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SUSTAINABLE MANAGEMENT OF THE COASTAL ENVIRONMENTS IN THE FRAMEWORK OF THE SPICOSA PROJECT: THE STUDY CASE OF THE MAR PICCOLO IN TARANTO (IONIAN, MEDITERRANEAN SEA)

Carmela Caroppo, L. Giordano (IAMC-Napoli), F. Rubino (IAMC-Taranto), N. Palmieri (IAMC-Napoli), G.Bellio (IAMC-Taranto), A.P.Bisci (IAMC-Taranto), A. Petrocelli (IAMC-Taranto),
P. Sclafani (IAMC-Napoli), T.S. Hopkins (IAMC-Napoli), E. Marsella (IAMC-Napoli)
IAMC - TA
carmela.caroppo@iamc.cnr.it

Abstract

The Institute of Coastal Marine Environment (IAMC) of the CNR is a coordinator of the four-year EU Integrated Project SPICOSA (Science and Policy Integration for COastal Zone Assessment). SPICOSA is developing and testing an operational research approach framework for the assessment of policy options in the context of Integrated Coastal Zone Management (ICZM). The integration of the economic, social and environmental components of the coastal zone is essential to supporting sustainable environmental policies. The SPICOSA methodology, System Approach Framework (SAF), is being implemented and tested simultaneously in eighteen European Study Sites.

We are three-quarters through the exercise with the Mar Piccolo, and we are now analyzing the results of our simulation analyses. In 2010, the results will be translated into various formats for deliberation and distribution to Policy makers, Stakeholders, and Public to provide them with means to understand the effects of their policies and help to promote a sustainable use of the Mar Piccolo resources. The results of the SPICOSA Study Site will be available on a user-based website for SAF support and archive of scientific reports and models.

1 Introduction

1 The SPICOSA FP6 Project

The coastal problems encountered today worldwide are primarily the result of unsustainable use and lack of appropriate directives. As an Integrated Project, SPICOSA is assisting Coastal sustainable development through the use integrated, multidisciplinary of system-based models. These models and their accompanying analyses are designed to provide higher-level information and decision-support tools for policy makers dealing with problematic issues in coastal zones.

The IAMC is sharing the science coordination of SPICOSA with the IFREMER - Institut Francais de Recherche pour l'Exploitation de la Mer. The two primary goals of SPICOSA are to develop a methodology for simulating coastal systems and to improve the science-policy interface of communicating research results to policy makers. The System Approach Framework (SAF) is a holistic management strategy for coastal zones that allows for specific focus on problems and options for their resolution. The SAF is currently being tested and implemented in eighteen different Study Site Applications (SSAs) throughout Europe (Fig. 1). The resulting data, models, and information are contributing to web-based center to support the continued use and evolution of the methodology dedicated to Integrated Coastal Zone Management (ICZM).

The IAMC SSA team is working on an ecological, social, and economic simulation to investigate the environmental and socio-economic factors relevant to the decline of mussel farming in the Mar Piccolo. In this paper, we discuss and illustrate our preliminary results on relevant policy options concerning this decline in the context of sustainable policy scenarios for the Mar Piccolo.

2 The System Approach Framework (SAF) for the Coastal Zone

The Systems Theory (Von Bertalanffy, 1968), states that complex, non-linear systems function differently in vivo than a separate scrutiny of their component parts might indicate. The goal of the Systems Approach is to devise strategies to extract information on the functioning of complex systems that could not have been garnered from a sequence of subsystem-scale studies. This requires the best-possible understanding of the processes and dynamics of a system. The theory of Biocomplexity (Kauffman, 1995) implies that self-organization is a function of the diversity and interaction of its components, i.e. many diverse components constructively interacting can evolve to a more complex organization that better optimizes its available resources. This suggests that systems issues concerning resilience and recovery need to devise system indicators of the strength and number of interactions (Patricio et al., 2004).

An essential characteristic of quasi-stable systems is their capacity to self-regulate in response to external inputs through adjustments in its internal interactions. These external inputs often exceed, in substance or intensity, those occurring naturally. Because natural systems reorganize slowly in response to changes in energy or mass inputs, but can degrade in response to large changes as now occurring due major human interventions leading to a spiral of degradation.

