# SAF Handbook
# GUIDE TO SYSTEM DESIGN & ISSUE DEFINITION
# v.3.09

Spicosa WP3/WP6

March 4, 2011

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# Part I
# The Systems Approach Framework

*This part provides an introduction to SPICOSA's 'Systems Approach Framework', including a summary of the main theoretical ideas involved in the SAF and guidance on how to use this document.*

**Additional resources** *available at:* ***www.coastal-saf.eu***

# 1 Introduction

What you are reading is a product of the SPICOSA research project, funded by the European Commission from 2007 - 2011. SPICOSA stands for '**S**cience and **P**olicy **I**ntegration for **CO**astal **S**ystem **A**ssessment'. Its research was aimed at developing and testing a toolbox of methods for providing multidisciplinary and trans-disciplinary advice to environmental managers and policy-makers concerning environmental problems in the coastal zone, in order to improve the zone's ecological *sustainability*, economic *efficiency*, and social *equity*. **Sustainability** relates to the capability of an ecosystem to go on supplying humans with 'goods and services'. **Efficiency** is about making the best use of those resources for the satisfaction of human needs, and **equity** is about the fair distribution of such satisfaction.

It was in response to the need for such a methodology, that the SPICOSA project developed and tested the 'Systems Approach Framework' or SAF. This has three main parts:

- the use of General Systems Theory (GST) and Soft Systems Methodology (SSM) to understand and model problems in coastal zones; [1]
- the simulation of *scenarios* including problem management options;
- the engagement of *stakeholders* at the science-policy interface.

Both GST and SSM consider systems to be networks of components and links with certain formal properties (section 6); GST assumes the existence of such systems in the real world, whereas for SSM systems are merely ways to understand the complicated inter-relationships that exist in nature and society. A SAF application includes the stakeholder-aided design of a 'soft' *virtual system*, or conceptual model, that is simpler than the 'hard' real-world coastal zone system under investigation

As explained in section 9, a SAF application has fIve main steps:

1. Issue Identification - the problem is diagnosed by stakeholders;
2. System Design - a virtual system is conceived;
3. System Formulation - a simulation model is made;
4. System Appraisal - the model is tested and run for several scenarios;
5. System Output - stakeholders deliberate the scenarios.

This handbook introduces the SAF and provides a short, practical, guide to steps 1 and 2.

[1] von Bertalanffy, L. (1968) General Systems Theory: Foundations, Development, Applications. New York: George Braziller. Checkland, P. B. and Scholes, J. (1990) Soft Systems Methodology In Action. Chichester: John Wiley and Sons, Ltd.

# 2 Who are 'you' and who are 'we'?

The first drafts of the material contained in SAF handbooks were written for members of the Spicosa project to test during a set of 'Study Site Applications', or SSA, at sites as diverse as a Swedish fjord, a Spanish beach, or a Turkish estuary. Based on SSA experience, we have re-written this guide to the first step, 'System Design', for a wider audience. We assume that you, the reader, are an environmental researcher or regulator, or a member of the public; that you have a concern about an environmental problem arising from human activity in the coastal zone; and that you want to help find a solution to this problem that optimizes human well-being whilst preserving environmental sustainability. We also assume that you have a general knowledge of coastal zone ecology and geography.

The Spicosa method involves three main groups of actors, or three sets of roles for actors to play. The relationships amongst the institutions to which the actors belong are shown in Figure 1, and the three groups are:

**'stakeholders':** people or institutions that have an interest in the environmental problem because they cause it, or are impacted by it, or might be affected by the solution

**'governance':** people or institutions who make laws or policy regarding environmental problems, or who implement those laws or policy;

**'scientists':** the technical experts, including ecologists, economists, mathematical modelers, political scientists, social scientists, and systems analysts, who will apply the SAF to provide stakeholders and governance with the information they need for better deliberation of management or policy options.

When we address 'you' in this guide, we sometimes mean 'you' in the general sense of 'you, dear reader, from any of the three groups of actors', and sometimes in a more focussed sense of 'you, someone who will implement the steps of the SAF, or who will manage a team doing this'.

When we write 'we' in this guide, the pronoun is meant to refer to the team that assembled the material for the first drafts of the 'System Design' handbook, from which this short guide has been abstracted. Members of this team are listed at the end of the guide: 'we' include oceanographers, marine ecologists, modelers, social scientists and economists, who learnt interdisciplinarity and 'systems theory' during the writing of these drafts and from the experience of our Spicosa colleagues in applying the SAF.

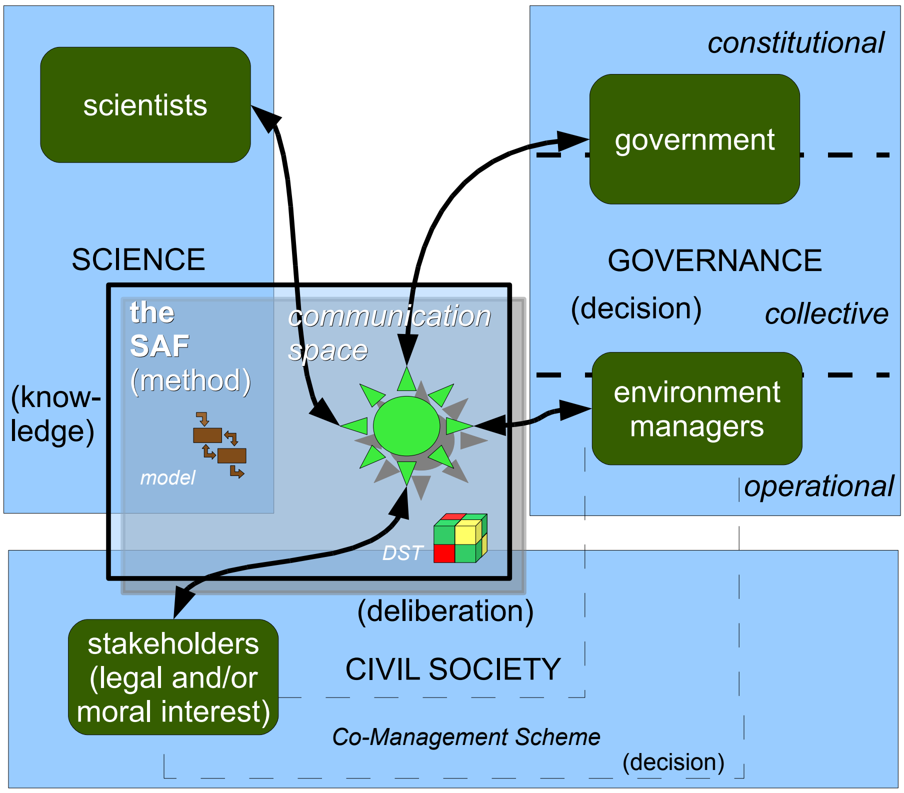



Figure 1: The SAF as an interface between ‘science’ and ‘policy’, with ‘science’ (the institution) providing scientific knowledge and expertise to ‘governance’ and ‘civil society’ . The human actors - or roles for them to play - are those of scientist, stakeholder and public official (either ‘policy-maker’ in government, or environment manager applying this policy). People can play several roles - for example acting as scientist in the day and as stakeholder during the evening. ‘DST’ stands for ‘Deliberation Support Tools’, and the ‘communications space’ allows exchange of information amongst the three groups of actors, leading to better deliberation by the stakeholders. The argument is that *communicative rationality* – which emerges after free communication and deliberation – leads to *collective rationality* – the process of making decisions together that produces outcomes that are rational for a larger group, for instance concerning a social-ecological process that is sustainable in the long run. (This argument derives, mainly, from Jürgen Habermas (1984) The Theory of Communicative Action, Vol. 1: Reason and the Rationalization of Society. Translated by T.McCarthy. Boston, MA: Beacon Press. We have added the part concerning sustainability.)

