SCIENCE AND POLICY INTEGRATION FOR COASTAL SYSTEM ASSESSMENT (SPICOSA): AN APPLICATION TO A MUSSELS FISHERY

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ABSTRACT

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 policies. Based on a system approach, a multidisciplinary assessment framework is developed with a balanced consideration of the Ecological, Social and Economic sectors of Coastal Systems. This System Approach Framework (SAF) is used to explore the dynamics of Coastal-Zone Systems and potential consequences of alternative policy scenarios. Achieving this objective requires a restructuring of the science needed to understand the interactions between complex natural and social systems at different spatial and temporal scales including the overall economic evaluation of alternative policies. Furthermore, SPICOSA contributes to a more integrated science-policy interface, by developing and testing deliberation support tools for the transfer of scientific products to policy decision-makers, stakeholders, and end-users. The SAF and its tools are implemented in 18 coastal Study Site Applications, from Norway to Romania. A SAF Portfolio consisting of generic assessment methodologies, specific tools, models, and new knowledge useful for ICZM, will be produced in a user-friendly and updateable manner for future CZ researchers and professionals. Implementation design is based on an iterative, accumulative manner such that all of its products will be well validated and that community of researchers will grow along with the evolution of the SAF methodology for future use towards Sustainable Development in coastal zones.

Keywords: Systems Dynamics, Systems Approach, ICZM, Mussels Fisheries, Feedback Loop, Policy

INTRODUCTION

SPICOSA is an integrated project funding under the 6th FPRD of the European Commission (www.spicosa.eu) 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 policies. The approach of SPICOSA relies on systems dynamics. Based on a system approach, a multidisciplinary assessment framework is developed with a balanced consideration of the Ecological, Social and Economic sectors of Coastal Systems. This System Approach Framework (SAF) is used to explore the dynamics of Coastal-Zone Systems and potential consequences of alternative policy scenarios. The SAF approach mainly consists in (i) identifying a policy issue based on a participative process, (ii) design the system (the conceptual model scheme) in relation with the policy issue, (iii) formulate this model (the updated model) and (iv) evaluate and simulate the model.

But before entering into the system approach framework itself, it is first proposed to address some preliminary issues and practices related to systems in general. Then the SAF will be presented by focusing on economics and an application over a mussel fishery will follow before concluding and discussing about limits and uses of this approach, especially regarding others such as individuals or agents based modeling, as well as multicriteria approaches.

SYSTEMS DYNAMICS AND SYSTEMS APPROACH

Systems and general structure of systems

"A System is a configuration of parts connected and joined together by a web of relationships to serve a particular purpose". Ex. a car, a plane, the human body, an organization, an economy, a regional system, a coastal system, etc.
The joining and integrating of the web of relationships creates Emergent properties of the whole (is more than sum of parts). Parts of the system can be systems of their own, and systems can be parts of bigger systems. They fit in a hierarchy.

Ex. engine of the car < car < car in the transportation system;

Ex. fisherman in the fishing community < fishing community < fishing community in the global economy;

System approach relies on the mathematical formulation of cause/effect relations, the objective being to assess how the system evolves over time (stability, 'overshooting', thresholds effects). General structure of systems can be then defined by:

- State variables representing successive (over time) states (stocks, levels) of systems
  - Integration of instantaneous variations through time
  - Number of inhabitants, pollutants concentration, number of enterprises, …

- Rate of change representing activities and processes leading to changes in the systems' state.
  - Decision rules, continuous function
  - Investment rate, growth rate, …

- Interactions between variables determining action rules
  - Positive, negative feedback loops

- Limits and boundaries within those interactions take place

Historically system approach was first used for the analysis of the living organism as a system. A classic case is the energy allocation in a living organism and asymptotic growth (von Bertalanffy). This firstly allows to identify and define several important concepts related to systems:

- Behavior rules or laws such as energy fluxes (processes), energy accumulation (state variables) and feedback (causal)
- Boundary: environmental conditions are represented by forcing variables; if the organism influences its environment, system's limits will take into account some other processes and state variables.
- Mathematical formulation: integration of differential equations
- Emerging property: asymptotic growth, reproduction effort

It was then extended to the study and analysis of population dynamics with the definition and use of life cycle and feedback loops and their mathematical formulation as illustrated by Bald et al. (2006) on Figure 1.

