, Tavira, Fuseta and Cacela in an order of decreasing importance. The Ria Formosa, being largely near Faro, the capital city of the region, has borne most of the tourist burden. The city of Faro houses a number of notable ancient edifices to visit (e.g. Figures 4-11 & 12), marina for boat travel to the surrounding islands and hotels to cater for the incoming tourists, a fact that contributes to the population increase during high tourist seasons.

Figure 4-11: Church of Sé Pedro (http://www.portugalvirtual.pt/_tourism/algarve/).

Figure 4-12: Nossa Senhora de Fatima.

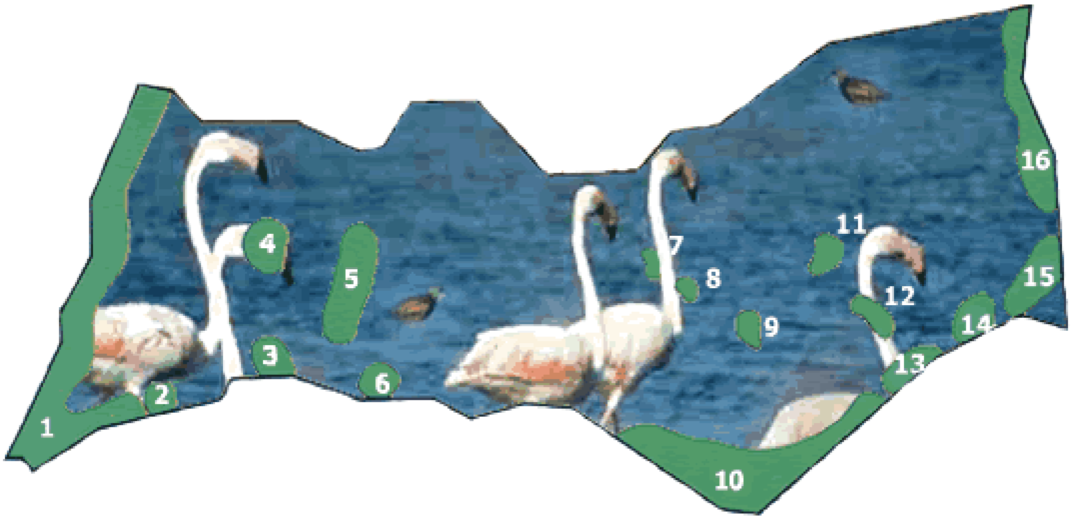


Figure 4-13: Nature reserve, No 10 is the Ria Formosa.
(http://portimao.com/algarve/nature_reserves_uk.htm)

The Algarve region continues to be a retreat for those who want to escape from the excessive and rather chaotic congestion of the Lisbon and O Porto metropolitan areas (Estevens & Barroqueiro, 2004). In 2008, residents of Portugal spent 61.3 million overnight stays outside their usual place of residence and Algarve absorbs 23.4% of this (INE, 2008). Its agreeable, mild climate has even made it one of the most sought after locations for foreigners to enjoy their retirement and as holiday/secondary homes, especially the British, Germans and other northern Europeans too (AlgarveMais, 2009, WTTC, cited in: Petrov et al., 2009).

4.1.1.4. Urban Development

The Algarve region has been increasingly urbanized owing mostly to a thriving tourist industry. Since 1970 important changes of land use pattern throughout the country, especially in Algarve occurred and tourism has been the driving force that influenced significant changes of the landscape, economy, social structure, and cultural behaviour (Petrov et al., 2006).

According to Petrov et al., (2006) the changes in the last 30 years led to a construction pressure, mainly that of residential and tourist facilities on the agricultural and nature areas; and based on statistics they stated that an increase of 64% of development of residential area from 1972 to 1986 was observed, mainly on the shorelines. Besides, the growth in the industrial buildings was 8.7 % in the nineties. In 2008 alone 3279 family dwellings and other buildings were constructed in Algarve. Among these 2618 were new constructions and the rest constitute expansions and reconstructions (INE, 2008). INE (2008) further elaborates that in association with these buildings, 6976 pavements covering an area of about 2 km^2 were made. Moreover 9346 apartments were constructed. From 2002 to 2008, about 23,201 family dwellings and other buildings were built in the Algarve region (Fig.4-14) (INE, 2008).

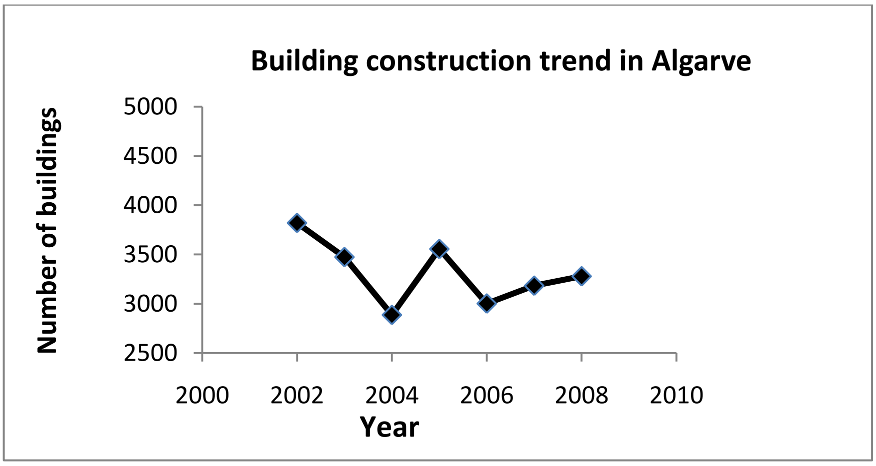


Figure 4-14: Family residences and other buildings in Algarve (INE, 2003-08)

The number of these types of buildings was the highest in 2002 and decreased till 2004 and increased again in 2005. Having decreased in 2006, showed a steady increase till 2008. However, big hotels and large apartment buildings are no longer allowed to be constructed. Nonetheless, golf courses and holiday villages continue to develop along the Algarve coast; and urban areas continue to expand as very small and dispersed patches along the shorelines (Petrov et al., 2006).

Tourist development has been one of the most important stimulating forces behind urbanization. As the tourist industry grew, new infrastructural development was necessary to cater for tourists. Table 4-2 summarises establishments in 2008 for the benefit of tourists.

Table 4-2: Establishments for tourists in Algarve (Source, INE, 2008)

Year 2008	**Hotels**	**Hotel-apartments**	**Tourist apartments**	**Tourist settlements**	**Motels**	**Hostels**	**Inns**	**Pensions**	**Total**
	90	**63**	**137**	**25**	**5**	**3**	**8**	**86**	**417**
Rooms	12730	6895	10957	4467	249	120	208	2007	**37633**
Capacity (Prs)	27500	20768	32608	12245	625	240	451	4287	**98724**
Employment (Prs)	7176	2728	2767	1591	85	96	208	423	**15074**

According to the criteria used by the Portuguese National Institute of Statistics, the Algarve region consists of 18 urban centres, most of which are located along the coast, and accounts for 5.7% of the total number of urban centres in the country (Estevens & Barroqueiro, 2004). Estevens and Barroqueiro (2004) further explain that the spatial distribution of the urban centres is indicative of considerable urbanisation along the coast and of the existence of two spatial sub-systems: one structured around the Faro urban centre, the other around the Portimão, Lagos and Lagoa urban centres.

The area around the Ria Formosa is an important urban centre as Faro is the capital and the most important centre of the region. For example, The Faro,Loule and Tavira urban centers located within the Ria Formosa are ranked 31^{st},48^{th} and 64^{th} in the country with respect to their centrality; especially the Faro urban centre fulfilled 112 of 117 criteria for constructing centrality index, indicating its importance in the Algarve region (Estevens & Barroqueiro, 2004).

Besides residential and industrial buildings, parking lots, pavements, hospitals, industrial buildings and waste water treatment plants have been constructed. For example, additional to existing waste water treatment plants (~ 27 in number, Nobre, 2009), a 9.7 million euro UWWTP has been inaugurated in September, 2009 (Aguas do Algarve, 2009). UWWTPs, particularly have an important implication to the lagoon's eutrophication as the effluent they release in to the Ria Formosa is a significant pressure.

Urbanization in the region is still going on. AlgarveMais (2009) enumerates the following plans that will be completed in the next few years.

- A €130 million project to develop the capacity of Faro airport from six million passengers a year to eight million by 2013 is planned.
- More than ten private hospitals with the primary aims of serving tourists will be built in Algarve. The first one in Faro built on 12,000 ha of land was recently opened (Fig 4-15).
- Luxury town-homes and apartments in Vilamoura, only with less than 30 minutes distance from Faro airport, and a hospital with 50 beds in Albufeira will be built.
- A €150 million luxury resort called Quinta da Praia will be built on 22.5 ha area close to the beach in Alvor .It includes five star hotel, 197 villas and town houses. An area between the development and the beach will be renovated and walkways to the beach will be built.

The industrial development accompanying urbanization is a feature that should not be neglected. Manufacturing industries were about 2564, 3013, 2985 and 2913 in number in the period of four years from 2003 to 2006 respectively (INE, 2003-2006). Likewise, those enterprises involved in agricultural, livestock, fishery and forestry products, manufacturing and processing industries numbered 5926, 5916, 5398 and 5801 in the period of the same four years respectively (INE, 2003-2006).

Figure 4-15: Hospital Particular Do Algarve.

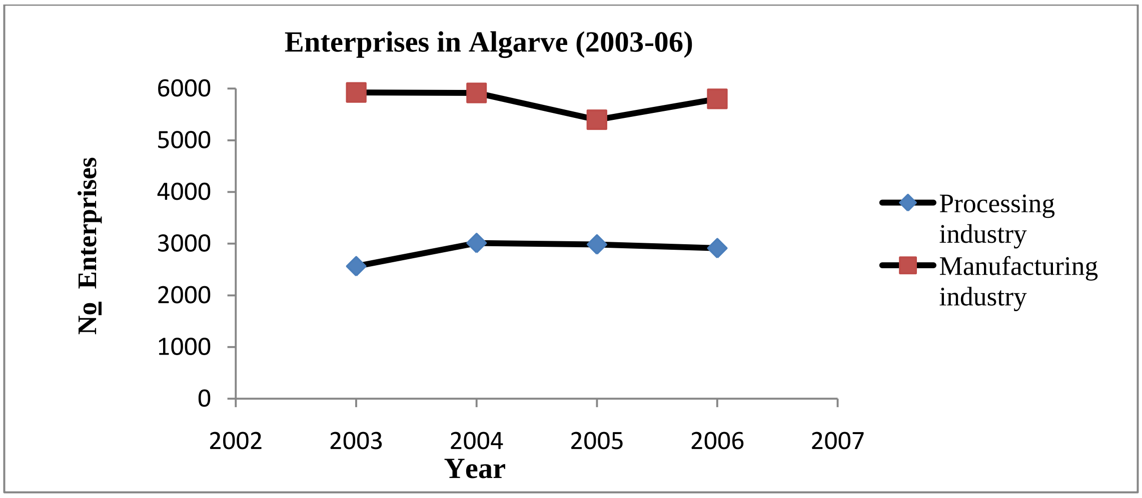


Figure 4-16: Manufacturing and processing enterprises in Algarve (INE, 2003-2006).

As most of the urbanization process and population concentration is along the coasts, wetland decrease due to reclamation has been observed in the Ria Formosa. Deforestation too is associated with urban development. Decrease in green spaces of cities also is a problem if urban planning is not properly carried out.

Figure 4-17: The towns of Faro (a) and Albufeira (b), Algarve

(www.observatoriodoalgarve.com/cna/noticias_ve), (www.tripadvisor.com/Hotel_Review-g189112-d286...)

4.1.2. Pressures

Pressure with respect to eutrophication in the Ria Formosa has different forms. It can be in the form of domestic sewage containing organic matter, fertilizer-laden run-off from agricultural fields and feedlots, as well as sediments on which chemical elements are adsorbed. All these forms end up in nutrient enrichment that enhances a profligate algal growth and other symptoms of eutrophication in the lagoon. One additional pressure on the lagoon has been parasitic infection of clams.

Several studies have shown that the Ria Formosa is enriched annually with nutrients originating in the four major categories of socio-economic activities discussed earlier.

Agriculture and Golf courses use fertilizers and release nutrients. Animal rearing releases organic matter and nutrients in the manure. For example, the intensive agriculture of Campina de Faro and Campina da Luz, the golf courses of Quinta do Lago ,the chicken farm at Aviludo and pig and livestock farms are some of those responsible for producing this pressure. Thus released nutrients find their way in to the lagoon as run-off.