# 3 How to use this Guide

This document gives an overview of the 'Issue Identification' and 'System Design' steps. It is a short guide, in essence a set of lists of things to do, with brief explanations of key ideas. We recommend that you:

1. read the Guide once through completely, to understand the nature of the 'Systems Approach Framework';

2. subsequently, work from the 'to-do' lists (in Tables 4, 7, 8, 9, and 10), referring to separate and more detailed handbooks when you need further guidance in technical tasks.

There are a number of words, such as 'stakeholder', that we use, and want you to understand, with a particular technical meaning. These words are often emphasized in various ways - by the use of 'inverted commas' or *italic font* - and are briefly defined at points where the word appears in **bold font**. There are a few ideas that are crucial to understanding the SAF, and we present them (briefly) in sections 5 to 8. Following these are a set of sections (9 to 11) giving an overview of the SAF as a whole and guidance for starting a SAF application and deciding (in consultation with stakeholders) on the 'Issue' of concern. Finally, there are sections (12 to 16) that work through the tasks of 'System Design'.

The SAF web site at *www.coastal-saf.eu* offers additional resources. First, it provides a more dynamic and cross-linked version of the information contained here and in guides to other steps of a SAF application. Second, it houses detailed guides to methods ( some of these are listed as 'Supporting Documents' on the pages that start parts II and III of this guide). Third, it includes examples of results from most of the tasks and subtasks listed in the 'to-do' tables. Finally, it contains a more complete and more detailed glossary of Spicosa-related terms than we can provide here.

# 4 Assembling and managing an interdisciplinary team

This section is addressed to those who are carrying out the technical work of implementing the 'Systems Approach Framework' in a particular case - i.e. to the actors that we refer to as 'scientists'. An application of the SAF needs knowledge of ecology, economics and social and political sciences, together with skills in numerical modeling and the management of relationships with stakeholders and governance. It will be unlikely that one person has all the necessary knowledge and skills, and a SAF application is therefore usually made by a multidisciplinary team. The section heading refers to an 'interdisciplinary' team, because we hope that, during a SAF application, team members will learn sufficient of each others' technical language for the team to function as a unit, so that the team's work will describe the behaviour of a 'Social and Ecological System' as an entity.[2]

The first task for the manager of a SAF application is this: consider your human resources: what people and skills can you draw on? How much of their time is available? How does this fit with the magnitude of the problem with which you are dealing and the deadline by which your stakeholders/customers need answers? Actually, you may not be able to answer these questions in full until the end of the 'System Design' step. See section 16 concerning how to better match your problem and resources when you reach that stage. Meanwhile, you need an initial team to identify and meet with stakeholders and to explore with them the environmental problem of concern.

When you have finished reading this guidebook, get your team together and ask them to read it also. And finally, keep this in mind: the team should see itself as part of a self-organizing human-environment system: it is to be expected that its members will learn, and change, and that methods will evolve, as a result of experiences during the application.

[2] The 'social' part of the 'Social and Ecological System' is meant to include an economic component. In earlier drafts of this guide, we referred to an 'EcoSocialEconomic System' or *ESEsystem*, and that term will be used again during the modeling steps of the application. These steps might involve separate construction of sub-models for economics, the social system, and the ecosystem, that are subsequently bolted together to make an *ESEsystem* model.

# 5 The problem: human activities lead to impacts on ecosystem goods and services

Members of the species *Homo sapiens* are, of course, components of **ecosystems**, where communities of animals, plants and micro-organisms interact amongst themselves and with the non-living environment. Nevertheless, it is common to distinguish between, on the one hand, 'humans', and, on the other hand, 'the environment', the milieu in which humans live. It is the second perspective that is adopted in the acronym **DPSIR**, which refers to the chain of links between the driving forces within society (D), the pressure on the environment (P), the state of the environment itself (S), the impact on people and nature (I) and the desirable response (R). [3]

One criticism of DPSIR is that it suggests a linear flow of cause and effect from Driver to Response. Thus, some users link Response back to (a change) in the Driver. It is such a feedback loop that is at the heart of the SAF analysis of coastal zone environmental problems (table 1). The starting point of a SAF application is the identification of a ***H**uman **A**ctivity* that results in a ***F**orcing* that brings about a change or ***R**esponse* in ***S**ystem **S**tate*, causing an ***I**mpact* on the *ecosystem goods and services* used by humans. In the context of the SAF, a **Human Activity** is something that humans do (in the physical world) that does, can, or might, cause a significant change in ecosystem state, whether by design or unintended consequence, and which thus significantly alters the ecosystem's capacity to provide goods & services.

The SAF sequence ends with a ***P**olicy **C**hange*, also called a *Management Option*, a choice amongst things that might be done. For example, in the case of eutrophication in a Swedish Baltic fjord, the choice could include: doing nothing; augmenting local sewage treatment to remove more nitrogen or phosphorus; closing private sewer discharges; flooding coastal land to create marshes to remove nitrogen by natural means; persuading Swedes to use low-phosphate detergents; and, paying Poles or Russians to reduce their nutrient emissions, thus reducing background levels in the Baltic Sea.

The Policy Change is expected to feed back to changes in Forcing, leading not only to an improvement in System State but also to more sustainable provision of goods and services by this part of the coastal zone. The local choice of management options is often constrained: in the example, by the Swedish transposition of the European Urban Waste Water Treatment Directive and the Water Framework Directive. At a higher level of governance - for instance, in the European Parliament and Council of Ministers, the choices relate to the sort of policy to make, and the issuing of these Directives could be the Policy Change.

[3] Luiten, H. (1999). A legislative view on science and predictive models. Environmental Pollution, 100, 5-11.

Table 1: The DPSIR, and equivalent SAF, cause-&-effect, chains, or loops, exemplified for the 'Issue' of eutrophication in a fjord in Sweden.

| **DPSIR** | Example | **SAF** | *Comment* |
|---|---|---|---|
| **D**river: | Generation of urban waste water | **H**uman **A**ctivity | *As we use the term, HA refers to a deliberate or unintentional human intervention in the function and structure of natural systems.* |
| *giving rise to a ...* | | *which results in a ...* | |
| **P**ressure, | from loading of the fjord with nutrients in the waste water, | **Forcing** | *(Pressure - in physics, a force per unit area - is too specific. Forcing is more general.) The SAF sees forcing as a change relative to a 'natural' level, as exemplified here by anthropogenic nutrient loading.* |
| *resulting, perhaps, in a shift in the ...* | | *which acts on ...* | |
| **S**tate | of the fjord's ecosystem, with increases in concentrations of nutrients, abundance of phytoplankton, and amount of primary production, | **System State** | *where 'State' or 'Status' represent the situation at a specific time.* |
| | | *to bring about a ...* | |
| | | **Response** | *a forced change in the ecosystem. Eutrophication would be seen as part of this.* |
| *which may be diagnosed as an ...* | | *perhaps causing an ...* | |
| **I**mpact, | the 'undesirable disturbance' of eutrophication (including, e.g., decreased water transparency, harmful algal blooms, deep water hypoxia, and fish deaths), | **Impact** | on ecosystem goods and services: *the end-result in a cause-&-effect chain, with direct consequences for ecosystem users, such as reduced attractiveness of the fjord for recreation.* |
| *causing a ...* | | *perhaps requiring a ...* | |
| **R**esponse | such as the 'more stringent treatment' of waste water required by the Urban Waste Water Treatment Directive. | **Policy Change** | either a choice amongst local management options or general action at a higher level of governance. *The SAF aims to forecast the results of different options or scenarios, not to dictate the choice amongst them.* |