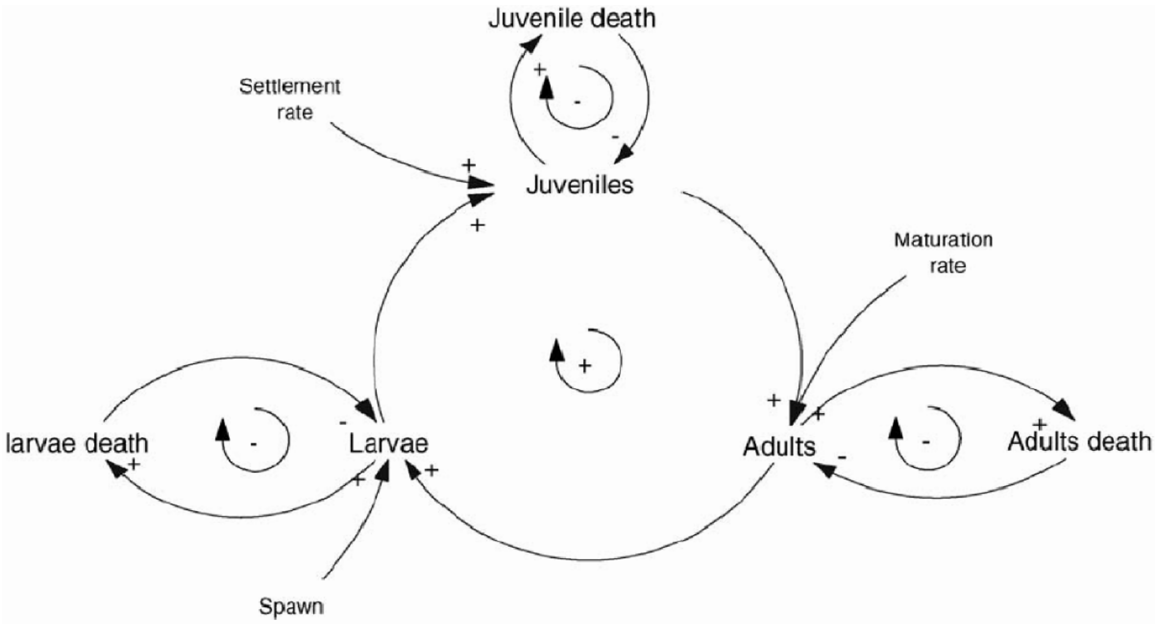


Figure 1 Causal loop diagram model, for the gooseneck barnacle management model from Bald et al. (2006)

$$\frac{\partial n}{\partial t} = G.\frac{\partial n}{\partial w}$$ with G the Growth Rate

History of systems analysis and systems dynamics

- Forrester 1961, Industrial Dynamics
- von Bertalanffy 1968, General System Theory
- Forrester 1969, Urban Dynamics
- Forrester 1971, Principles of Systems
- Meadows/Randers/Meadows 1972, 2004, Limits to Growth

« overshoot » (overpassing the carrying capacity of dynamic system) under 3 conditions (analysis of socio-eco-systems dynamics)
Limits of growth: analysis of socio-eco-systems dynamics, consequences of existing limits, importance of non linearities

- Morecroft 2007, Strategic Modelling and Business Dynamics

The System Approach Framework (SAF)

Dealing with the challenge of an integrated assessment of coastal systems, the system to be considered is then the socio-ecological system (SE system) also called ecological, social and economic system (ESE system). The difficulty to model socio-ecological systems is calling for such an approach. This difficulty is mainly related to intrinsic characteristic of SE systems: SE systems demonstrate Non-matching scales, “Surprises” (non-linearities), Interconnection with other systems, Memory effects, Choke points. Such difficulty is calling for new methodologies to study SES. To that purpose, SPICOSA develops and test new approaches and extend our conceptual understanding. As an integrated approach this is a “high risk” multidisciplinary exercise requiring a systematic research methodology based upon “learning by doing”. And in an objective of achieving such methodology over different contexts and application sites, everyone must understand the principles and follow a similar agreed strategy in order to produce an integrated and generic tool. Objectives can then be summarized as the followings:

1- Build an operational frame of coastal system (SAF, System Approach Framework);
2- Create functional interfaces between scientific knowledge and public policies based on deliberation;
3- Test these tools over 18 study sites from a Norwegian fjord to Danube delta;
4- Contribute to the development of share knowledge bases easy to use and evolutive, proposing assessment methodologies;
5- Strengthen communication and integration between stakeholders and institutions;
6- Develop new opportunities for academic and professional education.