In the SAF, Policy is regarded as a significant of control mechanism that can influence change throughout a Coastal Zone (CZ) system in response to information from its constituent components. Therefore, if policy is going to be effective in assisting sustainability in the system, it must understand how its components interact and institute policies that will promote resilience and productivity in the system.

Thus, Science must be accountable for providing better quality information through its deliberations with Policy. For this reason, the SAF requires a participatory relationship and to include the concerns of local stakeholders, institutional structures, and public end-users that play a strongly determinant role in policymaking. Simply put, a broader participation is needed in order that research results can be objectively and effectively presented to all involved sectors.

The SAF methodology is being written and revised during its implementation in all of the SSAs. The SAF is organized in a sequence of four different steps: e.g.:

• Design (problem definition and scope) ;

• Formulation (key interactions and analyses) ;

• Appraisal (simulations and assessments) ;

• Output (results, reformatting, deliberations).

Currently, we are working on the Appraisal Step and therefore the results reported here should be considered as preliminary.

3 The Spicosa Study Site: Mar Piccolo in Taranto

3.1 The Policy Issue

From 2000, two important policy changes influenced the carrying capacity of the Mar Piccolo system. These involved the reduction and relocation of sewer discharges and the areal extension of the mussel farming. An observed decline in the Tarantine mussel production is apparently correlated with these policy changes terms of quality (Fig. 4). In accordance with the SAF procedure, we conducted initial meetings with policy makers to negotiate a ‘Policy Issue’for our simulation exercise, which ultimately nominated this decline in mussel production.

3.2 Ecosystem Description

Mar Piccolo (Mediterranean Sea ; Southern Italy) is a shallow, nearly enclosed estuary of 21 km2 consisting in two basins separated by an intruding promontory (Fig. 2). The basins are referred to as Seno I and Seno II and have maximum depths of 13 and 10 m, respectively. The exchange with the larger semi-enclosed bay of Mar Grande occurs through a primary artificial navigation channel (12 m) and a small natural inlet. Mar Grande opens into the Gulf of Taranto and the Northern Ionian Sea.

The estuarine circulation in Mar Piccolo is driven by a positive water balance of $\sim$23 mil. m3 yr-1. The exchange with Mar Grande is moderate and varies seasonally depending on the inter-basin pressure gradient. The exchange results in flushing times of 2-3 mos. During summer season, a sufficient stratification develops that can induce hypoxia in the lower layer that damages mussel growth. Wind mixing is low due to the limited fetch and tidal-mixing is low due to the limited tidal range of $\sim$ 30-40 cm.

In Mar Piccolo salinity is influenced by the input of freshwater deriving from small tributary rivers, runoff from the surrounding agricultural soils and from freshwater springs (locally called “Citri”). These Citri are situated in Mar Piccolo, to the N of the Seno I and to NE of the Seno II. The total number of Citri is 34 (20 at the Seno I and 14 at the Seno II), and the average quantity of freshwater which contributes about 1,6 mil. m3 d-1 (Cerruti, 1938).

The exchange with Mar Grande has been modified in 1985 by the installation of a water-scooping machine (0.15 mil m3 d-1) to provide cooling water for the iron & steel industry. A more important disturbance has been the presence of discharge from 14 sewage pipes (5 at Seno I and 9 at the Seno II) coming from the Northern area of Taranto and from eight nearby towns (Fig. 3). These wastes were equivalent to about 18,272 m3 d-1 (of which 85% at the Seno II), with organic matter equal to 6,767 kg d-1 of BOD5, whereas Ntot and Ptot were of 17.2 and 0.3 t d-1, respectively (Caroppo & Cardellicchio, 1995). Starting from 2000 the number of sewage pipes has been progressively reduced to the actual 5 (1 at the Seno I and 4 at the Seno II) and are all subjected to depuration. These wastes have actually the capacity of about 3,000 m3 d-1 and the levels of nitrogen and phosphorus have been reduced to 8.0 and 0.12 t d-1, respectively (Annichiarico et al., 2008).