# 6 Understanding systems and models

An ecosystem is made of of living and non-living things interacting together. By analogy with this, we call the human part of the Coastal Zone a 'socio-economic system', and the whole thing an 'social-ecological system', where 'social' includes 'economic'. All this is compatible with the typical dictionary definition that a **System** is *a set of things working together as a mechanism or interconnecting network*. However, there is more to **Systems Theory** than this: systems have general properties (Table 2) above and beyond the properties of the 'things' that make up a system. An example is to be found in most household heating systems: the *emergent* property of temperature regulation derives from the system and not from the thermostat alone.

Table 2: A descriptive definition of 'System'

| |
|---|
| A **system**: |
| – consists of parts and relationships or interactions amongst these parts; |
| – often contains feedback loops which create *emergent* properties additional to those of the individual parts and relationships; |
| – has *boundaries* in space and time, which define system *extent* and *scale*; |
| – has an internal *state*, which responds to internal dynamics and trans-boundary processes; |
| – can contain a *hierarchy* of sub-systems; emergent properties of one level appear as relationships at the next higher level. |

Systems modeling is one of the main tools of the SAF. Several centuries ago, Adam Smith wrote: [4]

> *Systems in many respects resemble machines. A machine is a little system, created to perform, as well as to connect together, in reality, those different movements and effects which the [maker] has occasion for. A system is an imaginary machine, invented to connect together in the fancy those different movements and effects which are already in reality performed.*

The core idea here is that *a system is an imaginary machine*, something that captures the essence of reality but is less complicated. In the SAF, the imaginary machine, or the *model*, or the *Virtual System* as we'll often call it, is constructed in three stages:

[4] The quote is from Smith's essay on 'Astronomy' in *Essays on Philosophical Subjects*, 1795, as given in the Introduction by A. Skinner to Smith's *The Wealth of Nations*, Penguin Books, London, 1986 reprint; the word 'maker', here, replaces 'artist' in the original.

1. a **conceptual model**, typically, a drawing of system parts connected by arrows showing functional or cause-& effect relationships between the parts (as in fig. 6);

2. a **mathematical model**, a set of equations that specify how each relationship works: exemplified on page 13;

3. a **numerical** or **simulation model**, in most cases made using computer software to solve the equations and make quantitative predictions about the behaviour of the Virtual System (and, hopefully, the real system that it mimics).

Your 'imaginary machine' does not need to take account of all reality in your coastal zone: it only has to capture the key features of the real system's behaviour in relation to an identified problem, so that it can predict the outcome of different management options. Making the model is helped by recognizing that systems have boundaries and that these define the *scale* of internal dynamics. As Figure 2 emphasizes, the 'system' is what is within the boundaries; the 'rest of the world' is apparent to the 'system' as *boundary conditions*, which act on the 'system' but are not themselves influenced by it. Furthermore, the boundaries define what is to be included and on what scales: a coastal zone model need not start at the origin of the Universe in the 'Big Bang', nor does it need to include quantum dynamics.

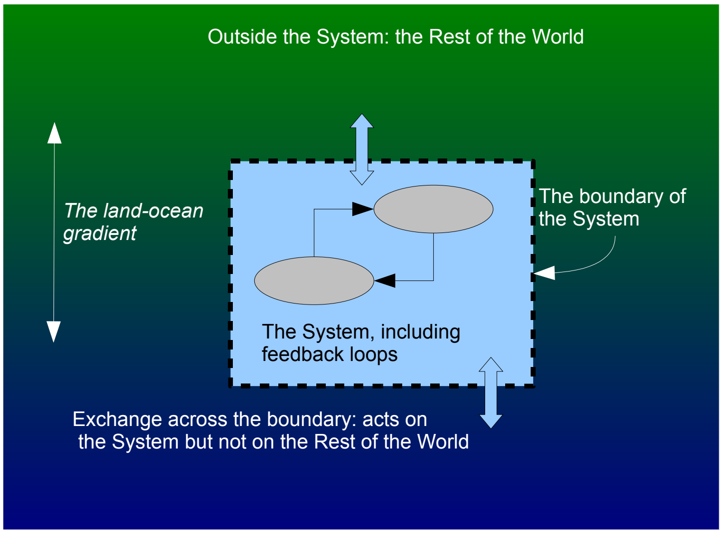
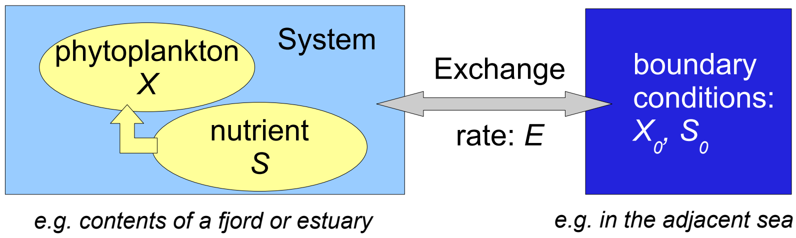



Figure 2: A coastal zone system and its boundaries.

**Box: a simple ecological model illustrating key terms**

This example shows the conceptual model of a simple pelagic ecosystem as a single box with two *state variables*.




The mathematical model includes a pair of differential equations, and the **state variables** are the subjects of these equations:

| | rate of change: | is defined by the equation | where the *state variable* is: | |
|---|---|---|---|---|
| (phytoplankton) | $\frac{dX}{dt}$ | $= r \cdot X + E \cdot (X_o - X)$ | $X$ | (1) |
| (nutrient) | $\frac{dS}{dt}$ | $= -\frac{r \cdot X}{q} + E \cdot (S_o - S)$ | $S$ | (2) |

Change in the system depends on *internal processes* and on the effect of **boundary conditions**. Water exchange between the system and conditions at or outside its
214 boundaries brings influxes $E \cdot X_o$ and $E \cdot S_o$; the boundary effects are included in the model by providing data either for these fluxes or for the exchange rate $E$ and the boundary concentrations $X_o$ and $S_o$. The outfluxes $E \cdot X$ and $E \cdot S$ are supposed to have no influence on the boundary conditions. The **internal processes** include the effects of phytoplankton increase rate, $r$, on amount of phytoplankton and, taking account of the coupling constant $q$, on amount of nutrient. Feedback from nutrients and phytoplankton to $r$ can be provided by an equation such as:

$$r \quad = \quad r_{max} \cdot (1 - \frac{X}{X_{max}}) \cdot \frac{S}{k_S + S} \tag{3}$$

Like $q$, $X_{max}$ and $k_S$ are likely to have constant values in any one application of the model. It is, however, better to refer to each as a **parameter** (Greek: 'auxilary measure'), because their values may depend on the type of phytoplankton or local conditions, rather than being universally constant.