To reach these objectives, SPICOSA will try to act over the Coastal Zone Feedback Loop by modifying the feedback loops path. Historically, the default correction loop involves that human society waits until the damage is obvious before reacting to adapt, mitigate, or correct the situation (external loop line in Figure 2). Most commonly, society reacts by adapting to the change in the goods and services provided by natural resources. In times of accelerated degradation, where economic and social risks are more obvious, society commonly reacts through regulatory controls. Arguably, exercising the precautionary principle would be more prudent, as well as cheaper in the long run, to anticipate changes and implement solutions before damage occurs. This is the goal of SPICOSA, i.e., to provide new knowledge and technologies directed at strengthening a shorter, internal information feedback loop, which begins and ends with the policy decisions, and thereby facilitates more preventive, proactive decision-making. By employing the integrated Ecological, Social, and Economic (ESE) Assessment box, SPICOSA will increase the potential for quick evaluation of policy changes.

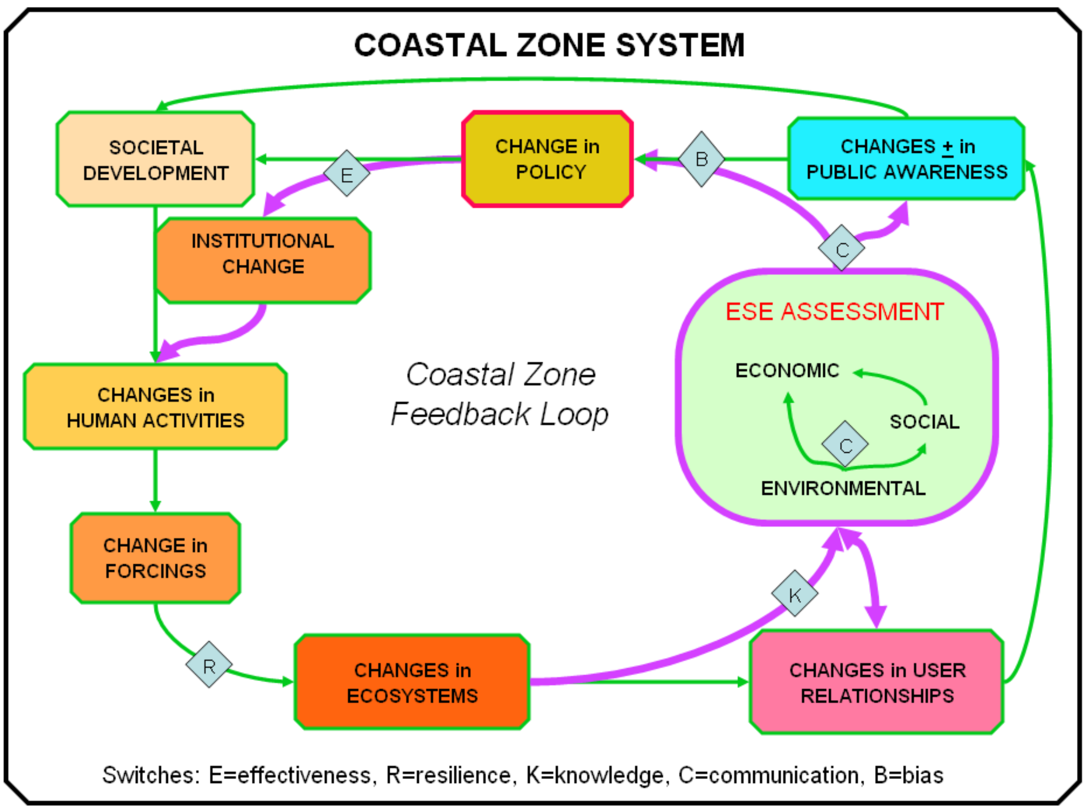


Figure 2 Coastal Zone System Information Feedback Loops

The Ecological-Social-Economic (ESE) Assessment box represents the central activity of SPICOSA. The small diamond boxes represent critical threshold constraints on the interactions between components of the system, which need to be properly represented for successful forecasting of policy scenarios.

System approach will then be implemented in order to modify the feedback loops path that are at the core of the coastal systems dynamics: by placing at the core public policies and considering them as control factors over the fate of systems, by developing a knowledge more integrator of ecological, social and economic dimensions, presented under scenarios approach, and based on a deliberative approach of the interface between scientific knowledge and public policies for issues identification as well as for the evaluation of science's products (production).

Based on this approach, the procedure defined is then to:
a) define a Policy Issue in a participative way (co-construction and co-definition of the issue with stakeholders)
b) design the system (structure and components (conceptual model))
c) proceed to mathematical formulation (updated conceptual model)
d) implement scenarios
and based on those steps to:
e) integrate knowledge and provide deliberative and decision making processes

The methological developments and application will be implemented over 18 study sites presenting different contexts in terms of ecological, social and economic environment and different policy issues.