The load of nitrogen in to the Ria Formosa from agriculture, forest and other vegetation is 1060 t /yr (Ferreira et al., 2006). Furthermore, Nobre (2009) estimated a diffuse load of about 4000 t/yr of N and about 2700 t/yr of P originating in both agriculture and livestock in the period between 1980 and 1985. Likewise this author estimated~2450 t/yr of N and ~1500 t/yr of P to enter the Ria Formosa from the same diffuse source between 1995-99. The main source of silicate in the Ria Formosa appears to be a flux from the inner lagoon sediments in the summer months and freshwater inputs during the rainy season (Newton et al., 2003, Newton, 1995; Cited: In Newton & Mudge, 2005) which reaches 761 µM m^{-2} d^{-1} (Falcão & Vale, 1990).

Aquaculture has its own significant contribution to the pressure of nutrients and organic matter. The organic waste from the shellfish farms, artificial food leftovers, faeces and excreta from the finfish cultures are the sources of these pressures. Disturbance of sediments by trawling allows re-suspension in the water column. Fish discard could also be an important source of pollution to the lagoon. Though shellfish farming has a significant effect at reducing the pressure by grazing on phytoplankton, some of what was ingested is returned to the lagoon in the form of excreta. Thus Ferreira et al., (2007) estimate it to be 40%, which means only a 60% net removal of nutrients ingested as phytoplankton.

Though urbanization and tourism may have their own particular pressures on the lagoon, they have some common characteristics with regard to eutrophication. The development of infrastructures such as housing and waste water treatment plants, the demographic factors such as population increase accompanied by elevated waste production and the consequent load on UWWTPs are among these common features. With an increase in population during tourist seasons, besides the significant volume of sewage entering the Lagoon (both treated and untreated) the amount of food debris dumped on the beaches and other organic pollutant sources contribute their own share to the organic matter input.

According to the study by Wayland et al., (2008) the sewage treatment plants release 146 µM and 180 µM of ammonia to the river Esteiro da Maria Nova and Ramalhete channel respectively, which drain in to the lagoon. Similarly Phosphate from the former was 44 µM and the latter released 2.4 µM. Furthermore, World Bank (1993) indicated that approximately 400 metric tons of nitrogen/yr and 200 Metric tons of phosphorus/yr from domestic sewage and detergent are supplied to the lagoon (Cited in: Newton & Mudge,2005).With a triple increase in population during summer months, the figure may be elevated correspondingly. Nobre (2009) estimated the point source discharges from the UWWTPs in 1980/85 to be ~500 t yr^{-1} of N and 125 t yr^{-1} of P, and in 1995/99 to be ~500 t $yr^{-1}$of N and ~100 t $yr^{-1}$of P. The UWWTPs have reduced the organic load in the entire catchment but might have induced a localized increase of nutrient load in the vicinities of their outlet (Nobre, 2009).

Ferreira et al., (2003) showed that 421 tons of nitrogen and 83 tons of phosphorus per year were loaded in to the Ria Formosa originating from urban and industrial effluents (Cited in: Ferreira et al., 2006). However, the same authors claim that these figures represent only part of the total load of nitrogen and phosphorus which is 1028 tons and 164 tons per year respectively (Leote et al., 2008). According to Nobre (2009), the waste contribution of industry to the Ria Formosa in terms of BOD_5 was ~1880 BOD_5 yr^{-1} and~500 BOD_5 yr^{-1} in 1980/85 and 1995/99 respectively.

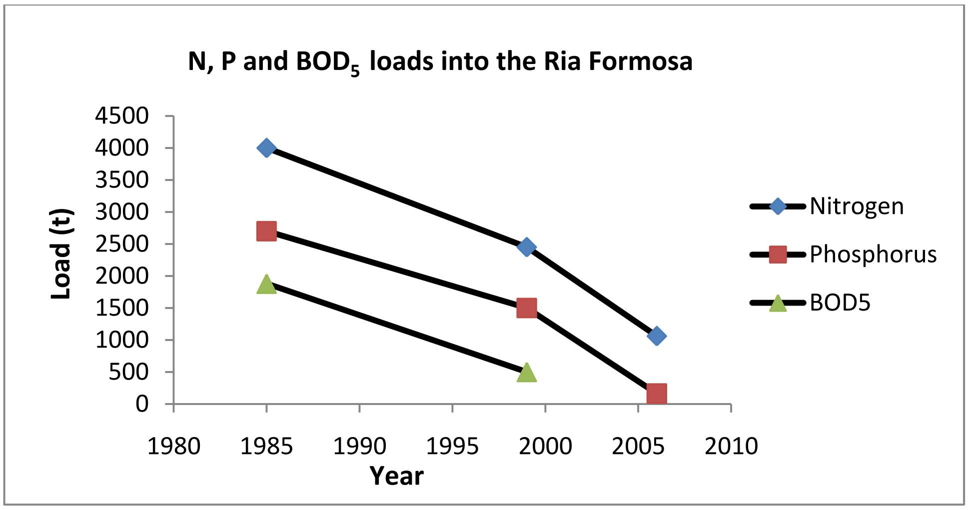


Figure 4-18: Pressure trend in to the Ria Formosa (Ferreira, 2006, Nobre, 2009).

Urbanization is usually accompanied by wetland reclamation and deforestation which has an impact on nutrient cycling. Nitrogen is fixed by bacteria in the soil and legumes of plants. The natural death of plants releases nitrogen in to the soil, which is eventually used by the living plants. This ensures the natural nutrient cycle. But deforestation, resulting in loss of riparian vegetation will disrupt this cycle. Moreover, atmospheric deposition of phosphorus due to biomass burning will decrease depleting the soil of this element. Runoff washes off all available nutrients and denudes the soil of its mineral content, while enriching the receiving water, i.e, the Ria Formosa. This results in an increased pressure of nutrient enrichment (Nitrogen and Phosphorus) in the lagoon.

Urbanization, agriculture and aquaculture seem to be closely linked. The population increase which is an integral part of urban development places high demands on agriculture and aquaculture. So, more food should be produced. This necessitates an increased use of fertilizers, increased number of food processing enterprises, artificial food for finfish farming and more area for aquaculture as a whole. All these factors lead to an increasing pressure on the Ria Formosa.

Figure 4-19: Faro Noroeste UWWTP releasing its effluent in to the Ria Formosa.

4.1.3. State

The state of the Ria Formosa lagoon has changed for the worse as a result of anthropogenic activities in the system and its catchment. Some authors (eg. Nobre,

2009) base this assumption on the abnormal clam mortalities due to parasite infection and on benthic eutrophication symptoms in specific problematic areas.

Nutrient concentrations exhibit spatial and temporal variations indicating the non-uniformity of the lagoon. The mean concentrations of DAIN fluctuate around 20 µmol dm^{-3} with greater concentrations in the eastern lagoon compared to the western, and this difference is greatest during the winter months, with concentrations in the eastern lagoon increasing up to 150 µmol dm^{-3} (Newton et al., 2003). Newton et al., (2003) further elaborate that the mean concentrations of phosphate are generally greater than 0.6 µmol dm^{-3} and, except in February, are always higher in the eastern lagoon compared to the western lagoon .The same authors indicated that during late spring and early summer months, the peaks being up to 1.4 µmol dm^{-3} decrease to below 0.8 µmol dm^{-3} during the late summer and early autumn. The concentrations of phosphate increase during the late autumn and the early winter, particularly, in the eastern lagoon where it increases up to 1.2 µmol dm^{-3} in November (Newton et al., 2003). With respect to silicate, Newton et al., (2003) showed that the mean concentrations are generally low for most of the year with an increase during the winter months to 80 µmol dm^{-3} in the western lagoon and a much greater 600 µmol dm^{-3} in the eastern lagoon.

Nobre (2009), based on ecological model results showed some problematic areas mostly in the eastern part of the lagoon which have shown benthic eutrophication symptoms, especially due to pressures from UWWTP effluent having their outlet in the vicinity. According to the author, while total biomass increases relatively little in response to nutrient load, the macroalgal growth of the larger mass class was from less than 50% to about 150%. This is an important result indicating that although the overall seaweed biomass does not increase significantly under higher nutrient loads, the larger algae, responsible for smothering of benthic fauna and seagrasses becomes important (Peckol & Rivers,1996; Cited in: Nobre et al.,2005).

Newton et al., (2003) using the criteria adopted by European Environment Agency (EEA) and United States National Estuarine Eutrophication Assessment (US-NEEA) reached contrasting conclusions on the eutrophication status of the Ria Formosa. The former suggests the usage of winter nutrient concentrations, chl-a and bottom oxygen

concentrations; and the latter makes use of only the eutrophication symptoms of chlorophyll and oxygen concentration for assessment. Thus on the basis of nutrient concentration the Ria Formosa was in a state of "Poor" to "Bad" (particularly in winter) according to EEA and almost pristine according to US-NEEA on the basis of chlorophyll and oxygen concentrations (Newton et al.,2003). Table 4-3 shows the EEA standard of nutrients for comparison with nutrient concentrations obtained at different seasons in the Ria Formosa.

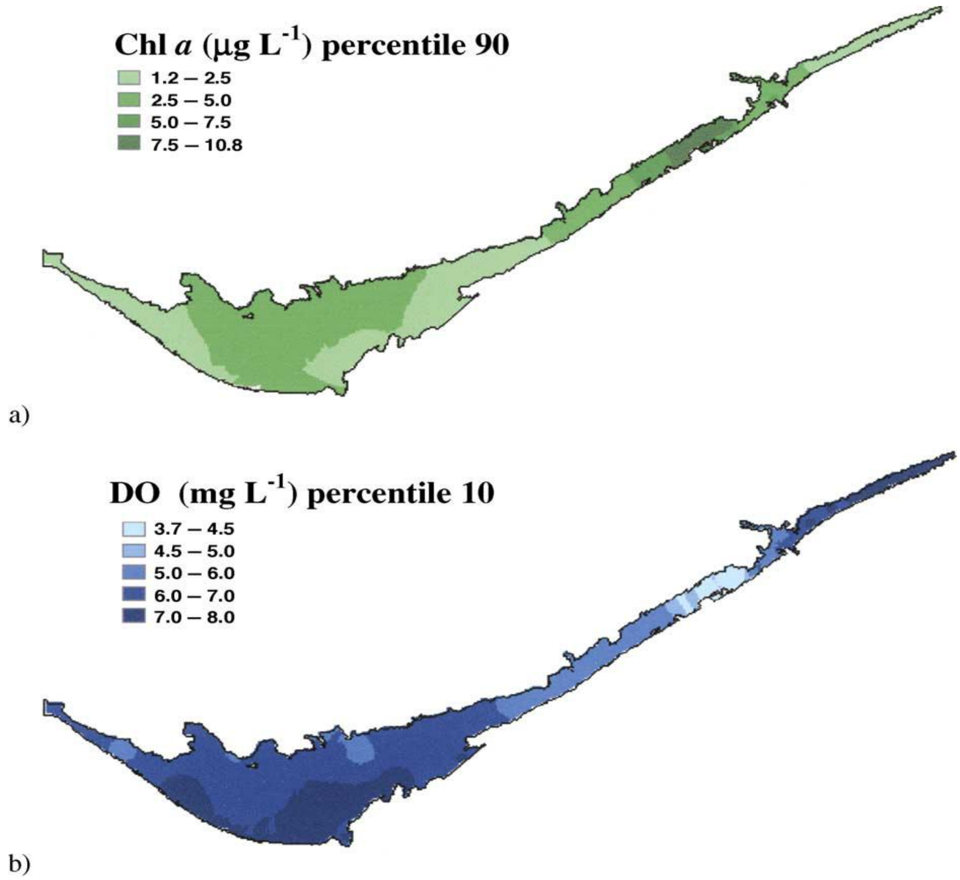
Table 4- 3: Nutrient quality standard of Transitional, Coastal and Marine waters (EEA,1999)

Quality	**Nitrate+Nitrite** (µmolL^{-1})	**Phosphate** (µmolL^{-1})
Good	< 6.5	< 0.5
Fair	6.5-9	0.5-0.7
Poor	9-16	0.7-1.0
Bad	>16	>1.1

The mean values of chl-a are in the range of about 2–3 µg dm^{-3} and 90% of the measured oxygen concentration values showed 90% saturation in the Ria Formosa indicating the near pristine condition according to US-NEEA criteria (Newton et al., 2003). However, a morning oxygen sag (48% saturation) and afternoon super-saturation, especially during the summer months was observed (in 1995) but no anoxic bottom water layer was found except for ephemeral stratification at the seawater inlets and near the mouth of the river Gilão (Newton et al., 2003). A recent study by Newton et al., (2009) revealed a night DO sag and regular early morning hypoxia (< 2 mg/dm^{-3}) in the inner lagoon near the city of Faro.