The **scale** of the model is set by its *extent* and *grain*. In this single-box model, spatial extent (the distance between boundaries), and grain, are the same. Thus, exchange rate, the probability that, in a given time, any small packet of water inside the box may be swopped with a packet from outside the boundary, combines - and therefore does not distinguish as more detailed models might - the effects of smaller-scale water movements. If the model is used to simulate day-to-day changes during a year, then temporal graininess, such as hour-to-hour changes in exchange due to tide or wind, need not be explicitly represented, net effects being averaged over 24 hours. The parameter $r_{max}$ might vary during a daily cycle because of the effect of changing illumination on phytoplankter photosynthesis, but this high-frequency variation could be neglected in a seasonal cycle model by expressing $r_{max}$ as a simple function of 24-hr mean illumination.

# 7 Understanding stakeholders, institutions, governance, laws and environmental management

Stakeholders, and people representing governance, are key players in a SAF application. The two groups may overlap. Furthermore, they are also part of the real Coastal Zone system, and may enter into the 'virtual system' that is to be described in a model. In order to explain them further, we need to say something about 'society' (in the Coastal Zone).

Society is made up of people and the links between them. Some of these links are transient and small-scale: peoples' relationships with their neighbours, for example. In addition, the pattern of, or the information in, links has some existence in its own right, and is built up, handed on, and evolves, from generation to generation. We're speaking of 'culture' and 'norms' here, the kind of rules that people obey when, in certain cultures men raise their hats to ladies, and in others, women cover their heads in the presence of males. Sets of rules that become formalized are called **institutions**, a word also used for the organizations and the buildings where people work under these rules. Societies can be mapped or modeled in terms of the relationships between institutions, as we'll see, and the 'social capital' of a society lies in its institutions and its local networks of trust.

Churches, fishermen's co-operatives, and industrial businesses are all examples of institutions. Over-arching all of these, in an ordered society, is 'Government', made up of deliberative, executive, legal, and police, systems. These ruling institutions are collectively called **governance**, defined as *the act or manner of, or the system for: ruling or controlling the subjects or citizens of a State; or, conducting the affairs of an organization.* The word derives from the Latin 'gubernator' and that from a classical Greek word for the person who steers a ship - who is helmsman, navigator and captain.

In modern states, and other large institutions, governance takes place on several scales. We distinguish three of these. The *operational level* is, in our context, the level at which the direct interaction between human activity and the biophysical resources takes place, and at which stakeholders or public officials implement rules dealing, for example with public access to the shore or the contents of individual sewage discharges. Rules on the *collective level* govern the management of coastal resources; they tell how the decisions leading up to rules on the operational level are to be made: for instance, who is in position to make decisions, who can block decisions, how decisions are made (unanimous or simple majority), the amount of information required etc. At the *constitutional level*, rules specify how changes in the management of coastal resources can be made - e.g., how lower level rules or governing bodies can be changed.

We define **environmental management** as *'governance' extended to ecosystems, with the aim of sustaining an ecosystem's ability to provide goods* *and services; it includes the prevention of pollution, the conservation of species and habitats, and the remediation of damaged ecosystems.* An 'environment manager' is a public official who carries out environmental management; on the operational level, managers plan or consent individual Human Activities (HAs) taking account of their likely environmental impact; at the collective level, they make environmental plans or oversee the implementation of environmental policy, at the constitutional level they decide policy or support legislators who make environmental law. It is likely that some of these managers will play an important part in a SAF application.

In a democracy, of course, all citizens have a stake in their Governments, but there is a difference between 'citizen-voter' and 'stakeholder' as we will use the words here. Governments are elected to deal with many aspects of society. In the SAF you will focus on just one 'Issue', meaning a set of matters related to a coastal zone problem (or group of related problems) arising from a Human Activity. A **stakeholder** is *an organisation, community or individual who has a 'stake' in that 'Issue' because they are concerned about it, potentially or actually affected by it, or have or want a voice in the making of decisions about it.* The words 'stake', 'interest' and 'concern' are interlinked, and carry with them, in our usage, some sense of a moral right to be consulted about any proposal or plan than might have an effect – for better or for worse – on the stakeholder. Some stakeholders carry out the harmful HAs and others are affected by consequent impacts. A third group might presently be unaffected but might be affected by remedial measures - for example, they might have to pay the cost of these, or suffer a new sewage treatment works to be build close to their houses.

In implementing the SAF you will need to know something about the institutions, and the categories of stakeholders, in your coastal zones, relevant to the problem you address. There are tools for getting this information:

**institutional mapping** : *a process of analysis for identifying the rules governing the relations between organisations, groups and individuals, optionally resulting in a diagram*; in a hierarchical system this analysis may focus on the relationships between institutions, including governance; all of which are themselves sub-systems;

**stakeholder mapping** : *a subset of institutional mapping that involves the identification of stakeholder groups relevant to a particular matter*, such as a HA, impact, public environmental policy, or 'Issue'.

Environment managers, members of governance institutions, might also be seen as stakeholders. We prefer to distinguish them because of their specialized role in a SAF application.

# 8 Understanding ecological economics

The 'eco' components in 'ecology' and 'economics' have a common origin in the Greek word *oikos* for 'house', and so 'economics' may be thought of as 'rules for housekeeping' in human society, and 'ecology' the 'study of (nature's) household'. However, there is a difference between the real world in which ecosystems are to be found, and the world of economics and money that some people refer to as 'real', but isn't. To explain the difference, we will introduce the three 'worlds' postulated by Karl Popper. [5] They are:

1. the real, physical, world, in which exist ecosystems including their fleshy human component;

2. each human mind (Descartes: *"cogito ergo sum"*);

3. the world of information, shared amongst humans in the form of narratives, pictures, computer programs, cultural norms, laws, etc.

Ecology is world 1 (but understanding of it is in world 2 or 3, and system models will be made in world 3). Economies, defined in money terms (for example when Gross National Product is cited), are in world 3. If we define the purpose of an economy as the 'efficient satisfaction of human well-being needs' then those needs are, properly, in world 2. People need food, drink, etc for their corporeal bodies, of course, but their perceived needs are in their minds. As figure 3 shows, there are three routes to satisfying these needs: by central allocation of resources ('hierarchies'), by local social networks ('collective arrangements'), or by way of the impersonal market.

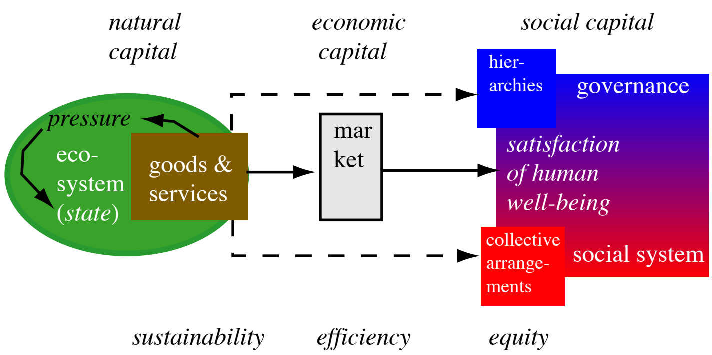



Figure 3: An ecological-social-economic (ESE) system

[5] Popper, K. (1972). Objective knowledge: an evolutionary approach, Oxford University Press.