The combined effect of these changes appears to have influenced the phytoplankton communities. In the past these were dominated by diatoms, which have since been largely substituted by nanoflagellates (Caroppo, pers. com.). Taking into account that in shallow coastal environments phytoplankton represent the main component of the mussels diet (Mac Donald & Ward, 1994), structural changes of this important food source have likely changed the quality of the mussels in Mar Piccolo.

3.3 Human activities

Mar Piccolo is strongly utilized by an intensive mussel commercial fishery at ~30,000 tons per year (ISMEA-MIPAF data). Other important human activities exert additional stress on the system. Seno I is utilized for mooring the local fishing fleet and activities of the largest Italian naval base. The industrial site located to the West (Fig. 3) indirectly influences the environmental quality of air, water, and sediments. The drainage of agricultural soils and the sewage inputs are also important factors that influence the water and sediment quality. As a result Mar Piccolo has been designated as a Site of National Interest for highly polluted areas.

Large increases in these activities have characterized the city of Taranto in the last decades and induce both changes in the socio-economic sectors as well as in the use of natural resources. For example, the heavy industry was established in Taranto in the 1950s and completely changed the economy of the city and Province, which had been based on agriculture, aquaculture, and naval port space.

During this period, the population of Taranto has doubled resulting in severe social problems, such as unemployment, in addition to ecological problems, such as increased substance loading of the Mar Piccolo. The aforementioned policy changes reflect an attempt to better manage the Mar Piccolo ecosystem.

2 Methods: Issue definition, System Design and Formu

1 Policy-stakeholders involvement

During the Design Step the Team began a negotiation and familiarization process with the Participant Group (PG) in regards to the objectives of SPICOSA. Of priority to the PG was their concern about the Impacts related to the decline in quantity and quality of mussel aquaculture.

In subsequent meetings, the Policy Issue has been refined to define a set of specific scenarios for our SAF simulation analysis. The Policy Issue that resulted was: "How to include mussel culture in a management plan for the sustainable use of the Mar Piccolo resources?". In the SAF, a scenario is a specific policy question that concerns the Policy Issue. It is expressed as a question one would ask of the simulation analysis, to obtain quantitative information for decision making. For the Mar Piccolo SSA, three categories of scenarios were defined:

• What are the environmental conditions that control or are causing the mussel decline?

• What would be the costs and benefits derived by enacting the measures needed for sustainable mussel growth?

• What are the effects on human and ecological health resulting from the exposure to hazardous contaminants and organic wastes?

Implicit in this Policy Issue is the question of whether it might be possible to compromise between economic, social, and ecological costs and benefits, which is an excellent objective for the SAF.

The plot showed in Fig. 4 illustrates changes in the size of mussel flesh and its shell in grams together with the flesh-to-shell ratio, which is taken as an indicator of mussel quality.

The reduction of mussels flesh/shell ratio led to a consequent loss of market value for the Tarantine mussels that in the past had a high reputation due to their little shell full of delicious meat. Recent trends in the quality decline coincide with the policy changes concerning waste discharge and mussel farming practices (see Sec. 1.3.1).

2 Virtual System Design

The Systems Approach requires an ability to focus on a specific functionality of a system and analyze how it responds to change. In the SAF, we try to represent the functionality that traces an Impact (problem) within the natural CZ system to a causal Human Activity and response in the social and economic sectors. This is done by defining a Virtual System (VS) that is an extraction from the real CZ system of the primary functionality causal and reacting to the Impact to be simulated. It is "virtual" in the sense that its boundaries are determined by relevance and are not necessarily coherent spatially. Moreover, conceptual models are a schematic way to obtain a downscaled configuration of the system and represent only those first-order inputs, interactions, and processes that govern the flows of information (mass, energy, money, employment) relevant to the cause & effect chain.

The conceptual diagrams (Figs. 5 & 6) allow us to visualize the function of the primary components of the ecosystem and its connection with human activities through links to socio-economic components.

3 Formulation

In the SAF, a scenario is a specific policy question that concerns the Policy Issue. It is expressed as a question one would ask of the simulation analysis, to obtain quantitative information for decision making. For the Mar Piccolo SSA, three categories of scenarios were defined:

• What are the environmental conditions that control or are causing the mussel decline?