Nobre et al., (2005) state that the Ria Formosa has a short water residence time with no apparent eutrophication symptoms in the water column, but benthic symptoms are expressed as excessive macroalgal growth and strong dissolved oxygen fluctuations in the tide pools. According to Baptista (1993, Cited in: Newton et al., 2003) some evidences show an increasing incidence of harmful algal blooms.

Fig 4-20 below shows chl-a concentration ranging from 1.2 to 10.8µg L^{-1} and oxygen concentration ranging from 3.7 mg L^{-1} to 7.8 mg L^{-1}.



4-20: Interpolated surfaces indicating chlorophyll-a and Oxygen concentrations: (a) chl-a—90 th percentile; (b) dissolved oxygen—10 th percentile (Nobre et al., 2005).

Moreover, Ferreira et al. assessed the eutrophication status of the Ria Formosa by means of the ASSETS screening model, and a grade of Moderate Low, which corresponds to a Water Frame work Directive (WFD) classification of Good, was given on the basis of data collected over a number of years for primary and secondary eutrophication symptoms.

Table 4-4: Summary of the State of the Ria Formosa

Nutrient concentration (µmol dm^{-3})		**Chl-a conc.**	**DO conc.** (mg L^{-1})	**DO saturation**	**Macro algal growth** (larger class)
DAIN	20-150	1.2-10.8 µg L^{-}	< 2 – 8.0	48% - 140%	50% -150%
Phosphate	0.6-1.4	-	-	-	-
Silica	35-600	-	-	-	-

4.1.4. Impact

4.1.4.1. Ecological Impact

According to several authors (eg. Nobre, 2009, Newton et al., 2003) the most important ecological impact associated with bacterial infection enhanced by deterioration of water quality in the Ria Formosa is clam mortality. The local clam species of *Ruditapes decussates,* which constitutes 80-90% of the national production drastically decreased from 1980s (Azevedo,1989, Bebiano,1995, Newton et al., 2003) on wards and only recovered somewhat in 2005 (MADRP,2007). The decrease of bivalve production was from 3-4 kg m^{-2} to 500 g m^{-2} and the concurrent increase in bivalve mortality was 50%, (Bebiano, 1995).

Nobre (2009) attributes the clam mortality, in addition to the bacterial infection and low dissolved oxygen (DO) that enhances the disease, to benthic eutrophication symptoms; but suggests more research to establish a link between the introduction of the Japanese clam *Ruditapes fillipinarium* and the appearance of the parasite. Additionally, fish kills occur with increasing frequency in the summer months (Newton et al., 2003) probably due to harmful algal blooms and low DO.

In addition to actual impacts observed so far, the potential impacts if eutrophication intensifies are oxygen depletion, decrease in water clarity, and adverse habitat change resulting in loss of biodiversity in the lagoon.

The losses of ecosystem goods and services are revealed in lower clam production, lower fish catches, decreased nutrient removal capacity of bivalves, lowered oxygenation of the lagoon and less provision of nursery habitat for juvenile fishes by seagrasses. All these losses are linked with the consequent socio-economic impacts.

4.1.4.2. Socio-economic impact

Nobre (2009) using a differential DPSIR approach estimated the economic loss in the Ria Formosa due to anthropogenic activities (1985-95) to be between €315 million and €565 million. Similarly for three time periods between 1980-1999, the economic loss was estimated by the same author to be from €502 million to €752 million. Out of this €299 million constitute a negative change in the economic value of the economic activities (Drivers). The rest (€202.9M - €453.7M) was in the form of responses.

Taking into account the fact that about 10,000 individuals representing 5000 families depend on aquaculture and fishery in the Ria Formosa, the socio-economic effect created by a continuous decrease of production is considerable. When seen on a wider perspective the decrease in the Ria Formosa’s clam production which covers 80-90% of the total bivalve production of the country produces a significant economic impact on the nation. According to Campos and Cachola (2006) most of the production is exported to western European countries, especially to Spain. The presence of occasional harmful algal blooms and other pollutants associated with fish kills is another source of concern for economic loss.

The effect of the deterioration of water quality due to nutrient enrichment can reveal itself in the loss of tourism too. The economic trend in the region of Algarve is seen in shrinkage of the primary sector (Agriculture) and expansion of the tertiary sector (Services and Commerce) (INE, 2007). This trend owes its existence to the expanding tourist industry. So, loss of tourism will have a tremendously grave impact on the economy of the region and the country. The obvious social impact is loss of jobs associated with decreased production both in aquaculture and fisheries while health problems are the possible results of algal blooms. For example, dinoflagellate biotoxins were found to be accumulated in Donax clams harvested at Fuzeta resulting in human intoxication (Vale & Sampayo, 1999).

4.1.5. Responses

4.1.5.1. Earlier responses

In tackling the actual and potential problem of eutrophication and clam mortality due to bacterial infection, various responses have been made. Most of the responses were against the pressures, i. e. nutrient enrichment. Nobre (2009) mentions the Management Plan of Ria Formosa Natural Park as having several actions aimed at reducing nutrient enrichment and protection of the aquatic resources. These include: load reduction, industrial process improvement, aquatic resources quality improvement, sustainable tourism, environmental education, technical and scientific research, and agriculture-related actions. The cost of the actions adopted was estimated by Nobre (2009) at €175.9 million.

One of the load reduction methods was the construction and upgrading of UWWTPs. These infrastructures certainly reduce the organic and nutrient load into the lagoon, though localized nutrient enrichment is observed. Upgrading UWWTPs to have a tertiary treatment unit as suggested by Newton et al., (2003) removes much more nutrients. Dredging has been performed which improves the tidal dilution and flushing of nutrients by deepening the channel (Newton & Mudge, 2005). Further, the opening of a new inlet in the west of the lagoon encourages the tidal exchange of phytoplankton between the lagoon and the adjacent coastal waters. Dredging enhances this function. However, according to the same authors, dredging has shortcomings of mobilization of nutrients and metals found in higher concentrations in the sediment. Moreover, it can physically damage important components of the ecosystem such as seagrass beds and clams: it can also increase turbidity temporarily (Newton & Mudge, 2005). Therefore making a balance between the losses and gains would be necessary before taking this management option. It would also be necessary to know where to use this method and where not to.

For reducing clam infection intensities and prevalence, different management options were suggested by Nobre (2009). They were; good screening of seed infections and buying certified seeds, improvement of DO condition (by reducing nutrient load) in clam beds and lowering population densities of clams. The economic value of these responses over a 10 year response implementation period was estimated to be €376,500. Furthermore, the Portuguese fisheries authorities regularly inspect the bivalves for toxins from blooms of harmful algae, which are sometimes detected, especially during the autumn (Edwards et al., 2005).

Newton et al., (2003) suggested a number of recommendations in relation to monitoring of the Ria Formosa. They were: establishment of an appropriate monitoring network for the ecological and chemical status of the lagoon by the national and regional authorities. The parameters (indicators of eutrophication) to be monitored were nitrogen, phosphorus, DO and chl-a. Additionally, Monitoring of the abundance of epiphytes and macroalgae, loss of submerged aquatic vegetation and appearance of toxic algal blooms was suggested. Measurement of biomasses and species composition of phytoplankton, macrophyte, macrozoobenthos and their depth distribution are features to be included in the monitoring programme. A regular monitoring of at least a 5-year period for trend analysis was also recommended.

In line with this, some measures have been taken. For example, the project "Monitoring Plan for Water Quality and Ecology of Portuguese Transitional and Coastal Waters", or MONAE, was financed by the Portuguese Water Institute, INAG, and carried out by an interdisciplinary team drawn from marine science and management experts in the E.U., U.S. and South Africa (Ferreira et al., 2006).

4.1.5.2. Recommendations

Important responses have either been made or planned. Useful management options have been suggested and scenarios simulated. Several studies on the Ria Formosa have been concluded with valuable recommendations. What might be lacking could be the financial and institutional resources and the will to implement the plans. The following recommendations are not replacements to the already adopted and suggested measures but rather complementary and reinforcing.

4.1.5.2.1. Agriculture/Livestock

Agriculture and livestock share the largest contribution of organic matter and nutrient enrichment to the Ria Formosa. So an effective Agricultural Waste (and runoff) Management Plan (AWMP) should be prepared. The planning process, while owned by the Ministry of Environment, Spatial Planning and Regional Development (MESPRD), it should involve MDARP, INAG, Portuguese Association for Water Resources

(APRH) and the property owners (Farmers and livestock raisers' representatives). Experts such as geologists, soil scientists, agronomists and engineers should be present in these institutions. Property owners should be convinced of both the environmental and economic implications of agricultural waste treatment.

The agricultural waste (and runoff) management system should be simple and easily managed.

- Use of constructed wetland is an environment friendly way of agricultural runoff management which greatly reduces nutrient load (Fig. 4-21).
- Use of Cover crops, Filter strips, Strip cropping and crop residue management prevent erosion and filter nutrients.
- Grazing management and usage of grassed waterways trap nutrients.
- Nutrient management encourages effective use of nutrients, thereby reducing unnecessary load.
- Simple aerobic or anaerobic ponds could be constructed at feedlots and dairy product processing enterprises for reduction of BOD_5 and nutrients.
- Larger stabilization ponds could be constructed serving a number of farmsteads to treat diffuse agricultural runoff (Fig. 4-22).
- The soil characteristics to remove organic matter, nutrients and metals through filtration, biodegradation and chemical reactions (adsorption, precipitation, complexation) should be considered when siting a waste management system
- The resulting biosolids could then be utilized in areas which need fertilizers. This reduces commercial fertilizer costs.
- Economic instruments of emission levels could also be imposed on agriculturalists and livestock raisers.

Figure 4-21: Constructed wetland (USDA-NRCS, 1999).

Figure 4-22: Waste storage pond; the shoreline and the reflective surface of the pond make it appear to be a traditional farm pond (US-NRCS, 1999). Properly managed, it can contribute to aesthetic beauty of the area instead of marring it.

4.1.5.2.2. Aquaculture, fishery and manufacturing/processing enterprises

- Economic instruments of polluter's pay principle and emission standards for nutrients, organic matter and metals should be applied by MESPRD.

- Both manufacturing and processing industries should have on site WWTPs at least on a primary level. This requirement should be imposed upon them by MESPRD.
- With respect to finfish and shellfish farming, cooperation with the two activities so that the waste produced by the former is removed by the latter should be encouraged. A common platform for negotiations could be found by forming associations of aquaculture farmers.
- Moreover, following the suggestion by Ferreira et al., (2005) practicing nutrient emission trade will be extremely useful. Figure 4-23 summarizes the benefits of shellfish farming. Research institutions can promote this possibility.

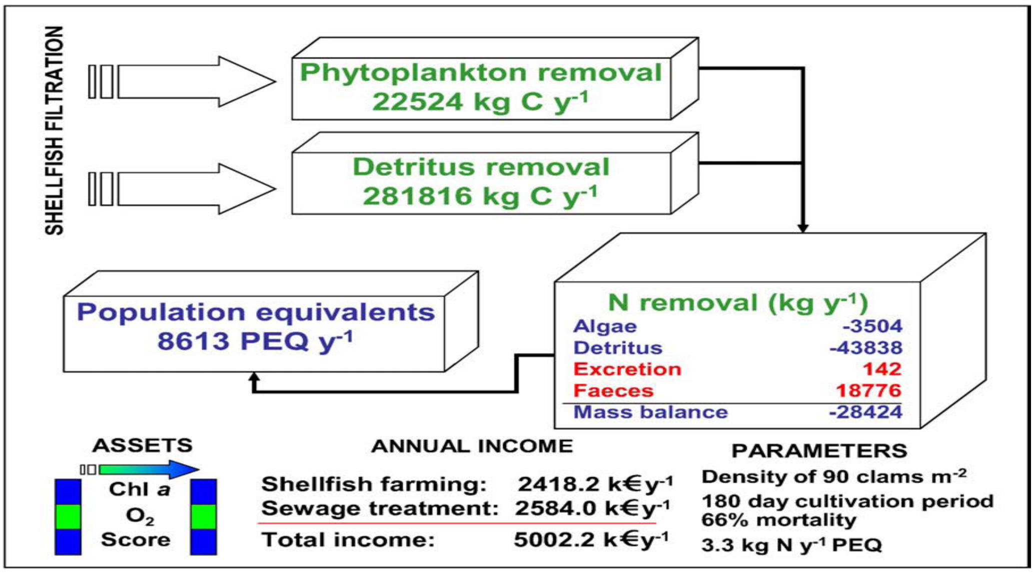


Figure 4-23: Mass balance and nutrient emissions trading for clam aquaculture in the Ria Formosa. (Ferreira et al., 2009).