SYSTEM APPROACH APPLICATION - THE WADBOS CASE ILLUSTRATION

The application is made over the mussels fishery of the Dutch Wadden Sea, based on an existing model (Engelen, 2003 and 2004). System design is then already achieved and the section will give the illustration of the next steps of the SAF (formulation and evaluation).

The Dutch Wadden Sea system

The Dutch Wadden Sea is a unique natural reserve, a shallow sea, but also an area where people live, work and recreate. This is a place of conflicts of interest and there's a need for Policy and Management. A simple economical model is presented for the Wadden Sea. The WadBOS economic sub-model is modeled at the macro-level and all the major economic activities present in the Wadden Sea are represented at some level of detail. Shell mining, Fisheries, and Recreation have been worked out in more detail (Figure 3). Most activities carried out at sea are an input into the local industry and cause directly or indirectly the need for transportation of good and people. Major economic activities are Shell mining, Fisheries, Recreation, Shipping of goods & people, Industry, Gas-mining and Electricity. Shipping of goods & people, Shell mining and Fisheries directly extract biological resources, while Recreation, Electricity generation by means of wind turbines, and Defence activities use the open space as their prime resource. Finally, Gas-mining taps underground resources (Engelen 2003).

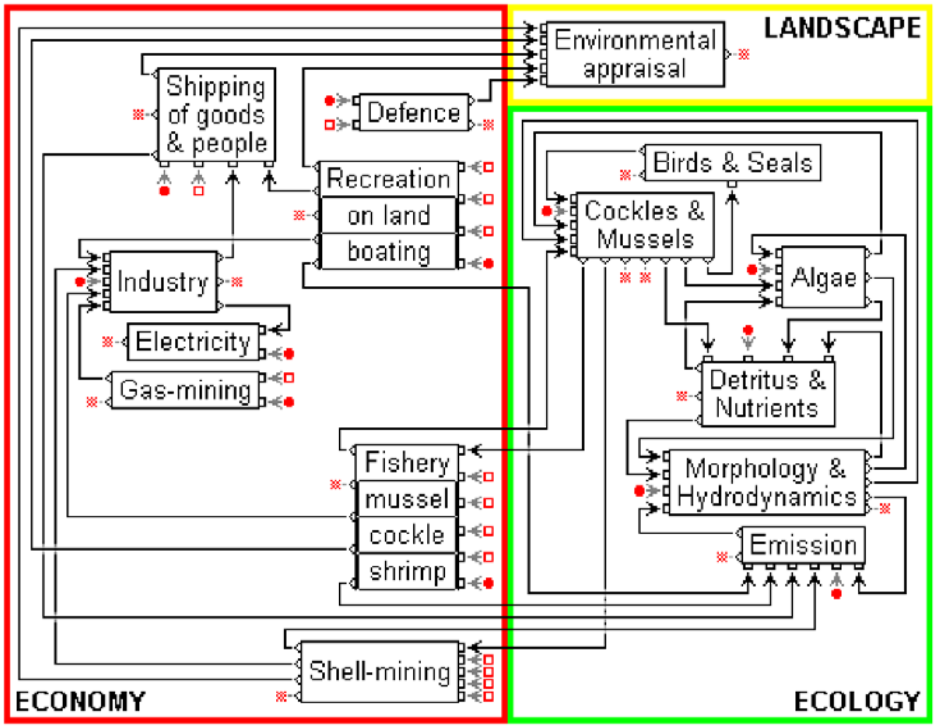


Figure 3 The WadBOS economic subsystem (Engelen 2003)

Application to the mussels fishery

The section focuses on the mussel fishery only which is used to illustrate the formulation of an economic subsystem. The model has a macro economic nature. The fishery is considered as a whole. Other sectors (Recreational activities, others Fisheries, Shell-mining) are formulated according to the same structure. The following formulation is undertaken under a cost and benefits approach. This is the most common way to assess the economic feasibility of an activity. It uses to operate best at a micro-economic scale, but can also be implemented at a more global scale as illustrated by the mussels fishery. It can answer to questions such as: what is the operational cost on one operational cycle, what are the main costs, is it profitable to invest, etc. This approach and its formulation can be reproduced for any kind of issues at local and intermediate scales.
The solely economic system is considered here. The ecological system is considered as a black box and the economic activity is considered under the private angle (decisions are based on private choices, public and social choices as well as the social dimension will be integrated and considered in the next step of the formulation through the coupling).