Modern markets operate with the aid of money. The 'use-value' of objects can lie in any of the three worlds, but the 'exchange-value', or monetary worth, of a good or service is strictly a world 3 entity. Money is both information (about this valuation) and institutionalized trust, a promise to provide some use-value on demand. The idea of **ecosystem goods and services** provides the link between world 1 ecosystems and world 3 societies and economies. We define them as *the material and non-material things that ecosystems supply to humans, including ecosystems' capacities to assimilate wastes as well as provide tangible and intangible resources.* They are categorized in Table 6, where we follow standard practice and refer only to services, classing 'goods' as a *provisioning service.*

Ecological economists make several criticisms of classical economics.[6] One criticism is that it deals only with what humans do to satisfy well-being needs: what we spend, what we pay each other. A second is that it recognizes only the several sorts of human capital that have been amassed to make the production of goods and the supply of services more efficient: durable capital, intellectual capital, financial capital. Thus, classical economics does not take account of natural capital, which needs to be maintained if a system is to be sustainable, and it does not take account of 'externalities' - the uncosted effects of human activities on other humans and the environment. Ecological economics takes these into account in seeking to ensure that 'goods and services' are used both efficiently (the aim of economic management) and sustainably (the aim of environment management).

As an example, let's look at eutrophication in a Swedish fjord. Food webs depend on primary production. Nutrients are compounds of nitrogen and phosphorus; their scarcity in most pristine coastal seas restricts the amount of organic matter that phytoplankton, seaweeds and seagrasses can manufacture using the energy of sunlight, and so set a limit to the number of animals dependent on this food, and the amount of fish that can be harvested. Human activities (such as the production of sewage, or the fertilization of farmland) increase the supply of nutrients to the sea, and so increase primary production. Hence: more fish or shellfish for harvesting, but, also, problems such as hypoxia in fjord basins, which might kill fish, and decreases in water clarity, which might decrease the attractiveness of recreational waters to visitors. Behind such obvious effects, there is hidden service provided by the sea: that of recycling nutrients safely. Humans need to take account of the value of such services in making the economic case to build and operate a sewage treatment plant. Otherwise, the use of the sea as a dumping place for sewage might seem the cheaper option.

[6] In writing 'ecological economists' we are merging two somewhat distinct groups: 'environmental economists', who emphasize efficiency of resource use; and 'ecological economists' proper, who emphasize sustainability and social considerations. See: van den Bergh, J. C. J. M. (2001) Ecological economics: themes, approaches, and differences with environmental economics, Regional Environmental Change, 2, 13-23.

# Part II
# Getting started

*A SAF application starts by identifying an 'Issue' (in discussion with stakeholders and/or 'governance'), and by confirming that the SAF is an appropriate tool for working on it.*

| **Supporting documents** | *available from: www.coastal-saf.eu* |
| --- | --- |
| Levrel, H., Couvet, D., Mette, A. and Raux, P. (2011) | Scenarios in the System Design, SPICOSA Project Report, ??: ???, |
| Mongruel, R., Levrel, H. and Mathews, M. M. (2011) | Defining Economic Dimensions of Coastal Systems, SPICOSA Project Report, Brest: Ifremer. |
| Vanderlinden, J.-P., Stojanovic, T., Schmuëli, D., Bremer, S., Kostrzewa, C. and McFadden, L. (with others) (2011) | The SPICOSA Stakeholder-Policy Mapping Users Manual, with worked examples, SPICOSA Project Report, Guyancourt: Paris, Université de Versailles-Saint-Quentin-en-Yvelines. |

# 9 The steps of a SAF application

Here are the steps of a SAF application (Figure 4):

**Issue Identification** : consult with stakeholders and environment managers to identify the 'Issue', a Coastal Zone 'problem' involving a cause-&-effect chain from a *HA* to its *impact* on ecosystem goods and services; agree remedial 'scenarios' or management options with stakeholders;

**System Design** : identify and describe a 'virtual system' that embodies sufficient real-world behaviour to allow this problem to be explored through modeling, and begin to prepare for simulation modeling;

**System Formulation** : build conceptual, mathematical and numerical models for use in simulating system behaviour or its ecological, economic and social components; get data needed by these models;

**System Appraisal** : test your model(s) against observations on the real system; where necessary link the separate components and use the final model to explore the implications of the management scenarios;

**System Output** : take your results back to the stakeholders, explain what has been done and help the stakeholders to deliberate on their choice amongst options, using the results simulated for each scenario.

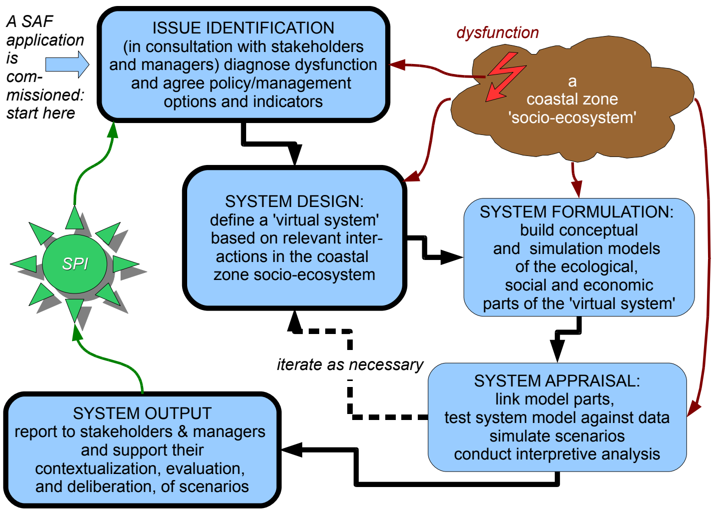



Figure 4: The steps of a SAF application. 'SPI' is the science-policy interface of Fig. 1. 'Socio-ecosystem' abbreviates *social and ecological system.*

This guide deals with the 'Issue Identification' and 'System Design' steps. Originally they were seen as a single step, but matters relating to starting a SAF application proved complex, and so we've separated them from 'System Design' proper. Starting an application involves not only identifying an 'Issue' to work with, but also answering two questions: 'who initiates an application?' and, 'is a SAF application really necessary?' If the answer to question 2 is 'no', then the application stops at that point, perhaps already having done some good by clarifying the nature of the problem.

If some 'Issues' are too simple to justify the time and resources required for a SAF application, others might seem too demanding: see section 16 about scaling the application to the available skills and time. The *System Formulation* and *System Appraisal* steps make heavy demands on the time and skills of modelers. [7] In other cases it may be possible to go directly from 'Design' to 'Output', the design of a 'virtual system' in consultation with stakeholders being sufficient in itself to help stakeholders' deliberations. All-in-all, do not treat this guidebook as dogma or a set of instructions that must be strictly observed. The SAF itself is a system, and may be adapted to, or evolve in response to, particular applications, so long as it remains informed by 'systems thinking'.

Finally, a caution. The SAF is a rational, 'Enlightenment', method. Given adequate data it should point to an optimum choice amongst management options. However, what will be chosen by a particular group of stakeholders will be constrained by law, culture and the existing distribution of power in the coastal zone society. 'System Design' tasks include a study of these constraints, but it should not be the aim of the SAF application to change them, except insofar as the provision of knowledge is empowering. You should be satisfied with any outcome that increases coastal zone sustainability.

## 10 Is your application really necessary?

A SAF application is appropriate only for some social-environmental problems. Figure 5 provides a flow diagram to help in deciding whether or not an application is required. This decision will, typically, be reached during the 'Issue Identification' task.

[7] Spicosa has made a library of model blocks, using ExtendSim software, to help them.