Shellfish farming in addition to the economic benefits it provides saves sewage treatment costs. This nutrient removal capacity can be traded.

The study done by Leite et al., (2004) indicated that high salinity and temperature, high clam density per bed and importing clam seeds, features favouring the enhancement and the spread of the *Perkinsus. sp.* infection were observed in the Ria Formosa.

Therefore:

- Tightening the control on imported seeds and screening them for the presence of the causative agent should be practiced by Ministry of agriculture (MADRP) to reduce clam mortality.
- Decreasing density of clam beds by aquaculture farms reduces the occurrence of proximity infection. What should be noted here is that it is much better to produce healthy individuals in reasonably stacked beds than lose the greater proportion of the product due to infection.
- As pollution causes physiological stress and makes shellfish susceptible to infections, reduction of pollutant load is essential. The role of UWWTPs in this respect is indispensable. The responsibility rests with the municipalities and Aguas Do Algarve.
- It might be advisable to avoid seeds of *Ruditapes phillipinarium,* as this species is a known host for the *Perkinsus.sp*
- Using appropriate fishing gears discourages discarding of fish and prevents organic pollution resulting from decomposition of dead fish.

Environmental research and monitoring as well as awareness creation activities regarding the Ria Formosa should be a continuous process. So, the current monitoring programmes (eg. MONAE) should be strengthened. The monitoring could be done by the Portuguese Water Institute (INAG) as the owner of the monitoring project and various national and international institutions could be involved. These include the

University of Algarve and other national educational and research institutions. Training volunteers and school children for the simple, routine monitoring activities can also save resources and raise the environmental awareness of the community. Since the Ria Formosa falls under the EU-WFD, institutions from the other European countries can also be invited.

4.1.5.2.3. Tourism and Urbanization

Tourism, as a very important economic sector for Algarve, needs to be an activity that holds the sustainability of the environment in high priority. Its fate is closely tied with aesthetically sound environment. One such feature is the golf courses. But they require the use of fertilizers which in turn affects the coasts. So with respect to golf courses the recommendations forwarded for agriculture apply. The tourism office of the region should take responsibility for this.

Regarding the cleanliness of the beaches; provision of garbage bins, notices calling tourists to a responsible behaviour, monitoring and a bit of control organized by the Department of Investment, Trade and Tourism (DITT) of the region and the Nature Reserve authorities is necessary.

The increase in population during high tourist seasons with the proportional increase in domestic waste is a problem that should be handled by UWWTPs. Construction of adequate UWWTPs is the duty of the municipalities and Aguas Do Algarve.

One of the consequences of urbanization regarding eutrophication is elevated sediment load into the Ria Formosa. So, measures that reduce this problem should be sought. Urban parks, besides their aesthetic, recreational, psychological and economic benefits to the communities, they provide significant ecosystem services (Loures et al., 2007).

One such service is to reduce the urban runoff and increase the infiltration rate of the soil. This can be achieved by increasing green areas in towns and by constructing un-cemented cobble stone roads instead of concrete-asphalt streets. In this regard, the sole responsibility rests with the municipalities.

Even more important is the population increase with all its requirements. Its important aspect with regard to eutrophication is waste production from households and manufacturing and processing enterprises, which cater for the needs of the population. So, concerning the domestic wastes, providing adequate sewer system and UWWTP is the responsibility of Aguas Do Algarve and the municipalities. The enterprises should be convinced or legally forced by MESPRD to treat their wastes on-site to meet emission standards or else bear fines (Economic instruments).

4.1.6. Environmental Indicators

Indicators are values derived from parameters, which provide information about a phenomenon, and they should neither be too large to avoid cluttering the overview nor too few not to fail to provide sufficient information (OECD, 1993). Environmental indicators could be pressure or state indicators. Pressure indicator with respect to eutrophication is nutrient load expressed as Kg $ha^{-1}yr^{-1}$ or alternatively Ton yr^{-1} of N,P and Si. Some of the state indicators selected are concentrations of nutrients (N,P,Si) in µmol L^{-1}, chl-a (µg L^{-1}), BOD_5 (mg L^{-1}), DO (mg L^{-1}) or DO saturation (%). Algal cell count, biotoxins, turbidity for water transparency and weight measurements for clam production also are included in the indicator's list.

OECD (1993) elaborates that selection of indicators depends on policy relevance, analytical soundness and measurability. The selected indicators fulfill these functions. Chl-a, for example indicates the algal biomass that is exactly a direct result of eutrophication, namely, the appearance of phytoplankton, macro algae and possible algal blooms. DO, like wise is an excellent indicator of the degree of eutrophication, as its concentration is depleted proportional to the severity of eutrophication. Nutrient loading provides information about the nutrient enrichment of the lagoon and the likelihood of eutrophication. The other indicators, too, are useful in providing the necessary information of their own. All the indicators are fairly easily measurable and can be analyzed based on standards.

4.2. Systems Approach Framework (SAF)

4.2.1. Rationale

SAF was originally adopted for the 18 Study Site Applications (SSAs) in the SPICOSA project. The Ria Formosa, however, is not part of this project. Still, this approach can be used in other coastal areas as well as other natural water bodies.

The Responses in the DPSIR framework are forwarded in the form of recommendations to the policymakers so that they are implemented. But SAF simulates different management scenarios and demonstrate to policy makers what occurs if these management options are taken. Presupposing what kind of policy decision to take is not its objective (SPICOSA-WP3, 2007).

So, as DPSIR was used to come out with recommendations for the management of eutrophication in the Ria Formosa, SAF can be used for finding several management options and simulate several management scenarios using appropriate model to demonstrate their outcome.. The final management decision rests with the policy makers.

Nevertheless, the scope of the present study is merely to indicate the use of SAF for the eutrophication management in the Ria Formosa. As such it does not attempt to formulate and run any model and does not simulate management scenarios. At best, it identifies stakeholders, drivers, issues and suggests management options as bases for scenarios and describes the various steps of SAF in relation to the Ria Formosa and provides examples of these steps as were conceived by the SPICOSA project.

4.2.2. System Design

As explained earlier, the first step in SAF is System Design. System design step, in turn, contains five sub-tasks. They are Issue resolution, System definition, Conceptual model, Methods & Information requirement and Problem scaling.

4.2.2.1. Issue resolution

4.2.2.1.1. Stakeholder mapping

The stakeholder mapping consists of identification of the stakeholders in a given coastal zone area and the way these stakeholders relate to one another, and the subsequent analysis of the way in which stakeholders relate to the issues (SPICOSA-WP1, 2007). As management of the coast is linked to managing the coastal uses of the society, the success of coastal management depends on the support and participation of the stakeholders who have a direct or indirect interest in actions or decisions. Therefore, inclusion of all stakeholders and addressing all the key policy issues pertaining to coastal zone is of paramount importance in ICZM.

The active involvement of the community and stakeholders at an early stage of ICZM provides local knowledge, encourages dialogue, fosters support and raises awareness of the programme, the outcome of which provides decision makers with a clear overview of the nature of the human and physical coastal environment, the urgency of the issues to be resolved and the limitations of the contemporary management regime (Cummins et al., 2003).

Stakeholder mapping calls for process legitimacy, process efficiency and transparency with respect to identification of both stakeholders and policy issues (SPICOSA-WP1, 2007). Process legitimacy refers to the fact that all stake holders and their concerns are included. Process efficiency, similarly, refers to that, that all resources having information are used and no key policy issues are left out. Transparency emphasizes on that all information are shared and no policy issue is hidden.

4.2.2.1.2. Stakeholders

Agricultural farmers, animal raisers, fishermen and aquaculturists, tourists and local inhabitants are the major stakeholders. Institutions concerned are different government, educational and private institutions with the management and control of the economic activities and the environment. Additionally research institutions are among the stake holders.

Hence, the Ministry of Agriculture (MADRP) and its regional branch (DRAP-Algarve), Nature Reserve, the Department of Investment, Trade and Tourism (DITT), Tourism operators, the Ministry of Environment, Spatial Planning and Regional Development (MESPRD), Municipalities, Aguas do Algarve, The Navy, Maritime Department (DMS), office of the Port of Faro (CPF), Portuguese Water Institute (INAG), Portuguese Association for Water Resources (APRH) and the University of Algarve (UAlg) are included.

The basis for choosing these stakeholders is the obvious influence they have on the lagoon by their economic, administrative and academic activities. Once these stakeholders are identified a forum for consultation by means of workshops, formal and informal meetings can be arranged.

4.2.2.1.3. Roles and views of Stakeholders

As Table 4-5 below summarizes, agriculturalists/animal raisers are beneficiaries of their activities as the lagoon is a sink to their waste. Aquaculturists, on the other hand, have initially benefited until deterioration of water quality caused a decrease in production of seafood. Tourists, likewise, benefited as the luxurious golf-courses were constructed which needed artificial fertilizers and there was plenty of seafood to consume. But, as the water quality deteriorated and there was some poisoning of seafood, they turned in to victims. The same can be said of the urban population.

The relationship among the various stakeholder groups is defined. The world view that governs economic groups is maintaining livelihoods and making profit. The government offices are more concerned with regulation and management. The world view of the scientists is sustainable utilization of natural resources. Therefore, concern about the consequences of eutrophication forms the core of their worldview.

The group of scientists conducting this study and MESPRD are the owner of the policy issue (eutrophication) and the world view about eutrophication is chosen to be that of these owners. In assigning the roles to the stakeholders, the view of the scientists and the Environment ministry is taken as a basis to give a context to the transformational process of eutrophication. This is in consideration of the vast, objective knowledge and understanding this group has on the phenomenon, the impartiality of its stand and the position it has as a policy owner.

Table 4-5: CATWOE in the Ria Formosa, relative to eutrophication.

C	Customer	**Beneficiaries** - Agriculturalists/Animal raisers - Aquaculturists - Tourists	**Victims** - Anglers - Tourists - Aquaculturists -Seafood consumers
A	Actors	• Agriculturalists • Aquaculturists • Tourists • Urban Population	
T	Transformational Process	Nutrient input leading to Eutrophication	
W	Weltanschaung	Consequences of Eutrophication	
O	Owners	MESPRD & Research Institutes	
E	Environmental constraints	Climatic factors (Flood, Sunlight etc…)	

4.2.2.1.4. Institutional map

SPICOSA-WP3 (2007) suggests the identification of the main property rights and governance structure related to the policy issue and making institutional map. The agricultural, fishery and aquaculture sectors belong mainly to private ownership but the governance rests with MADRP, particularly to DRAP-Algarve. The environmental governance is the domain of MESPRD and Nature Reserve. The Naval office, the DMS and CPF are concerned with naval activities and port development. Tourism activities are exercised by various tourism operators but regulated by DITT. Urban development lies in the realm of the municipalities. Research and educational institutions (INAG, UAlg, APRH etc...) play the roles of consultants on environmental issues.

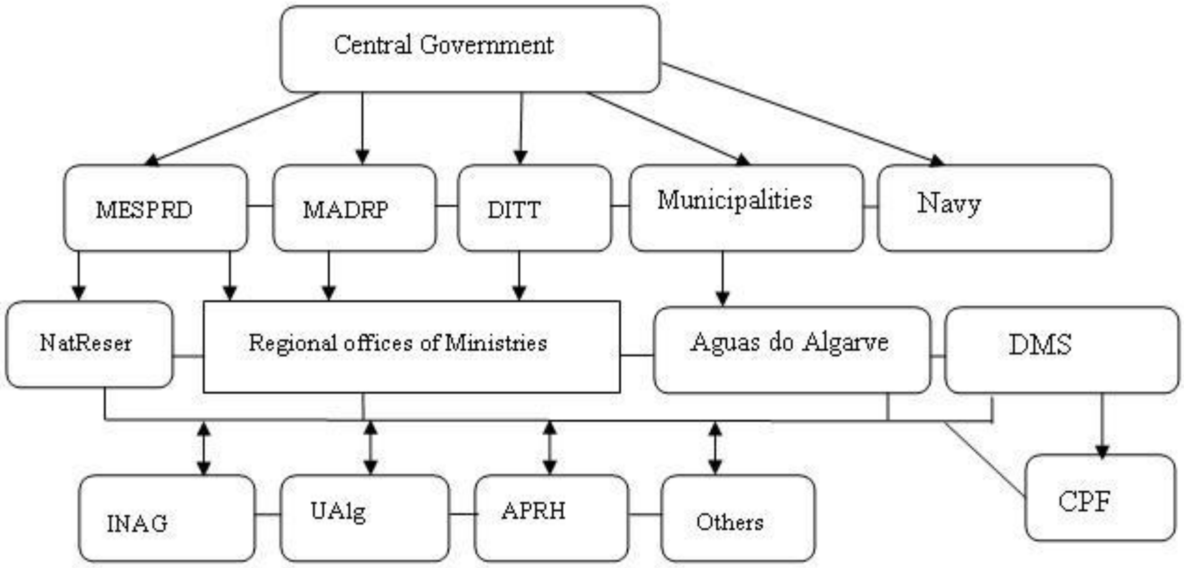


Figure 4-24: Map of the stakeholder institutions.