Assumptions made over the mussels fishery:

INFRASTRUCTURE: (stock) Total infrastructure has units horse power. It represents the total capacity of the fleet. Infrastructure has a lifetime and then depletes at a constant rate per month. Investments increase the infrastructure. The maximum is set at 100,000 HP.

INVESTMENT: (flux) A certain fraction of the profits can be invested in infrastructure if the profits outweigh the costs due to employment, taxes and maintenance of the infrastructure.

EMPLOYMENT: (stock) Employment depends on the total infrastructure (man months needed to staff units of infrastructure).

CATCHES (flux) (Q) result in the fishing effort (hours per month) over Mussels population through a catchability coefficient (per hour). Monthly catches accumulate and are limited by TAC. Once TAC is reached there's no more fishing (fishing mortality = 0).

TURNOVER (TO) is the valuation of Catches according to the price per ton of mussels (P). Mussel price decreases when supply increases: $P_t = P_{t-1} \times \varepsilon_t$ (where ε is the price elasticity).

ADDED VALUE: Added value is assumed to be a fraction of the turnover. Added value is taxed by a tax rate.

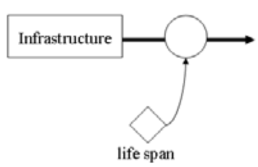
POLICY COST is related to the tax rate applied to added value.

State Variables = stock and Processes = flux

Several scenarios can be played over this system such prices scenario, or policies scenarios (technical and regulation measures). The latter are expressed in terms of fleet size (limit over the total effort), quota (limits over catches to prevent the exhaustion of the species) and through taxes (here applied on added value) and subsidies.

Simple dynamics of the fishing fleet infrastructure

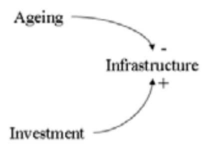
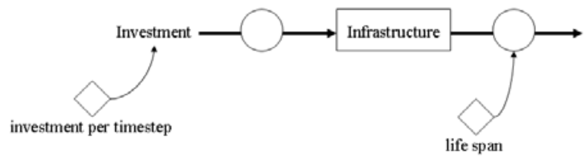
Infrastructure such as fishing vessels continuously looses its value if no maintenance is performed. As for the model of detritus in an ecosystem, the dynamics are quite similar:

Feedback loop	
Conceptual model of the flow of currency	
Mathematical model	$\frac{dInfrastructure}{dt} = -1 \times \frac{Infrastructure}{l}$
Updated conceptual model	

Infrastructure is the state variable of this simple model. If no maintenance is performed, the infrastructure decreases. The rate of this decrease is expressed by the depreciation. Such depreciation can be linear or non linear, depending on the intrinsic characteristics of the infrastructure. Swapping between units is easy if you know what the price is of one unit of infrastructure.

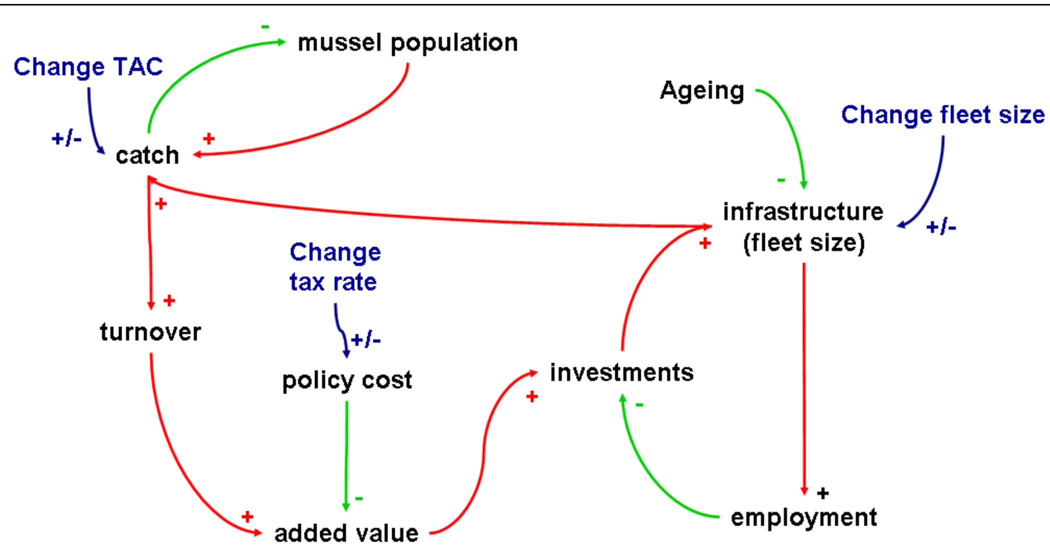
Adding investments to maintain or increase the infrastructure