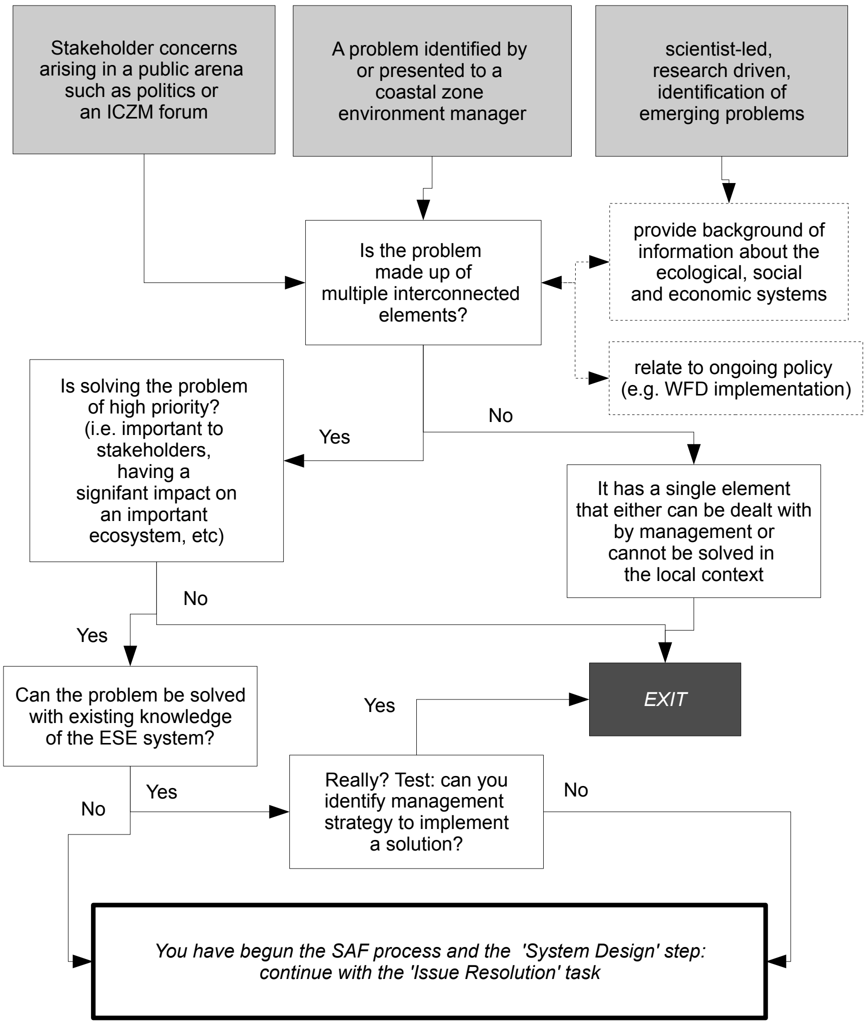



Figure 5: Is a SAF application necessary? A decision diagram.

# 11 Discussing and agreeing the 'Issue'

A SAF application starts with the task called 'Issue Identification'. *'Once upon a time,'* our tale might begin, *'scientists were talking together, when a stakeholder rushed into the room and said, "I've been impacted by a Human Activity, and something must be done!". Whereupon the scientists got together with other stakeholders and with environmental managers, identified the cause-&-effect chain from HA to impact, who was responsible for the HA, who was affected by it, what the economic consequences were, and some management options for ameliorating the impact. And thus 'Issue Identification was accomplished and the SAF application got underway.'*

In reality, the application might be initiated by stakeholders who seek better information to help them choose amongst management options already proposed, for example, by regional planners. Or the starting gun might be fired by local environment managers, who have themselves identified an environmental problem, or know that they soon have to implement a new law, and would like more information about the consequences of their planned actions. Or scientists themselves may start the process, through their own concern about an environmental problem, or their need to fund their work. In many cases the kick-off will be a messy process, involving repeated meetings between the three groups of actors, during which the essence is slowly distilled from of an initially confusing set of problems, perceived impacts, and potential solutions

This essence should be a well-defined HA-forcing-impact problem and its management options. We call the set of problem and options, the **Issue**, and the process of identifying it is, logically, called **Issue Identification**. Note that this task is about *defining* the Issue, [8] and not about *solving* the HA-impact problem, either now or later. A SAF application does not aim to solve problems, merely to give advice to stakeholders and environment managers, so that they can better deliberate about the options available to them. Sometimes solution will be achieved by the discussion that starts 'Issue Identification'. The SAF application need continue only if there remain uncertainties or disagreements that can be reduced by scientific study.

Questions may arise about who pays for that scientific study: we don't address those here but see section 16 about adjusting the SAF application to fit within the resources of time, people, skills and equipment available to the scientific team. Consider, also, a stakeholder's own deadlines. If a decision has to be made about a choice of management options within 6 months, then later information will be no use.

It is usually not feasible to engage with large groups of stakeholders during Issue Identification. Instead, aim to work with a small group of

[8] In earlier versions of the SAF guides, the task was called 'Issue Resolution', from the metaphor of bring the problem into focus by adjusting a telescope.

environment managers and representatives of stakeholder concerns. We'll call this the **Reference Group**, because matters are *referred* to them. [9]

Table 3 contains an example 'Issue', and Table 4 lists sub-tasks and action points for this step. The subtasks include the identification, not only of the environmental problem, but also of who is involved and what is likely to determine the economic costs and benefits of the problem and the options for dealing with it. Indicators of the state of the social-ecological system will be needed. The example uses 'water transparency' as an environmental indicator. It is easy to measure, widely understood, clearly relevant to the Issue of Eutrophication, and allows the success of management options to be assessed. The socio-economic indicator is the annual number of visitors to the fjord, considered as either an index of social satisfaction with water quality, or a proxy for money income from tourists.

Finally, note that the SAF requires simulation and appraisal of system state under several **scenarios**. Think of these as *'what-ifs'*. What would happen if management option B were chosen instead of A? [10] A SAF application aims to compare consequences in a safe 'virtual' world.

Table 3: Example Policy Issue

| | |
|---|---|
| Site: | A fjord in Sweden, south of Stockholm |
| Reference group : | About a dozen, including farmers, private citizens, elected representatives, officials from municipal authorities and the Environment Protection Agency |
| Human Activities: | Discharges from Sewage Treatment Plants, agriculture, and private sewers |
| Forcing: | Enrichment of the fjord with nutrients |
| Impact: | Degradation of water quality which can deter tourists |
| (Policy) **Issue**: | **Eutrophication** |
| Management options (scenarios): | (i) increased stripping of nitrogen from STW discharge; (ii) connection of private sewers to public STW plant; (iii) change in farming practices so that small er amouts of nitrogen compounds enter the fjord |
| Social concerns: | Desire for 'clean' water in fjord, distribution of costs amongst stakeholder groups. |
| Economic aspects: | Costs of sewage treatment, benefits of leisure visits |
| Provisional Indicators: | Water transparency, number of visitors during year |

[9] In earlier drafts the term 'Stakeholder Participant Group' was used

[10] Previous versions of this handbook referred to 'policy option'. 'Management option' seems the better term when dealing with choices at the operational level of governance; 'policy option' could be used when working at collective or constitutional levels.