As is evident in Fig. 4-24, the institutions under the central government and their regional offices are regulatory bodies of the economic activities and environmental aspects. They interact among themselves. The research and educational institutions, acting in the capacity of consultants interact with the regulatory entities and among themselves. Due to shortage of data, public institutions such as trade unions and professional associations related to the economic activities are not included. In the presence of these entities, interaction with the regulatory bodies and the consultancy groups is obvious.

4.2.2.1.5. Economic activities

The major economic activities in the Ria Formosa are Agriculture and Livestock, Aquaculture and Fishery, Tourism and Urbanization. Though data on the full economic values of these activities in the Ria Formosa is unavailable, INE (2007) states that 9148 tons of cereals, 210,000 tons of citrus fruits, 15,824 tons of fresh fruits and 1785 tons of nuts were produced in the Algarve region. As described in the previous chapters, the total heads of livestock in Algarve ranges from 10,000 to 60,000 in 2008. About 5356 tons of aquaculture products were harvested from the Ria Formosa in 2005. More than 2 million tourists visit this region annually.

The negative externalities envisaged within the Ria Formosa are the costs associated with loss of shellfish products caused by parasitic infection and benthic eutrophication symptoms. Response costs, for instance, those of UWWTP construction also are counted towards externalities. The latter cost was estimated by Nobre (2009) to be €176M in 1980-99.

Several methods of economical valuation of ecosystem goods and services are used by several environmental economists. Travel cost method; hedonic valuation and stated preference are the common examples. In the absence of sufficient data, the value of economic activities (Drivers) that depend on the ecosystem can be approximated (Nobre, 2009). It gives the partial ecosystem value (PEV). In relation to the economic analysis of management scenarios, cost-benefit analysis (CBA) will be used.

4.2.2.1.6. Policy issue

There are a number of multiple issues requiring attention in the Ria Formosa (e.g. tourism, erosion, fishing, aquaculture, salt production, eutrophication, etc…). In this study, it was not possible to go through all of the SAF's steps of issue resolution due to time limitation of the project. Therefore, eutrophication was chosen as an example to show the usage of SAF for eutrophication management.

The symptoms of eutrophication have been reported to appear in the Ria Formosa. Macro-algal growth, occasional appearance of toxic algal blooms and fluctuation in oxygen concentration are among the symptoms. The symptoms are associated with nutrient enrichment from the identified economic activities and UWWTP out lets. The impacts of deteriorated water quality are revealed in fish kill, decrease in shellfish production as well as shellfish and human poisoning due to HAB.

To add impetus to the collaborative process among the stakeholders to agreeing on issues, assistance from European directives and treaties that have been transposed into the country's laws and regulations can be sought. Water Framework Directive (WFD), the Nitrate Directive (ND) and Urban Waste Water Treatment Directive (UWWTD) are among these.WFD aims to achieve European waters of good ecological quality by 2015. The ND has the objective of reducing water pollution caused by nitrate from agricultural sources. The UWWTD stipulates the provision of UWWT facilities to urban areas based on population and the sensitivity of the receiving waters to eutrophication.

Therefore, the issue for consideration was chosen to be **eutrophication**.

4.2.2.1.7. Scenarios

The main concern in the eutrophication of the Ria Formosa is nutrient load. So the objective of the management should be **nutrient reduction**. Therefore, scenarios based on the following policy options will serve this purpose:

- Do nothing
- Construction of UWWTPs of varying technical status. This includes from primary to tertiary UWWTPs.
- Installing Agricultural runoff management system (Constructed Wetland, Strip cropping, Filter strips, Nutrient management).
- Making AWMS of varying scale, capacity and type. Scale refers to AWMS on a farm or at the community level. Capacity refers to the size of ponds to be constructed, and type indicates whether the ponds are aerobic or anaerobic.
- Using economic instruments (Polluters pay principle) is important management option which encourages economic actors to treat their waste and initiate nutrient trade.
- Policies aimed at change of Drivers can also be considered. These could include, for example, arresting urban development close to shores or decreasing areas of finfish farming.

The views of different stake holders on the management options vary. For example, the farmers and livestock raisers might be concerned with the cost and feasibility of AWMS as well as with the economic instruments. Finfish farmers, besides the economic instruments, might be worried about the reduction of finfish farming areas. Discouragement of Golf course development could disconcert tourism operators whereas arresting urbanization might worry municipalities. However, negotiation is the key to overcome such concerns. The agriculturists and livestock raisers might be encouraged by the prospect of turning waste in to money (selling manure as organic fertilizers). Nitrogen trading could be a consolation to finfish aqua-culturist.

4.2.2.1.8. Indicators

The possible indicators of the success of the policy responses are the environmental indicators of change in the Pressure and the State. So, the following indicators should be selected:

Table 4-6: Selected indicators (Source: OECD, 1993, EEA, 1999, EEA, 2001)

Environmental Indicators	
Pressure	***Indicator***
Nutrient Enrichment	N,P,Si (Load)
State	***Indicator***
Nutrient Concentration	N,P,Si
Organic Pollution	BOD_5
Algal Biomass	Chl-a
Algal Abundance	Cell count
Macro algal growth	Area cover, % increase
Oxygen Concentration	Dissolved Oxygen (DO)
Toxic Blooms	Biotoxins, Cell count
Species composition	Cell count
Water Transparency	Turbidity, Secchi depth
Shellfish, Finfish Production	Kg/Ton

4.2.2.2. System Definition

The extent of the Ria Formosa has already been described in the previous chapters. But to put it very briefly, it extends to about 55 km in length and 6 km in width at its widest point. It is a shallow mesotidal lagoon with natural biogeochemical cycles essentially regulated by tidal exchanges. The lagoon is a true barrier island system, comprising mainland, inlet deltas, and barrier islands. It covers 163 km^2 of area 20 km^2 of which are occupied by salinas and aquaculture ponds.

The Ria Formosa is subject to eutrophication due to the four major economic activities identified. Whereas fishery and aquaculture are practiced right in the lagoon, agriculture and livestock are activities done outside of it. Finfish farming supplies nutrients to the lagoon while shellfish farming both supply and removes nutrients from it. Agriculture and livestock contribute the greatest share of nutrients to the lagoon. Tourism affects the lagoon directly, for example, through boat trips (including bird watching), recreational fishing and swimming; and indirectly by increasing pressures on the UWWTPs. Urbanization likewise has a direct influence on the Ria Formosa by enriching it with domestic sewage, sediments and construction debris, and indirect influence by increasing the population of town centers. The increase in population is accompanied by an increased food demand including seafood and an increased waste load.

The Ria Formosa is much affected by what is occurring outside of it, namely, by runoff due to a few torrential streams and the perennial river Gilão, by increased tourist population which augmented the load of waste. Urbanization exerts similar pressures on the lagoon. It has important interactions with the coastal water with respect to tidal flushing and nutrient exchange. Therefore, the catchment of the Ria Formosa around the town centers and the Atlantic coast form its system boundary conditions.

4.2.2.3. Conceptual model

In the SPICOSA project conceptual models are constructed using the EXTEND modelling software. However, in this study the software used to make the conceptual model is Adobe Illustrator version CS4. SPICOSA states some of the reasons to use EXTEND as its ability to turn conceptual models in to numerical models and for easy communication among SSAs and other researchers by using the same modelling software and symbols. However, the purpose of the present study is not to actually formulate and run a numerical model, but to show that eutrophication can be managed through SAF. So, as long as the conceptual model is sufficient to qualitatively convey what is happening in the system and show relationships among the important components of the system, it is considered sufficient.

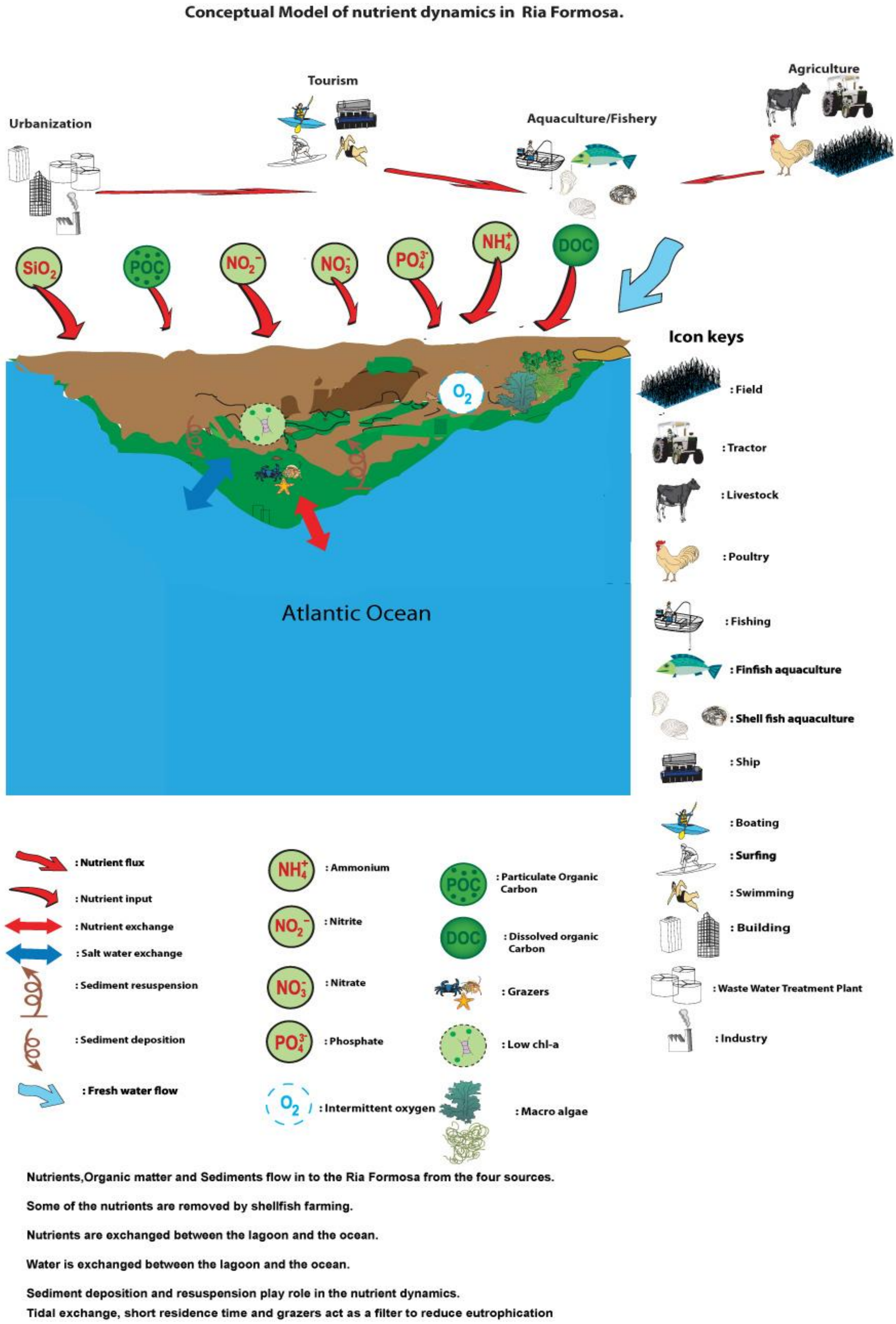


Figure 4-25: Conceptual model of nutrient dynamics in the Ria Formosa.