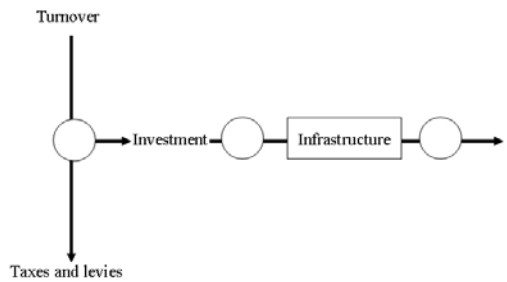
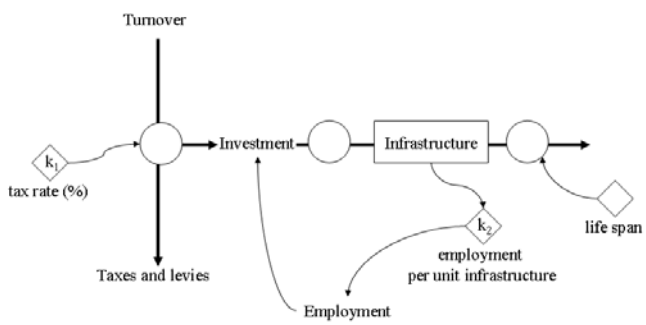
Next, we consider investment as a source leading to an increase of the infrastructure. This slightly alters the different models:

Feedback loop	
Conceptual model of the flow of currency	
Mathematical model	$\frac{dInfrastructure}{dt} = Investment - \frac{Infrastructure}{l}$
Updated conceptual model	

If a time step of one month is considered, the above equation states that infrastructure increases by spending every month a constant amount of money to maintain the infrastructure or to buy new infrastructure. Investment is not a variable in this model. It is a rate of change with units currency per month. This dynamic equation is the basis of the WadBOS fishery economy. Further elaborations on this model try to build in decisions as to whether or not to invest in infrastructure and if there is an investment, how much should this investment be. Under these conditions, investments may be entered as a discrete event rather than as a continuous inflow of currency.

The source of money that flows in the economic system is based on a natural resource: the money that fishermen receive when they sell mussels that are caught using the infrastructure they have (turnover). Now, the simple economic model can be completed using simple linear thinking. The investment is simply what remains from the turnover after deduction of all the costs. Turnover is the total sum of money that fishermen receive for their catch. Costs are taxes and salaries. Salaries are linearly related to the amount of infrastructure. These statements are expressed using the following models

Feedback loops and policy options	

Conceptual model of the flow of currency	
Mathematical model	$\frac{dInfrastructure}{dt} = (k_1 \times Turnover - k_2 \times Infrastructure) - \frac{Infrastructure}{l}$
Updated conceptual model	

Infrastructure is the state variable of this simple economic model. Investments increase the infrastructure, aging depletes the infrastructure. Investments are a simple linear equation in which the salary costs are subtracted from the turnover upon which a tax rate k_1 is applied. The tax rate is applied as a percentage. Salary costs are related to the total infrastructure using a second parameter k_2.

Further elaborating the investments

In the simple model above, the value of the infrastructure declines each year, following technical economic lifetime (for instance 40 years). Infrastructure is renewed based on investments. Under this assumption, the fishery sector is a closed economic system. Investments from outside are not considered. This simple model can be extended with more realistic economic dynamics. In reality, investments do not depend on past earnings, but on the perceived future earnings or profits generated from the investments. At each time step, or say every year, the economic actor makes decisions, first to stay in business or leave the business, and at which level to invest in fishery for the long term (in infrastructure) and make costs in the short run (hire labour and buy fuel). These decisions depend on his or her view on the development of future costs and incomes and comparisons with returns in other sectors. These views will partly depend on the potential maximum catch (biomass) for which evolution of past catchments will be an indicator.

Lessons and limits from the illustration

The economic system of the mussels fishery illustrates a simple and partially aggregated approach. It follows an important recommendation in modeling in system approach: first make your model as simple as possible, then generalise it. If you've made your model as simple as possible, it will be much easier to see how to generalise it since you know what the key pieces are that make the model works. But the structure of the economic model as proposed by WadBOS is maybe not reproducible over different issues, depending on the availability of aggregated data and information such as the added value part in the turn over sector, etc. That's the reason why the structure of the model had been reformulated in a slightly different way where the structure of the economic sub-system answered more to a specific issue in terms of investment. This classic approach in terms of cost and revenue in a very linear way from inputs to output and addressing the different steps of the production process can be applied over every study sites where the issue is dealing with micro to intermediate scales. At the regional scale, regional economic valuation tools such as I/O or Market Chain will be favored.