• What would be the costs and benefits derived by enacting the measures needed for sustainable mussel growth?

• What are the effects on human and ecological health resulting from the exposure to hazardous contaminants and organic wastes?

The aim of the CZ System Formulation Step is to represent the functioning of the system, in both quantitative and qualitative terms. This requires that processes and interactions, including the controls and constraints of the socio-economic components, be formulated into functional modeling blocks that are individually validated.

4 Research tools: the Ecological-Socio-Economic (ESE) simulation model

Historical studies of Mar Piccolo ecosystem are mostly limited only to circulation models (Adduci et al., 2004 ; De Serio et al., 2007 ; Malcangio & Mossa, 2004 ; Umgiesser et al., 2007) and to statistical studies on hydrology and chemical-physical features (Alabiso et al., 1997)). The SPICOSA simulation effort represents the first comprehensive quantification of the marine ecosystem linked to relevant socio-economical components. The multi-disciplinary modeling of Mar Piccolo utilized the simulation software EXTEND™-Sim ”(http://www.extendsim.com/).

The purpose of the Simulation Model is to represent the productive capacity of the system in response to the specified scenarios. It was constructed to determine the potential Mussel harvest in units of Carbon based on the photosynthetic capacity, which in turn is driven by the nutrient discharges and controlled by the light available and circulation. The mussel harvest is the main link with the economic component. The ecosystem health is a direct connection to the social component through public perception and an indirect (through harvest) and a direct connection to the social component.

In the following section, a brief description of the components of the Ecological and Socio-Economic (ESE) model is given in order to provide the overview of the model functionality.

4.1 Ecological Model: physical and bio-chemical components overview.

Geo-morphologically, the Mar Piccolo has two interacting basins with a double-layer stratification in which the following processes are simulated:

• Freshwater balance: The freshwater balance represents the sum of the rain on the estuarine surface, the land runoff, and the evaporation from the surface.

• Circulation exchange: An approximation of the Thermohaline Exchange Method (TEM) (Hopkins, 1999) is used to derive the circulation formulation.

• Salt budget: The total salt in the surface and bottom layers are calculated by simply considering that salt is a conservative parameter with a vertical diffusive exchange.

• Vertical diffusion: The magnitude of diffusion is inversely related to the salinity gradient and directly related to the KE available.

• Nitrogen budget: Nitrogen is a non-conservative property, with several processes that act as in-situ sources (e.g. external inputs, regeneration from POM, entrainment, advection) and sinks (e.g. uptake, sediment burial, sinking).

• Phosphate and Silicate Budgets: The purpose of modeling the P and Si concentrations is to retain information concerning any threshold limits with respect to the N concentrations. Main sources considered are regeneration and uptake strictly dependent on “F-ratio”.

• Oxygen Budget: The oxygen is modeled because hypoxia is a concern with respect to mussel growth, and it is a key indicator of several essential processes, several sources (e.g. photosynthetic production and the atmospheric input, and advectively entrained bottom water) and sinks (e.g. respiration of phytoplankton, mussels, and other heterotrophs, oxidation of organic matter in lower and sediment layers).

• Carbon Regeneration: The total bottom layer respiration of Carbon is taken as a delayed constant proportional to O_2:C ratio and calibrated with the bottom oxygen observations. Sediment respiration rates were based on literature values from studies of similar coastal waters.

• Irradiance simulation: The light input is used as a direct input but it is corrected with an attenuation parameter proportional to POM concentration.

• Primary Production: Growth equation for three phytoplankton groups (Murray & Parslow, 1999) was considered in order to simulate seasonal variations in the food supply and, to a limited extent, its quality.

• Zooplankton: Zooplankton grazing is considered as forcing factor on phytoplankton growth and it is parameterized following a modified Ivlev equation proposed by Franks et al. (1986).

• Particulate Organic Matter: The POM values combine the phytoplankton with an additive component estimated from the BOD values in the discharges.