4.2.2.4. Methods and Information requirement

Information about the Ria Formosa was obtained from published literature. The literature includes scientific studies about the environmental and socio-economic aspects of the lagoon, and statistical data published by the Institute of National Statistics (INE).

SPICOSA-WP3 (2007) elaborates that for constructing mathematical equations from the conceptual model, for solving these equations and to make a numerical simulation, methods are needed. The standard method in the SPICOSA project is EXTEND. Nevertheless, as the scope of this study does not stretch to the extent of making and running a model, there was no need for choosing such methods. Instead, a few mathematical models used by different modellers are shown to illustrate system formulation.

4.2.2.5. Problem scaling

It is believed that the conceptual model corresponds to the actual coastal system and includes all the necessary functionalities with respect to nutrient loading and eutrophication. This does not mean, however, that iteration is excluded. Depending on the level of information obtained on the lagoon and its boundary conditions the conceptual model can be improved.

Effort has been exerted not to complicate or to oversimplify the conceptual model. Appropriate scaling of the system and the scope of the task was crucial as the time and resource constraints are limiting. So, the current conceptual model does not include all the environmental and socio-economic features of the system but the major ones.

Conversely, it does not exclude the necessary environmental features, socio-economic activities and stakeholders. Most importantly, the study does not make any attempt at quantifying state variables by using models.

4.2.3. System Formulation

The conceptual model of the Ria Formosa can be formulated into a mathematical model by incorporating the necessary inputs in to the model. The features needed for evaluation of the system through modelling are nutrient loading. Algal biomass and abundance; Dissolved oxygen concentration and saturation as well as species composition (biodiversity) are among the important features. The actions of grazers, tidal exchange and residence time can also be included, for they influence the extent of eutrophication by acting as filters. The sedimentation and re-suspension also have a considerable significance in the nutrient dynamics. These features belong to the ecological and physical aspects of the Ria Formosa.

For determination of nutrient loading; flow rate of runoff in to the system and nutrient concentration in the runoff are the necessary inputs. The evaluation of algal biomass needs parameters such as light, nutrient and algal growth rate as inputs. Grazing rate and hydrodynamic characteristics of the lagoon (tidal range, flushing volume) are the necessary inputs for the determination of the influences of filters on eutrophication. Sedimentation and re-suspension rates are parameter inputs for simulation of sediment dynamics.

With respect to socio-economic aspects, economic activities in the system such as aquaculture and fishery, that part of tourism which has a direct impact on the system (recreational boating, swimming and fishing) should be considered. Agriculture, urbanization and waste production from tourism that act on the system boundaries as well as employment and impact on human health are included. But care must be taken not to clutter the model which renders it unnecessarily complex. The outputs of the evaluation are envisaged to be management options that will be suggested to policy makers.

The necessary equations and symbols to be used in the simulation model are chosen and adopted in this step. Some symbols mentioned by SPICOSA are shown here (Fig. 4-26).

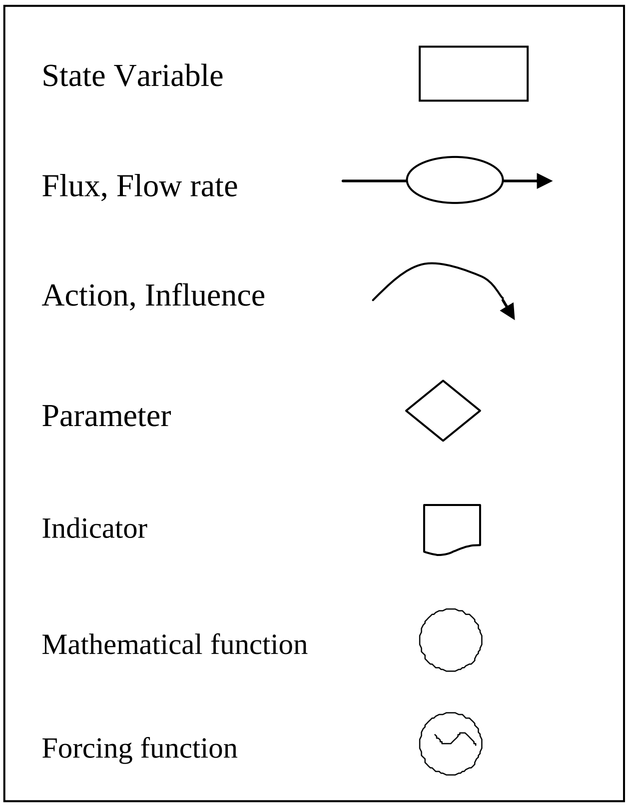


Figure 4-26: Symbols used in some graphic software (SPICOSA-WP4, 2009).

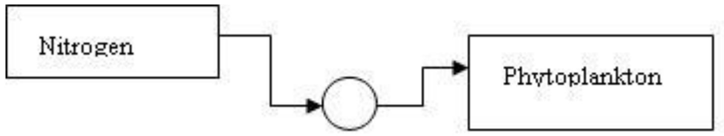


Figure 4-27: Conceptual mass flow model of phytoplankton growth (SPICOSA-WP4, 2009).

The conceptual mass flow model (Fig. 4-27) can be formulated in to a mathematical model of phytoplankton dynamics as is presented below:

dPhytoplankton/dt_ = $[k_{max}$ x (Nitrogen/k_N + Nitrogen) x (Light/k_L + Light)] x

Phytoplankton – (v/h – m_A– g x Clams) x Phytoplankton

Where the parameters:

k_{max} = Maximum growth rate of Phytoplankton (gram carbon per m^3 per month)

k_N = half saturation constant of the nitrogen limited algal growth (gram nitrogen m^{-3})

Light = Light incidence (W m^{-2}), forcing function

k_L = Half saturation constant of the light limited algal growth (W m^{-2})

v/h = Sedimentation of detritus and of the dead fraction of the phytoplankton (m per month)

mA = Mortality rate of the phytoplankton (per month)

g = Grazing factor of clams on phytoplankton (gram carbon per m^3 per month)

After formulation of the mathematical model, Fig. 4-27 can be updated as in Fig. 4-28 below:

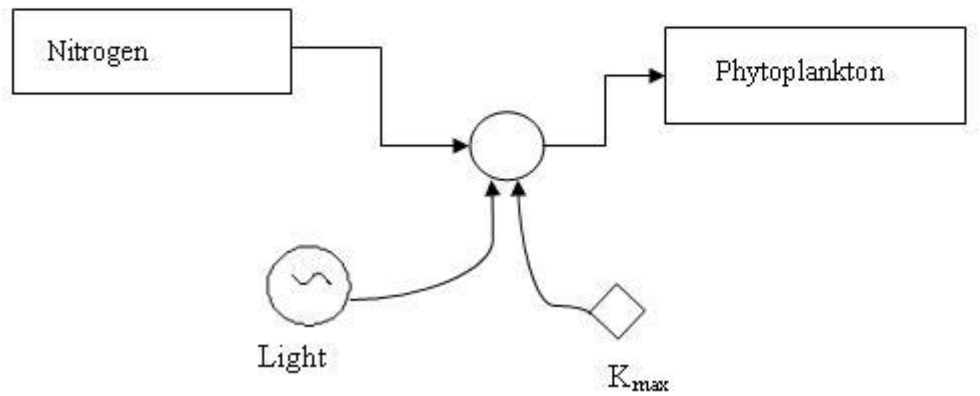


Figure 4-28: Updated conceptual mass flow model of phytoplankton growth (SPICOSA-WP4, 2009)

The ecological and economic sub systems then are linked. van den Bergh et al., (2006) stated that ecological- economic models usually describe a causal chain between socio-economic drivers that cause physical or ecological changes through polluting or resource harvesting (Cited in : SPICOSA-WP4,2009). So, a change in a socio-economic variable is linked to a change in physical variables; then the changes in the ecological system provide a feedback to the socio-economic system (SPICOSA-WP4, 2009). van den Bergh (2006, Cited in: SPICOSA-WP4,2009) further provides example of fisheries management in which fish catch reduces a fish stock which increases the harvest costs.

The benefits derived from the major socio-economic activities in the Ria Formosa and the costs on the ecosystem due to negative externalities can be quantified by coupling ecological and economic subsystems. Several material and energy flows exist between the ecological and economic subsystems in the Ria Formosa. Fisheries and aquaculture directly extract biological resources in the lagoon. Tourism and Urbanization likewise exert direct and indirect pressures on it. This utilization of resources (seafood, recreation) enriches the lagoon, in return, with nutrients and sediments. Agriculture draws on the lagoon water and supplies nutrients to the system.

The added value, revenues, employment and social welfare in general are the benefits whereas expenses incurred to remediate the deteriorated water quality, decreased production in aquaculture, loss of ecosystem goods and services are the costs. These are some of the inputs needed to model a coupled ecological-economic system.

SPICOSA-WP4 (2009) provided a pertinent example on economic-ecologic linkage that serves as an example for the interaction between these two sub-systems (Fig. 4-29).

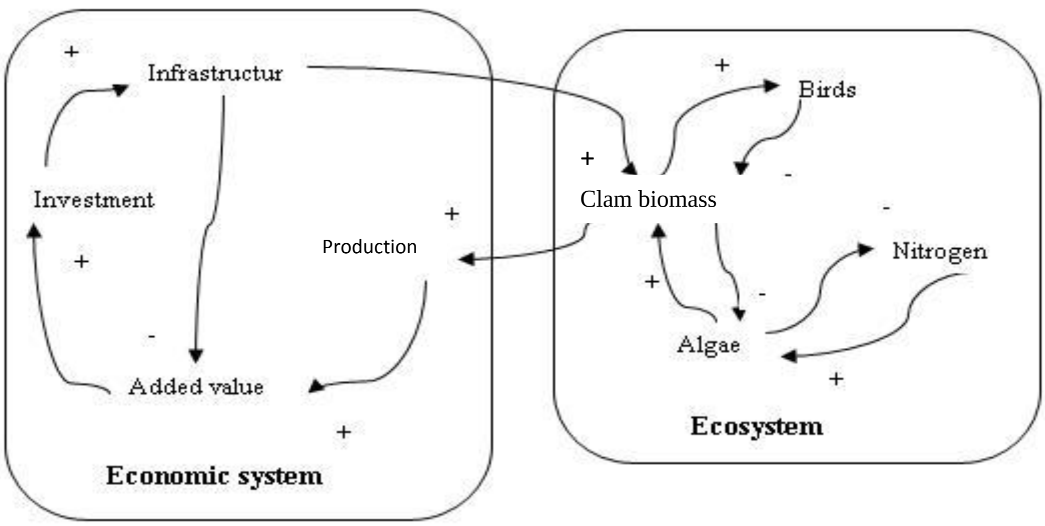


Figure 4-29: Feedback loops of Ecological-Economic models (Adapted from SPICOSA-WP4, 2009).

The economic and ecological systems show the flow of money and carbon respectively. At two points, flows cross the interdisciplinary model borders; the money flow enters the ecological subsystem where the infrastructure (the value of which can be represented in money) exerts a pressure on the clam biomass. The converter is efficiency to grow clams, the rate at which clam biomass increases. In the same manner, the carbon flow enters the economic model when clam biomass (ton of clams) is converted to money. The converter in this case is the price per ton of clams. A mathematical model is formulated out of this relationship. More elaborated economic feedback loop and updated conceptual model are also presented in the figures below (Figures 4-30 and 4-31) to serve as examples of formulation of economic models.

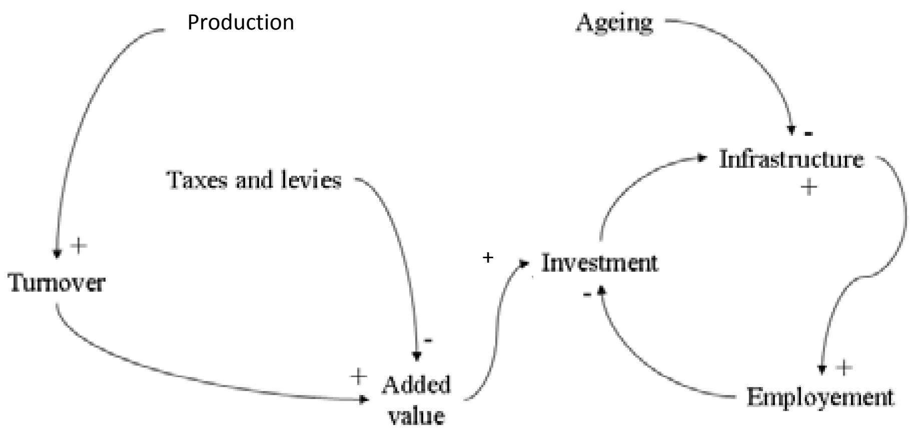


Figure 4-30 Economic feedback loop of clam farm (Adapted from SPICOSA-WP4, 2009)

The mathematical model:

dInfrastructure/dt = (k_1 X Turnover - k_2 X Infrastructure) - Infrastructure/L

Where: k_1= Tax rate (%)

k_2 = Employment per unit infrastructure.