Under such an approach and according to particular issues it will be possible for instance to enter into the costs structure and analyze the dynamics at a more detailed scale where issues can be more relevant (detect the most sensitive factors to dynamics in order to implement some policy options in a more efficient way). Model can again be made more complex by introducing markets, supply and demand functions (then introducing another dynamics through endogenous prices), more complex catch models or linking shellfish fishery to habitats for instance. According to economic results, decisions or choices sub-models can also be introduced or extended, as well as policy options and scenarios.

DISCUSSION OVER THE SAF PROCEDURE

The SAF procedure and ESE coupling

Finally the SAF procedure as explained and illustrated in previous sections can be summarized by the following figure (Figure 4). From the system design cause and effect relations are identified and translated into feedback loops then mathematically formulated.

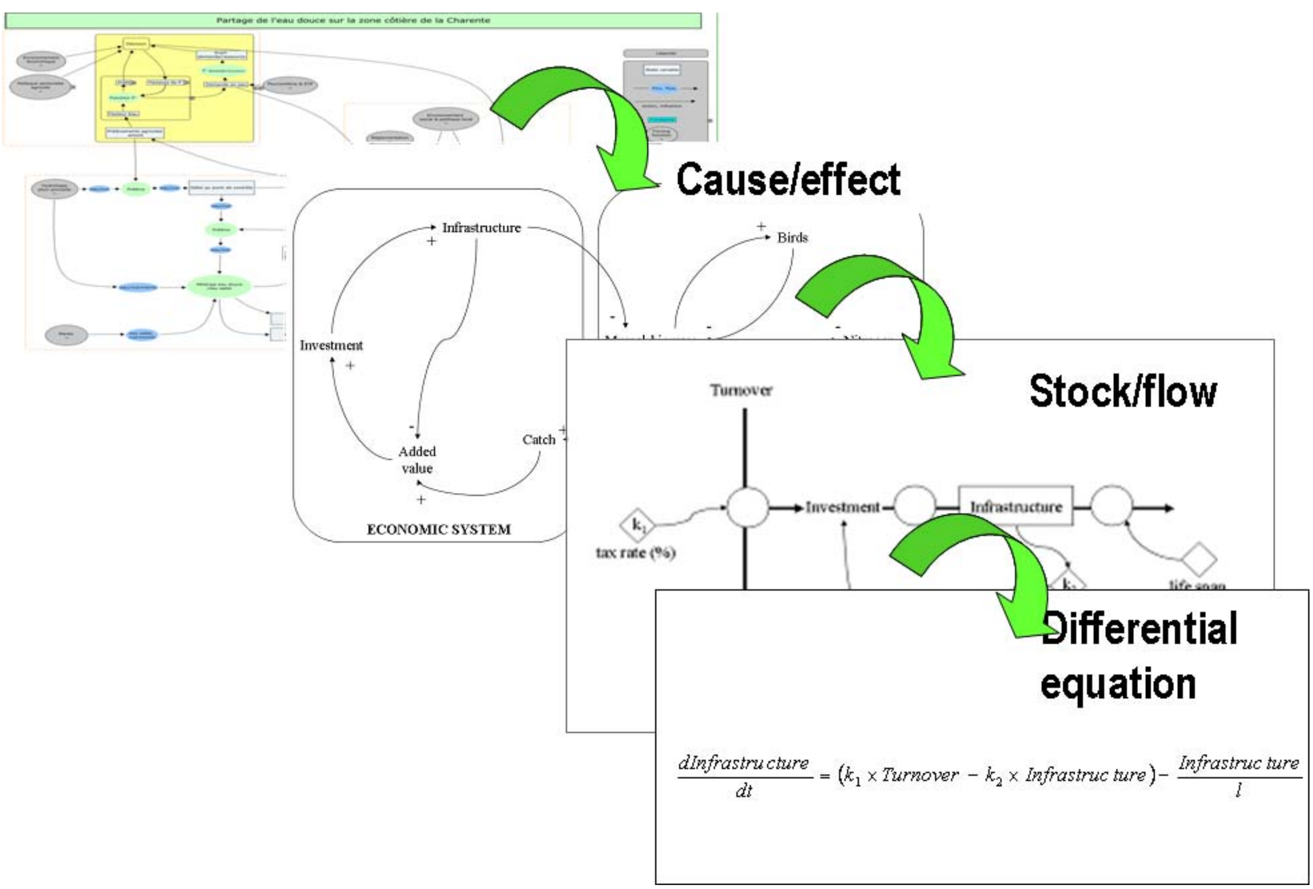


Figure 4 The SAF procedure

The same procedure is applied to ecological systems. Coupling ecological and economic subsystems induces dynamics all along the subsystems. For instance the dynamics of mussels' population will also impact the economic subsystem through catches. Adding birds to the system will also induce another dynamics: birds by having predation action over mussels' population will impact the economic system on the same way, but birds also induce an additional economic activity through tourism and birds watching. To this purpose, a contingent valuation method had been included in the model and formulated through the simulation platform software. It also illustrates the way to make the model more complex when introducing an additional issue.