• Mussel Growth: The growth equation for Mussel follows a bioenergetics model of Van Haren & Kooijman (1993), based on the assumption that mussel food is POM mainly constituted by Phytoplankton and Detritus. The entire life cycle, for two generations, was simulated using parameters fitted on historical Mar Piccolo mussels biometric data-sets (Pastore et al., 1976 ; Corriero et al., 2001 ; Portacci, unpub. data).

4.2 Social and Economic Components

The Social and Economic Components analyze the response of the system to the Output (Impact variables) of the Ecological Model. They do this both through directly linked simulation modeling and through conventional analyses in order to satisfy the information needs of the specified scenarios. Stating that, the main socio-economics components considered are:

• Mussels Farming and Harvest: The real mussel farming area was based on sea surface areas licensed to farmers (Harbour Office data). The volume is calculated considering that nets are disposed on lines and fixed as to be suspended under the sea level for 4-5 meters.

• Mussel Farm Profit: The market of Taranto is made up solely of mussel cooperatives, therefore we have analyzed all costs incurred and revenue obtained from a representative cooperative. The annual profit is the difference between total revenues and costs for the year. We considered the difference between two management structures: an individual cooperative and a consortium of cooperatives (Frizzera et al, 2008 ; Propersi & Rossi, 2008). The objective is to investigate the variability of profit of these two structures from the harvest, which is simulated in accordance with the different scenarios.

• Cost-Benefit Analysis (CBA): The first CBA analysis (Pennisi & Scannizzo, 2003) compares a limited set of costs and benefits for both a traditional-treatment plant and a natural-treatment plant (Maglia & Tredanari, 2008). The second CBA compares the construction costs against the market and non-market benefits of a shoreline public park, contingent on the scenario of pollution reduction in Mar Piccolo.

4.3 Simulation Scenarios on Mar Piccolo of Taranto

The simulation analysis will be focused

on the three main scenarios: 1) environmental conditions change ; 2) sustainable mussel culture ; 3) ecosystem-health benefits and for each one separate simulation runs will be performed.

The first scenario is related to the improvement of environmental conditions (e.g. food quality, contaminants level, mussels stock, and farming techniques) that control or cause a decline in mussel growth, which influences the carrying capacity of the system. Consequently, the most important aspect concerns what would be the optimal environmental conditions needed to reduce the costs of mussel culture through a different management strategy and an increase of socio-economic benefits. The second considered scenario is directed to the quantification of costs and benefits derived from the enactment of measures needed for sustainable mussel growth, and to provide better environmental conditions for mussel culture. This scenario is directly linked to the comparison of technological options or policy strategies that are available to mitigate these damaging effects (e.g. Cost and Benefits of a Depuration Plant and the socio-economic consequences of these options or strategies).

The third but not less important scenario concerns the potential benefits derived from a healthier ecosystem achieved through an improved waste management plan and cleaner shores, and more public facilities connected with the Mar Piccolo (e.g. health and exposure to pollution, Shoreline Park with accommodations).

3 Preliminary Results and Discussion

The results discussed are based on preliminary calibrations of the simulation model components of Mar Piccolo (Seno II) based on existing observational data of the external inputs. These were collected by the Institute, from literature, and from local Authorities. We calibrated out model of Seno II (Figs. 7-10) first and are presently connecting it to Seno I for final calibrations. This procedure will reduce the margin of uncertainness allowing us to test the sensitivity of the two basins to variations in forcing.

The environmental conditions are well reproduced, such as the fresh-water runoff, the water circulation, and the nitrogen. The model allowed us to obtain a simulation for water flux for each year considered ; e.g., Fig. 7 shows the inflow, outflow, and freshwater input for 2003. Note that the exchange decreases exponentially with a cessation of freshwater input but increases linearly with pulses of freshwater. The circulation is calibrated by tuning the resistance of the opening (to Mar Grande) and the vertical diffusion coefficient until a best fit is achieved with the observed salinities.

Pulses in freshwater inputs induce a direct increase in nutrient concentration due to runoff, advection and diffusion. The Nitrogen concentration is primarily controlled both by runoff variability and by primary production (Fig. 8).