L = Lifespan of infrastructure.

The mathematical model was updated in to the following conceptual model indicating the iterative nature of the systems approach.

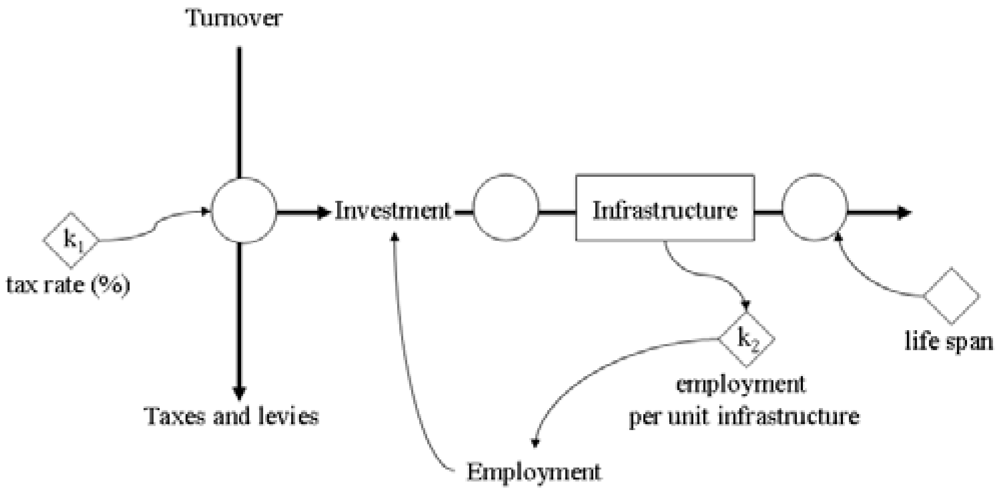


Figure 4-31: Updated conceptual model of clam farm (Adapted from SPICOSA-WP4, 2009)

Finally the model to run is determined. Any relevant and useful model can be used. For example, several authors have used different models for the assessment of the ecological and economic aspects of the Ria Formosa. Nobre et al., (2005), for instance have used a dynamic ecosystem model the output of which was used to drive the ASSETS screening model for eutrophication assessment of the Ria Formosa. Similarly, Ferreira et al., (2009) have used the FARM model for the assessment of aquaculture production, financial aspects and water quality conditions in the lagoon. Nobre (2009) has used the differential DPSIR approach to evaluate the economic and ecological (eutrophication) condition in the Ria Formosa.

The standard software for SPICOSA is EXTEND. This software links the different ESE components of the system for simulation of responses to management scenarios. The System formulation step involves the preparation of the information needed to set up the

Simulation Model and accompanying Interpretative Analyses (SPICOSA-WP4, 2009) by making use of this model and other models if needed.

4.2.4. System Appraisal

System appraisal involves construction of the simulation model which incorporates the ecological, social and economic models (ESE) and run simulation of scenarios resulting from management responses. The results of the simulations, then, are documented and interpretatively analysed. The system appraisal has sequential activities (Fig. 4-32). Since it will be unduly detailed to elaborate all the activities, some of the important ones are summarily described. It is the responsibility of the study team to follow minutely the sequential activities during the actual study.

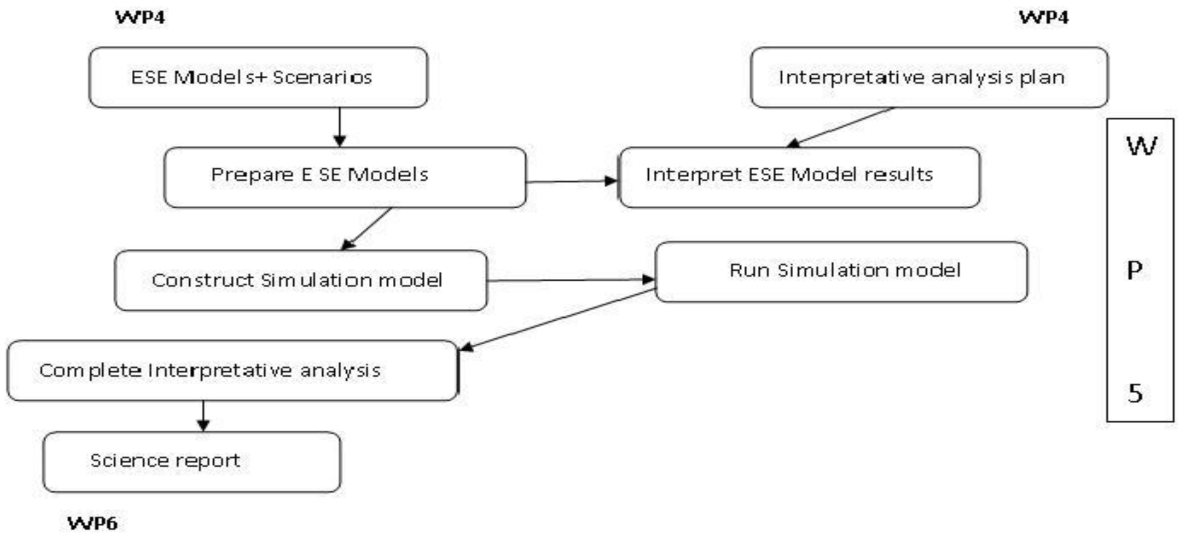


Figure 4-32: Appraisal sequence trajectories (Adapted from SPICOSA-WP5, 2009).

First, reviewing the actions taken in the System formulation step is an important measure. This ensures that the functional representation of the virtual system is focused on the simulation and information output of the selected scenarios and no major aspect of the scenarios are missing. Second, since the chosen software EXTEND cannot execute all the necessary tasks of the simulation process, seeking complementary or supplementary assistance from other models is necessary. So, the results of other models can be used as inputs, or dynamic linkage between other models and EXTEND can be made. Moreover, other models could generate results to the output independently of EXTEND in areas where it is inefficient. Third, though the ESE models are tested, calibrated and validated in System formulation step, they might require some adaptation when running the scenario simulation. This means running the ESE models has significant role in refining the simulation process.

The individual ESE components have interactions among them. So, the Simulation model is constructed by coupling them. According to SPICOSA-WP5 (2009) system models with unilateral interactions may be ecologically oriented in which the model focuses on the changes in the ecological subsystem caused by the economic subsystem. They could also be economically oriented in which the ecological subsystem provides inputs for the economic subsystem. In the Ria Formosa the first coupling seems more pertinent because the study focuses more on the changes in the lagoon caused by the economic activities.

The important task in linking the three components is finding appropriate linking variable. It is by means of this link that the Simulation model is constructed. Figure 4-33 shows how ESE component models can be linked.

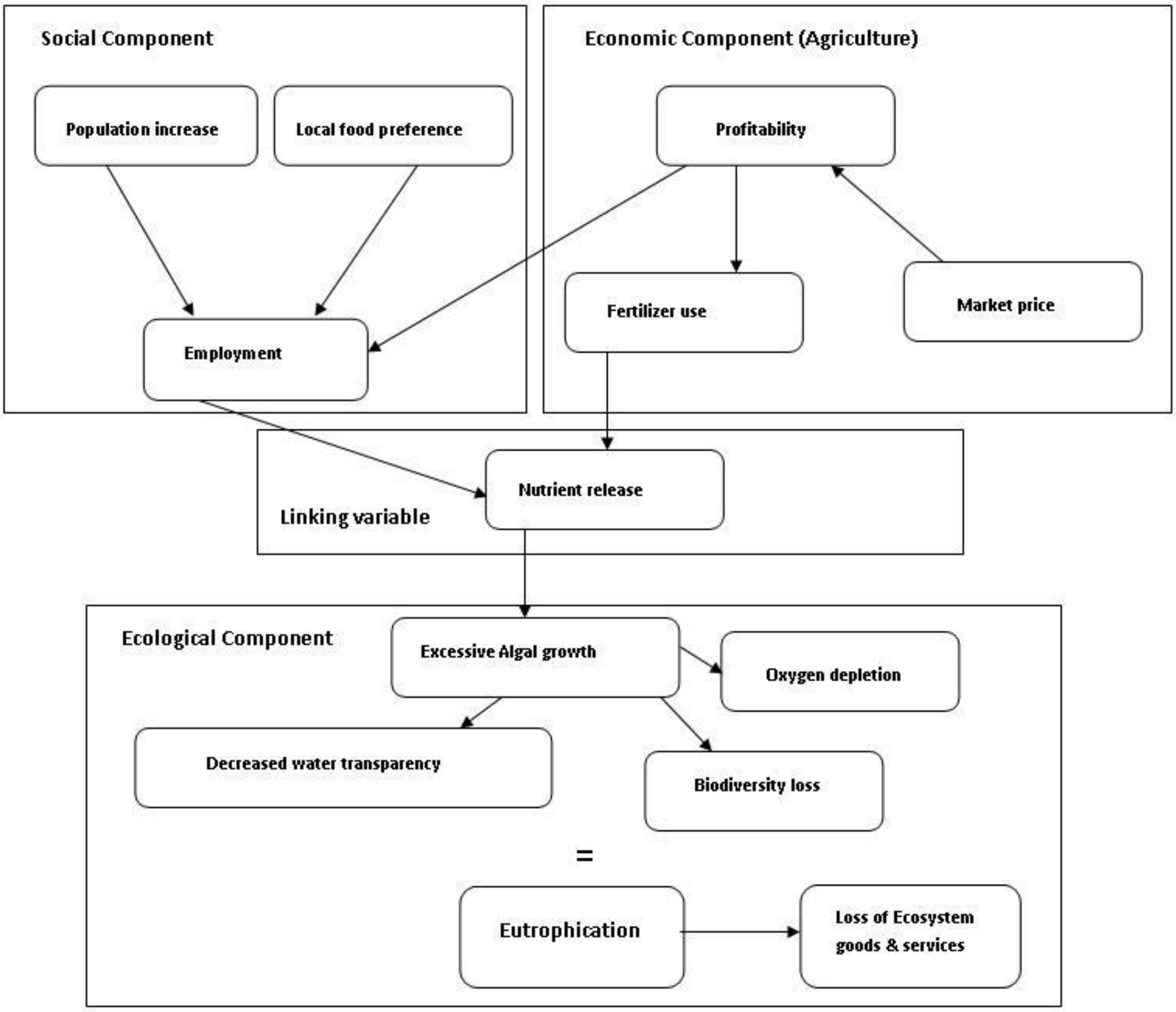


Figure 4-33: Simple model demonstrating direct links between ecologic, economic and social components. (Adapted from SPICOSA-WP5, 2009).

The linking variable *Nutrient release (load)* originates from fertilizer use and is a pressure produced by the employed people in the agricultural activities who use fertilizers. Nutrient release has effects on the Lagoon. So this variable links the three components of the Simulation model.

Verification, validation and sensitivity test of the Simulation model ensures that the system is represented by the model as closely as possible. The next step is running the model using the selected management options. SPICOSA-WP5 (2009) identifies three areas of scenarios; Public policy, Natural events and interactions between nature and society and suggests to evaluate the feasibility of scenarios. So, our scenarios belong to the first and the third categories and they are feasible and address the issue.

Once the simulation has been done the results are documented for further treatment. The treatment includes evaluation of their effectiveness in capturing information that can be passed on to policy .The need whether to modify them and why so do is also to be considered. The acceptance of the results by the stakeholders, and the ability of the scenarios to provide sufficient prognostic answers relative to the issue are important points which call for consideration.

4.2.5. System Output

This is the final step in the SAF protocol. It involves the preparation of the output package and disseminating it to the concerned stakeholders (In various formats) including those on the position of policy making. It contains an important part of deliberation among the stakeholders on the results obtained in the previous steps. SPICOSA-WP6 (2009) suggests the following steps (Fig 4-34) for preparation of Science-Policy consultation and deliberation.