Coupling ecological and economic subsystems is closely linked to what economists call environmental externalities. Ecological economic models usually describe a causal chain starting with socio-economic drivers like economic production that causes physical or ecological changes through polluting emissions or resource harvesting (van den Bergh et al. 2006). A change in a socio-economic variable is then linked to a change in physical variables and changes in the ecological system feedback the socio-economic system. For instance in fisheries management, catches reduce the fish stock, which can cause an increase in harvest coasts (van den Bergh et al. 2006). Feedback to the socio-economic system can be indirect when it leads to a policy response to mitigate or adapt to the change. Coupling economy and ecology and more exactly redefining the place of economy in the overall system, Constanza (2000) proposes an alternative "ecological economics" view of the process with changes in priority to the conventional economic vision.

But limits appear in terms of data collection costs (survey are costly to implement) and downscaling too much by considering individual units (farms, boats, etc.) can question the soundness of the system approach versus an Individual-based Model approach. To that purpose there're no quantitative rules or norms. The suitable scale for a system approach is the scale where processes are relevant for stakeholders in combination with the issues they want to address, where it reveals key issues impacting the system functioning as a basis for further scenarios.

Individual Based Modeling (IBM) and System approach

IBM is a shift in focus from populations to individuals. From analytical modeling IBMs are often more complex, therefore harder to develop, understand and communicate (Grimm 2005) IBMs have also made little use of reusable building blocks. IBMs are discrete events simulators. Instead of representing processes as occurring at continuous rates, processes are modeled as discrete event events happening independently at specific times. The choice of IBM, calling for more realistic, would be validated if we believe that individual behaviour is an essential process affecting the problem we want to solve compare to more aggregated models.

Individual-based Modeling (IBM) seems to be quite suitable to natural system dynamics compared with analytical approach which focuses on the study of fixed points reached once the evolution achieved. Its limits are linked to intrinsic characteristics of individual (also called agent) himself: an individual may appear as relevant for one discipline but as non relevant for another one, knowledge about individual is partial or incomplete, it is almost impossible to describe completely, precisely and analytically an individual's behaviour. Finally the final appropriation in classic social sciences approaches is not obvious (Amblard 2006) and requires a more participative approach for modeling with and for stakeholders, applying more particularly the participative modeling concept.

System approach proposes a new way to comprehend the World that doesn't take into account separate elements but systems. Compared to the analytical approach that reduces the considered system to simple constitutive elements in order to study them separately and analyze their interaction with the system (suitable to homogenous systems), the system approach is a more global approach, focusing on interconnections between sub-systems and going from the general to the particular. It puts forward the hypothesis that the system structure is much more interesting to forecast its behaviour rather than having a detailed knowledge about its initial conditions, and to issue some general rules devoted to a better understanding of those systems and to drive them. System approach can be split into three steps: systems analysis and therefore system concept definition (boundaries, frontiers, internal and external relationships, structures, rules or properties), modeling and simulation. System model organization is seen as an embedding of more and more complex systems.

CONCLUSION

Achieving the objective of a System Approach Framework to explore the dynamics of Coastal-Zone Systems and potential consequences of alternative policy scenarios requires a restructuring of the science needed to understand the interactions between complex natural and social systems at different spatial and temporal scales including the overall economic evaluation of alternative policies. Furthermore, SPICOSA contributes to a more integrated science-policy interface, by developing and testing deliberation support tools for the transfer of scientific products to policy decision-makers, stakeholders, and end-users. The SAF and its tools are implemented in 18 coastal Study Site Applications, from Norway to Romania. A SAF Portfolio consisting of generic assessment methodologies, specific tools, models, and new knowledge useful for ICZM, will be produced in a user-friendly and updateable manner for future coastal zones researchers and professionals. Implementation design is based on an iterative, accumulative manner such that all of its products will be well validated and that community of researchers will grow along with the evolution of the SAF methodology for future use towards Sustainable Development in coastal zones.

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