The phytoplankton growth is driven by the light and nutrient conditions, modified by the circulation and diffusion. Its representation is complicated due to the feedback with nutrient regeneration and predation by zooplankton and mussels. Three phytoplankton groups are simulated because the diet of mussels is likely based on a food preference factor as suggested by Navarro et al. (1996).

A typical cycle for mussels production (18 months) was simulated starting from a first generation of larvae and using biometrics data-sets of Mar Piccolo (Pastore et. al., 1976 ; Corriero et al., 2001 ; Portacci unpub. data) and the reproductive cycles given by Matarrese et al., (2003) (Fig. 9). The simulation of growth was performed considering the mussels life-cycle and including a “mother” generation sown in January and a second “daughter” generation (the resulting spawn: e.g. 25 % of the total amount of the first generation) of the previous autumn of the first year of simulation. Some refinements, such as phytoplankton groups, mussels life-cycle and mussels food preference, were added to improve the balance between approximation and accuracy required on the outputs.

The harvest “pressure” is simulated on the mother generation starting in May and ending in September as suggested by the information obtained directly from the mussel farmers of Mar Piccolo.

The mussel biomass harvested from the system during the production cycle is the link between the biological and socio-economic model. According to available data, the mussels harvest of Mar Piccolo is about 24,000 tons (Portacci, pers. com.). Each musselculture plan takes up areas comprised between 3,000 and 15,000 m2, with a total extension of about 10 km2. Mar Piccolo supports 31 mussel farms of which 25 are Cooperatives and 6 are small companies (Taranto Harbour Office) with ∼213 legal employees (Chamber of Commerce).

The simulation model allows us to evaluate the costs and revenue for the two types of farm management (Fig. 10).

Preliminary analysis of costs and revenue lead to slightly higher profits for co-operatives belonging to a consortium than for individual cooperatives. The difference is due to the consortium capacity to fix the market price, support employment in the mussel sector and promote their product, covering costs that the individual cooperatives would otherwise not be able to support.

The simulation that includes the option of mussels quality by means of a sewage management plan, (traditional or natural depuration plant) is now in progress of evaluation, to calculate in both cases the costs and benefits of different hypothetical scenarios.

The other scenarios, discussed previously but not yet simulated, aim to demonstrate how the mussel growth depends on its environmental conditions, how these conditions relate to sewerage management, how the ecological health of the Mar Piccolo might be improved. In the later case, we hope to demonstrate the added benefits of a public park provide compensatory socio-economic benefits for the city of Taranto.

4 Conclusions

The most obvious benefit of the Spicosa SAF application is certainly a model tool that allows us to perform a tuning of the whole system so as to embark on the complex understanding of the factors controlling on the mussels quality and on Mar Piccolo carrying capacity. We expect also that our results will help integrate the socio-economic needs into a more integrated plan for sustainable development in the Taranto Region.

In addition to the cited scenarios, we plan some sensitivity analyses to consider some “extreme-disturbance” scenarios i.e. anoxia events, drought or exceptional storms as to analyze not only the ecosystem resilience but also the economic response in the mussels farming.

Despite some deficiencies in the input data (runoff and substance concentration), we have achieved a good level of accuracy for the simulation of the environmental conditions. Equally important has been our participatory exposure and dialogue with city officials, regional environmental agencies, and stakeholders is proving to be a mutually rewarding experience. On a larger scale, the SAF “exercise” taught us how to manage a new approach to integrated multidisciplinary research and the ability to create a much wider, more accurate tool with important benefits both on the Science and Policy in the framework of environmental sustainability.

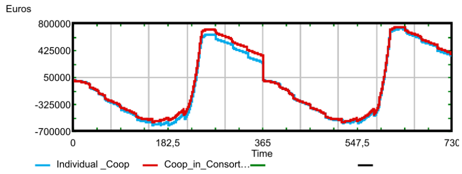

Figure 2: Fig. 10 Cost and Revenue of an individual Cooperative (blue) and Cooperative in Consortium (red) simulated on a 730 days period.

Figure 3: Fig. 2 Map of the Gulf of Taranto (Northern Ionian Sea).