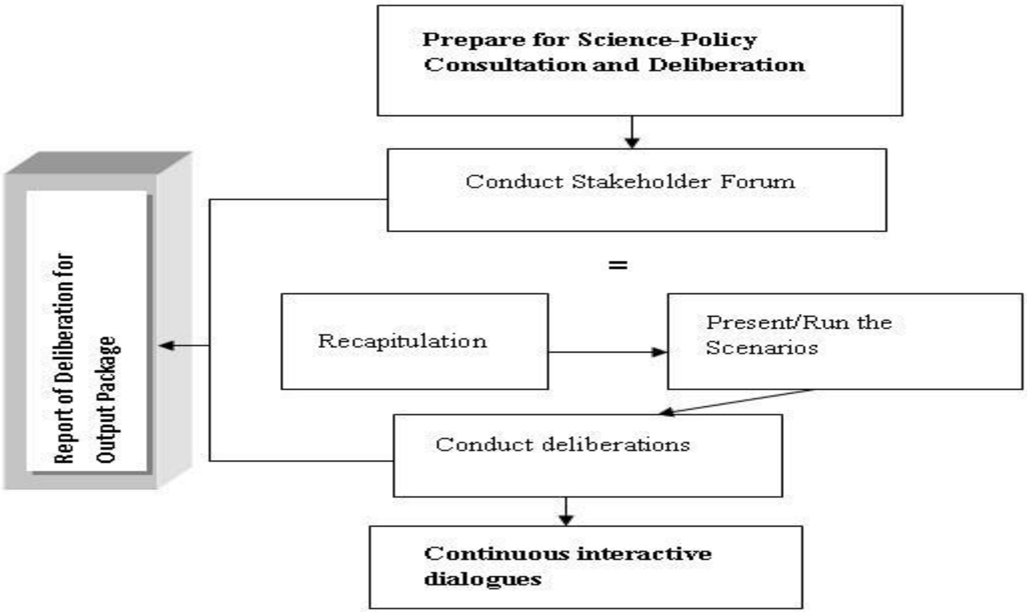


Figure 4-34: System Output steps; Adapted from SPICOSA-WP6 (2009)

The Deliberation Forum provides an opportunity for the stakeholders to understand the extent and consequences of eutrophication in the Ria Formosa. This will enable them to make decisions and implement it to arrest this environmental problem.

4.2.5.1. Recapitulation

What have been done in the previous steps should be explained to the stakeholders to increase transparency. In our case the chosen policy issue (eutrophication), the virtual system, i.e. the Ria Formosa with its catchment and the coast, its economic and social components must be highlighted. The formulation of the conceptual model in to mathematical/numerical model, the possible scenarios and indicators of the success of the policy options as well as the linked ESE model should be explained as clearly as possible. Care must be taken not to make this recapitulation process either too complex or too simple.

4.2.5.2. Presenting and Running Scenarios

Presenting scenarios makes stakeholders aware of the different alternatives for the future and help them make decisions (SPICOSA-WP6, 2009). So the chosen policy options will be presented and explained regarding their advantages and possible shortcomings. Additionally transparency is increased by exposing the limitations of the models and calling for their improvement. Uncertainties regarding the values of economic goods and services and the causes are explained.

Having run the scenarios, results are recorded. The outcomes are then compared with the current values. Presentations of the results should correspond to the levels of understanding and background of the audience. So modification of the information according to the stakeholders might be necessary. The information presented should be free of bias and value judgment. For example, a decrease in fish landings may be regarded positively by an ecologist because it means less pressure on the ecosystem, whereas it is disastrous for a fisherman because it means loss of livelihood (SPICOSA-WP6, 2009). Therefore the results obtained in the simulation of scenarios must be presented as scientific information for discussion by the stakeholders including managers and policy makers.

4.2.5.3. Conducting deliberations

Through a deliberation process stakeholders are able to scrutinize and change their preference as a result of persuasions by other participants (SPICOSA-WP6, 2009). Deliberation includes exploration of technical alternatives, for example, construction of UWWTPs and establishment of AWMS of different technical specifications, in the case of our scenarios. The implementation costs, long-term benefits and trade-offs associated with each scenario are important features deliberated. Moreover, the time scales of costs and benefits must be considered. This refers to the time frame within which the costs of a policy change will produce effects on the system. For example, how much does it cost to establish AWMS on a community level and when will the effect of nutrient reduction (benefit) be felt in that section of the Ria Formosa which receives the agricultural runoff from that community?

Some softwares are developed as Deliberation Support Tool, for example ker-DST, to facilitate the process. But when using this DST tool, the computer skills and interests of the stakeholders should be taken into consideration.

The output package which results from the previous steps and the deliberation process can be disseminated in different formats. SPICOSA-WP6 (2009) suggests a variety of formats to this effect (Tab.4-7).

Table 4-7: Formats for dissemination of the Output Package.

Format	**Advantages**	**Disadvantages**
Printed Material	Portrays complex information	Audience-tailored, Expensive, May not be read
Memory Sticks/DVDs	Likely to be picked up, Cheaper than printing	May not be read, Needs computer skills
Web pages	Cheap, Easy to update	Needs to be advertised, Needs to be updated, Needs to be maintained after the project
Local Media	Reaches large audience	Little control on content, May be misrepresented
Oral Presentations	Enforce information, Allows questions answering, Good public relations	Easy to be sidetracked, Bad communicator can destroy public opinion.

Concluding the deliberation process does not mean the end of the Science-Policy interaction. The outcome of the deliberation will then be used as a feedback to the system design step. Since SAF is a self-evolving research and assessment methodology, the dialogues continue in an interactive way. This ensures the ever developing characteristics of the systems approach framework. Every new piece of information adds up to the knowledge about the ESE components of the system and consolidates ICZM.

5. Discussion

A decreasing trend of nutrient load (Pressure) in to the Ria Formosa is observed (Fig 4-18). This might be due to a shift of Drivers in Algarve from the agricultural sector, which is most important as nutrient source, to services and commerce sector with less release of nutrients. The Nitrate and UWWT directives as well as the discouragement on the use of Phosphate detergents might be responsible for this trend. But still, 70% of detergents in Portugal contain phosphate (Wind & Henkel, 2007). The role of UWWTPs in reducing the overall load may be considerable. This is especially true when considering the P contribution from detergents in the raw sewage is about 43% (Wind & Henkel, 2007). However, Portugal's rank in complying with EU-UWWTD is among the lowest. For instance the country's compliance with more stringent waste treatment was only 13% whereas that of Germany and Netherlands was 100% (CEC, 2009). Similarly, while its compliance with the waste collecting system is 95%, it is only 41% regarding secondary treatment requirements (CEC, 2009).

The Ria Formosa cannot be considered a eutrophied system as a whole. Except for the inner parts of the lagoon where flushing is low and at localities where the UWWTPs release their effluent as well as the eastern parts where agricultural runoff enters, it does not show signs of eutrophication. This may be due to its short residence time and good flushing in which 50-75% of the lagoon's water is exchanged with that of the ocean. The role of filter feeders has also an important role in checking on the phytoplankton community. However, with the present release of nutrients which produced concentrations in the lagoon higher than the EEA's threshold value, it could potentially be eutrophied. This is especially true if anything that increases the residence time and decreases the flushing rate materializes, such as the closure or the reduction of the inlets.

The ecological impacts are revealed in massive clam mortality, fish kills and appearance of HAB. Human poisoning, possible loss of jobs, an employment shift from the primary sector to the tertiary sectors, lowered clam production and fish catch are some examples of the socio-economic impacts. Though there is a recovery in clam production, the earlier responses might not be enough as the recovery attained is only a bit higher than half of its previous value. This calls for more efficient and stronger responses.

Since the scope of the study was limited to indicating the way how different management options could be found for the management of eutrophication problem in the Ria Formosa and consequently anywhere in the world by making use of the DPSIR and SAF approaches, practical exercise had little role. This is particularly true in the System formulation, System appraisal and System output steps of SAF. The duration of the study was the limiting factor in this case. Moreover, it should be noted that the four SAF steps are not a one-man job. They were conceived to be implemented by several teams comprising multidisciplinary experts.

Data on the economic value of the Drivers particularly in the Ria Formosa were insufficient. Some data gap could have been narrowed if interviews with actors of the socio-economic activities were made. As the application of DPSIR and SAF were more of theoretical than practical, some assumptions have been made and examples are provided to illustrate the process.

What might be considered a limitation of DPSIR is that its Driver component is entirely concerned with anthropogenic causes of eutrophication and disregard natural causes. So a way must be found to expand the framework to accommodate the natural drivers.

After all, the framework developed through time from S-R to PSR to DPSIR. DPSIR can be either a fine or a clumsy tool for environmental assessment depending on the level of knowledge about the issue at hand and the system under consideration.

The SAF protocol is still a developing approach and needs more refining. Identification of stakeholders comes prior to identification of economic activities. But since economic activities are more obvious and easier to identify, their identification must come earlier. Since each economic activity has actors, the task of stakeholder mapping becomes simpler once the economic activities are identified. The standard model EXTEND might need some more refining to reduce dependency on auxiliary models.

The objective of the study is sufficiently fulfilled as it was possible to show how the two approaches could be used for responding to the policy issue- Eutrophication. The approaches could be refined and adapted to fit the particular system under study when they are actually implemented. This proves the ever-evolving nature of the methods.

6. Conclusion

DPSIR and SAF can be used as tools for the management of eutrophication in any part of the world with the necessary modifications on the basis of resources and system characteristics. In applying these approches, the limitations inherent in them should have adequate consideration for overcoming them. For the use of DPSIR in eutrophication management, a sound knowledge of the current conceptual model of eutrophication and the system characteristics is necessary.

The highlighted limitations of DPSIR such as its inability to create good communications among researchers, stakeholders and policy makers, as well as its unsatisfactory ways of dealing with the multiple attitudes and definitions of issues by stakeholders may be corrected by SAF. This is because SAF’s strong feature is provision of interface between science and policy, hence providing a means for permanent communication among researchers, stakeholders and policy makers. This suggests that a hybrid approach may be more effective.

Though the standard modelling software used in the System Approach Framework of the SPICOSA project is EXTEND, it does not preclude the use of other models. So in applying SAF somewhere else, other appropriate models can be used. It would also be appropriate to develop a better model, in line with the quest of science to ever improve.

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Apendix 1a: Summary of DPSIR (Agriculture/Livestock and Aquaculture/Fishery)

Driver	Pressure	State	Impact	Response*
Agriculture	Nutrient enrichment from agricultural field run-off Nutrient enrichment and Organic Matter pollution from animal waste discharge	Nutrient concentration Nutrient ratio Organic pollution Chlorophyll-a concentration Toxic algal bloom presence Oxygen concentration/saturation Clam production Species composition	WQ deterioration Biodiversity loss Sp. composition change Oxygen depletion Nut.ratio change Fish poisoning and kills Human intoxication Water clarity loss Revenue loss Job loss	Agricultural Waste M. Plan Nutrient/OM Load reduction Industrial process improvement Tech.& scientific research Monitoring Env. awareness creation Dredging Emission standards Economic instruments
Aquaculture/ Fishery	Parasitic infection	Low clam production	Clam mortality	Screen clam seeds Purchase certified seed Improve DO Decrease clam density/bed Inspect bivalves for toxins
	Nutrient/OM enrichment from fish excretion, faeces & fishmeal spill	Same as in agriculture	Same as in Agriculture	Nitrogen trade Emission standard Monitoring Research Improved aquaculture practice

* The responsible bodies for response implementations are mentioned in the main body of the report.

Appendix 1b: Summary of DPSIR (Tourism and Urbanization).

Driver	Pressure	State	Impact	Response*
Tourism	Nutrient enrichment and Organic Matter pollution from increased human waste discharge	Nutrient concentration Nutrient ratio Organic pollution Chlorophyll-a concentration Toxic algal bloom presence Oxygen concentration/saturation Clam production Species composition	WQ deterioration Biodiversity loss Sp. composition change Oxygen depletion Nut.ratio change Fish poisoning and kills Human intoxication Water clarity loss Revenue loss Job loss	Maintain cleanliness of beach Control, Monitor, use notices Provide adequate UWWTP
	Nutrient enrichment from Golf courses (run-off)			Agricultural Waste M.Plan
Urbanization	Nutrient enrichment from sediments (run-off)	The same as in Tourism	The same as in Tourism	Increase city green area Construct un-cemented cobble-stone roads to increase infiltration
	Nutrient enrichment and Organic Matter pollution from increased population	The same as in Tourism	The same as in Tourism	Provide adequate sewer system and UWWTPs Emission standards Economic instruments

* The responsible bodies for response implementations are mentioned in the main body of the report