Table 4: Subtasks and Action Points for the **Issue Identification** task. The arrows (→→) point to the 'deliverable' from each subtask. In some cases the 'Reference Group' may already exist, have identified the Issue, and be starting the process of a SAF application by asking to meet with scientists, who thus enter the process part way through step 2. In other cases it will be necessary to start with step 1.

| *Sub-task* | Action Point | |
|---|---|---|
| *1. Preliminary (before meeting with 'Reference Group')* | | |
| | – Make a preliminary list or map of human activities (HAs) and associated stakeholder groups | |
| | – Make a preliminary Institutional Map to understand Governance in relation to these HAs and stakeholders | |
| → | →→ `Scoping notes and maps.` | |
| *2. Reach agreement on Policy Issue(s)* | | |
| | – If necessary help form, and then meet with, the 'Reference Group' of stakeholders and environment managers | |
| | – Discuss Human Activities and Impacts with this group, and thus identify the dysfunction in the social-ecological system that will be the subject of the Policy Issue | |
| | – Analyse available information on the (ecological) cause-&-effect chain from HA to impact and evaluate the importance of different HAs and impacts and prioritize them in relation to the Issue | |
| | – Discuss the management, or policy, options in relation to the Issue | |
| | – Agree ecological indicators to use in comparing the outcomes of management options | |
| | – Thus, reach consensus on the 'Issue' | |
| → | →→ `Description of the Issue, including the problem, management options, and indicators.` | |
| *3. Identify economic and social aspects of the Policy Issue(s).* | | |
| | – Carry out Policy-Stakeholder Mapping to identify the main groups of stakeholders in relation to the Issue | |
| | – If resources permit, survey opinion amongst these stakeholders and list their main concerns in relation to the Issue | |
| | – Agree social indicators for use in the comparing the outcomes of management options | |
| | – List or map the main economic activities that have a relevant HA and Impact within the ecosystem | |
| | – List the main ecosystem Goods and Services that are relevant to the Issue | |
| | – Agree economic indicators for the Issue | |
| | – List the main economic drivers of change within the CZ system (relevant to the Issue) | |
| → | →→ `Outline report containing diagrams, lists, descriptions, and indicators` | |

# Part III

# System Design

*This part explains, briefly, how to carry out the 'System Design' step in a SAF application. It includes tables of tasks and action points, and the 'deliverables' from these actions points.*

| **Supporting documents** | *available from: www.coastal-saf.eu* |
|---|---|
| Bacher, C. and others ? (2009) | SAF Protocol Chapter on CZ System Formulation, SPICOSA D4.2, Brest: Ifremer |
| McFadden, L. and Priest, S. (2010) | Institutional Mapping, SPICOSA Project Report, London: University of Middlesex, Flood Hazard Research Centre. |
| McFadden, L., Green, C. and Priest, S. (2010) | Social Science Indicators for ICZM, SPICOSA Project Report, London: University of Middlesex, Flood Hazard Research Centre |
| Mongruel, R., Levrel, H. and Mathews, M. M. (2011) | Defining Economic Dimensions of Coastal Systems, SPICOSA Project Report, Brest: Ifremer. |
| Spicosa model library (containing example Extend models and blocks) | link from *www.coastal-saf.eu* to *www.spicosa.eu/dataportal* or directely to: *dataportals.pangaea.de/spicosa/models*, which requires login. |

## 12 The tasks in System Design

The **System Design** step is made up of the tasks listed in table 5, and described in more detail in sections 13 through 16. There is a table of subtasks and action points for each task. In these detailed task tables, the arrows (→→) point to the 'deliverable' from each subtask, the concrete outcome that shows that the subtask has been completed. Examples of these deliverables may be available on the *coastal-saf* website.

Table 5: The tasks and subtasks of the 'System Design' step of the SAF

| | |
|---|---|
| 1 | **System Definition**: section 13, table 7. |
| | *1.1. Define the Coastal Zone Virtual System* |
| | *1.2. Identify the external hazards* |
| | *1.3. Synthesize the state of the impacted system* |
| 2 | **Conceptual Models**: section 14, table 8. |
| | *2.1. Construct conceptual models of the Coastal Zone Virtual System* |
| | *2.2. Specify model outputs for later use.* |
| 3 | **Methods & Information required**: section 15, table 9. |
| | *3.1. Identify the modelling software and analytical methods to be used.* |
| | *3.2. Analyse the economic dimensions and identify suitable methodologies.* |
| | *3.3. Begin to acquire data.* |
| 4 | **Problem Scaling**: section 16, table 10. |
| | *4.1. Adjust the complexity of the Virtual System for scientific accuracy and balance and for feasability in implementation* |
| | *4.2. Begin to specify the formats for scientific publication and popular presentations of results* |
| | *4.3. Update the 'Designed System Report'* |

# 13 System Definition: describing the real coastal zone system, defining a *Virtual System*

This task (Table 7) requires *description* of relevant features of a Coastal Zone and *definition* of a *Virtual System* that contains only features relating to the identified 'Issue'. The distinction between, on the one hand, the complicated real Coastal Zone system, which includes both 'world 1' ecosystems (with their human populations and physical infrastructure) and 'world 3' economies and social institutions, and, on the other hand, the 'world 3' virtual machine that will enable you to predict the outcome of management options or policy scenarios, is crucial to the SAF. In 'System Design', it is, of course, the Virtual System that is being designed: the real world can only be described. As you move on to 'System Formulation', some parts of this virtual machine will be made into mathematical and simulation models.

During the 'System Definition' task of 'System Design', however, your main tools are written words, arranged in lists of key features and in narratives of the relevant politics and geography of the study area. A good narrative links the items of a list in an explanatory, sometimes causal, framework. Maps play a useful supporting role. There are two sorts of maps: those that show a territory realistically but at a much smaller scale, and those that, like most maps of city transport networks, emphasize functional links rather than exact spatial relationships. It is a small step from such simplified maps to those that are purely conceptual, such as those that show power relationships between institutions.

Spatial averaging, categorization and typification are further aids to simplification. For instance, real world systems can often be mimicked by a small set of boxes, or even by one box, in a Virtual System, as illustrated by the simple model on page 13. *Stakeholder mapping* involves grouping stakeholders, and is aided by recognizing essential features to allow use of prior knowledge of types. 'These are farmers, therefore they plough and sow . . . and use fertilizers.' In the case of eutrophication as an 'Issue', it may be acceptable to define all phytoplankters as a single entity in the virtual system. But don't go too far: do not homogenize two categories whose distinction is of the essence of the 'Issue'. For example, the definition of eutrophication includes the idea of 'disturbance to the balance of organisms', and the relevant Virtual System may thus need at least two phytoplankton components. Using one box to represent the whole of the physical system may make it difficult to simulate water exchange driven by a two-layer estuarine circulation. 'Farmers' may actually fall into two groups: those using conventional methods including much inorganic fertilizer, and those using 'organic' methods resulting in less leakage of nutrient.

The task of 'System Definition' starts by looking at the cause-&-effect chain within the impacted ecosystem. The Virtual System that you are designing is, however, a social as well as an ecological system, and so you need also to identify relevant economic and social features. Table 6 brings an economic perspective. *Stakeholder Mapping* and *Institutional Mapping* will help to complete your lists, which should include relevant organs of government and their roles. Key questions here concern the interaction between services and capitals, the ownership of capitals and access to services by different stakeholder groups, the role of laws and cultural norms in determining this at the operational and (local) collective levels. How do these relate to the Issue, which will change, or need to change, in the different management options? Some of them might become components of the models, others used to appraise the outcomes of the different scenarios.