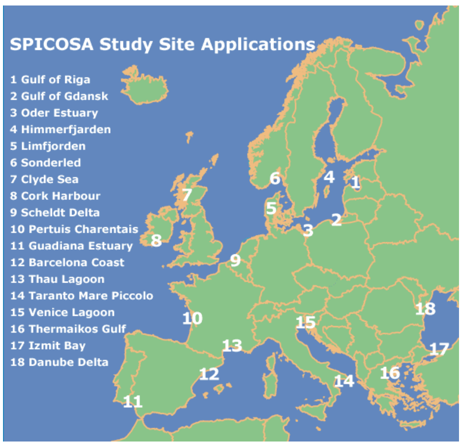

Figure 1: Fig. 1 Map of the eighteen SPICOSA Study Sites.

Figure 4: Fig. 3 Map of the Mar Piccolo in Taranto and location of the main human activities.

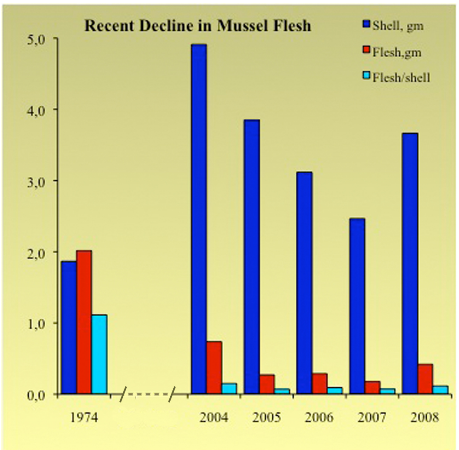

Figure 5: Fig. 4 Changes in Tarantine mussels quality expressed by flesh/shell ratio.

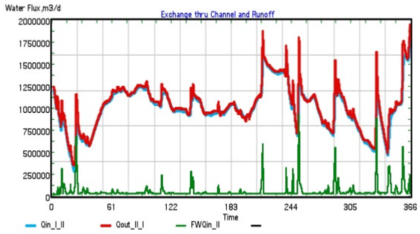

Figure 8: Fig. 7 The inflow (blue), outflow (red), freshwater inflow (green) transport for the test year of 2003.

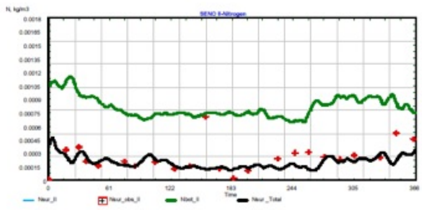

Figure 9: Fig. 8 The simulated Nitrogen concentration in the top layer (black), in the bottom layer (green) and the observed values during the year 2003 (red stars).

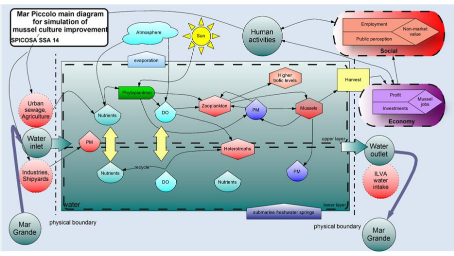

Figure 6: Fig. 5 The diagram represents the VS functionality of the ecosystem with regard to the Impact.

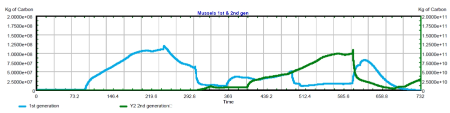

Figure 10: Fig. 9 The mussel biomass of two age classes (2003 -2004). One harvest event is shown in June after whom little growth occurred due to the declining phytoplankton production associated with decreases in runoff and new nitrogen, and a second one in late October allowing the younger class to profit from the increased availability of phytoplankton.

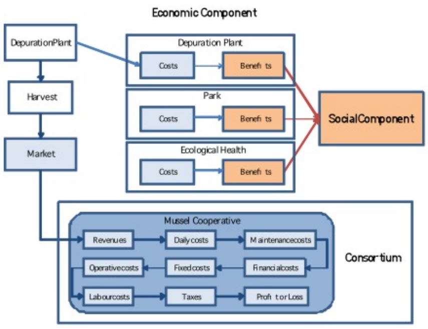

Figure 7: Fig. 6 The conceptual diagram

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