You need to identify the boundaries of your Virtual Coastal Zone. These may be administrative boundaries, or those set by topography, in the physical world. The essential feature of the boundaries of a Virtual System is that they separate a domain in which modeled processes can interact, from an 'outside' which will be represented by **boundary conditions**. As illustrated on page 13, boundary conditions can be set either as the state of the external world at the Virtual System boundary, or the fluxes across that boundary. As an example, consider the rivers that drain into a coastal sea. Does the river catchment need to be part of the Virtual System, or can it be placed outside the boundary and its effect simulated by data about discharge of water, sediments, dissolved substances, etc.?

Sub-task 2 concerns *Risk*. Think about what might go wrong as a result of events beyond the boundaries of your system. What are the likely major hazards, and what is the likely probability of their occurrence?[11] For example, around the Mediterranean basin, and in other tectonically active zones, the hazards include earthquakes and volcanic eruptions, and the possibility of these may influence choice between management options. Some may be more resilient against physical damage. What about socio-economic hazards, such as collapse in governance, or global economic recession?

The Reference Group of stakeholders etc. should be consulted again, towards the end of this task. Does your Virtual System definition correspond with the way in which they see things? Bear in mind that multiple representations of the real system are possible; it may be understood, and defined by more than one Virtual System. This does not mean that truth is relative to the observer. A defined Virtual System must be compatible with existing information about the real Coastal Zone system, and the results of the models of the Virtual System, must agree with observations in the real system. This agreement will be explored in the 'System Appraisal' step of the SAF application.

[11] *Risk* is formally defined in this context as the probability of something (bad) happening, multiplied by the intensity of the *hazard*. Risk can be reduced by decreasing the probability of occurrence, or ameliorating the hazard itself.

Table 6: Including economics in the Virtual System: capitals and services in relation to the clam fishery in the Lagoon of Venice

(a) Capitals

| category | subcategory | contents | examples |
|---|---|---|---|
| **physical** | fixed | buildings, fixed machinery, roads, harbours, etc | buildings for storing and processing shellfish |
| | movable | equipment | fishing boats |
| | working | stocks of raw materials and products for sale | dredged clams (which might be relaid) |
| **human** | individual | skills and knowledge | boat operation, clam dredging, etc |
| | intellectual | patents, books, software, etc | training courses in fisheries management; traditional ecological knowledge |
| | social | networks, institutions | fishing co-operatives, government fisheries office, etc |
| **natural** | renewable* | stocks of living things, soil etc | the stock of wild clams in the lagoon |
| | non-renewable* | fossil fuels, minerals, biodiversity | marine biodiversity |

* renewability is a matter of timescale: fossil fuels need millions of years

(b) Human activities

| economic sector | contents | examples |
|---|---|---|
| primary | exploiting natural resources (mining, fishing, forestry, some farming) | harvesting wild clams, or using lagoon to grow them |
| secondary | processing and distributing these resources or things made from them | shellfish processing |
| tertiary | supplying services to other people or institutions | insuring boats, licensing shellfisheries, fish restaurants |

(c) Ecosystem services*

| category | contents | examples |
|---|---|---|
| supporting | necessary for other ecosystem services | primary production by lagoonal phytoplankton |
| provisioning | products or goods, e.g. food, materials, medicines, biofuels | wild or farmed clams from the lagoon |
| regulating | climate and water regulation, erosion control, storm protection etc | waste removal as a result of lagoonal flushing |
| cultural | nonmaterial benefits: spiritual, recreational, aesthetic | 'sunset over the lagoon of Venice' |

* Millennium Ecosystem Assessment, 2003. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington, D.C.

Table 7: Action Points for **System Definition** task. This task begins the process that leads from knowledge of the real coastal zone system to end in the construction and use of a mathematical model. The Virtual System may also include relevant socio-economic features that can be conceptualized but will not simulated. It is important to ensure that all the main real-world social, economic and ecological functionality relevant to the 'Issue' is represented within the Virtual System, although maybe in a simplified manner.

| *Sub-task* | Action Point | |
|---|---|---|
| *1. Define the Coastal Zone Virtual System:* | | |
| | – Describe the cause-&-effect chain from Human Activity via ecosystem dysfunction to Impact that is involved in the problem.<br>– Draw a map of the real system showing the main features to be included in the Virtual System, including boundaries.<br>– Identify vertical structure that is important to the coastal ecosystem's functioning.<br>– List the main ecosystem components, and their main links, to be included in the Virtual System because they are relevant to the 'Issue'.<br>–Specify the physical boundary conditions: list or map the main trans-boundary exchanges that should be included in the Virtual System.<br>– Identify the social components to be included in the Virtual System, including the main property rights and Goverance structure relating to the Issue. Draw an Institutional Map.<br>– List the present and potential economic demands likely to be made in the real system in relation to the Policy Issue, and which should be included in the Virtual System. | |
| → | →→ `maps and lists.` | |
| *2. Identify the external hazards:* | | |
| | – List the main external hazards that pose a risk to the real system in relation to the 'Issue'. Evaluate the level of hazard, the probability of its occurrence, and its consequence for each management option, or begin the work needed to do this if there are complicated matters to consider. | |
| → | →→ `preliminary list of risks` | |
| *3. Synthesize the state of the impacted system:* | | |
| | – Include the outputs from sub-tasks 1 and 2 in an illustrated narrative that defines the Virtual System in relation to the 'Issue' and describes the effect of relevant Human Activities on the current state of the ecosystem, the goods and services that it provides, and the stakeholders involved.<br>– Discuss this narrative with other scientists and the Reference Group (of stakeholders and public officials) in order to identify knowledge gaps, take account of traditional ecological knowledge and the Reference Group's perception of the socio-economic system. | |
| → | →→ `First draft of the 'Designed System' report` | |

# 14 Making a Conceptual Model

'Conceptual Modeling' (Table 8) continues to formalize the description of the Virtual System. Whereas 'Issue Identification' was largely about discussion with stakeholders etc, and 'System Definition' mostly about written lists and narratives, 'Conceptual Modeling' is mainly about diagrams.

We recommend starting with a blackboard, whiteboard or flip-chart as a focus for discussion, and then switching to electronic tools to make the conceptual model more precise. During the Spicosa project we explored a a range of software. Microsoft PowerPoint or OpenOffice.draw[12] can be used to draw boxes and arrows and add annotations. EmergySystems.org hosts a set of symbols that can be used in such diagrams to characterize a range of systems properties.[13] The modeling software Stella enables conceptual models to be made using a simple set of icons for state variables, fluxes, parameters and information flow.[14] This can be done without adding the quantitative equations required to make the model work. We found the freeware Cmap to be especially useful at this stage.[15] As the example in Figure 6 shows, its boxes can be used to represent system 'nouns' or things, and its linking arrows, 'verbs' or relationships.

The example demonstrates several general points. A box has been drawn to include the main components and relationships of the ecosystem relevant to the Issue. Several arrows cross the left-hand side of the ecological box, and these represent the boundary fluxes (the 'external inputs'). All are relevant to the issue, but the arrows for discharges and leaching are directly involved in the Human Activity-forcing link, whereas the arrow for exchange represents a natural process that continues irrespective of the HAs but is essential to quantifying the effect of the human forcing.

The diagram includes key social and economic features of the coastal zone system as related to the locally defined Issue (table 3). There is a feedback loop from water transparency by way of Environment Managers to control of nutrient discharges. The managers, plus householders and farmers, are parts of the socio-economic system within the boundaries of the conceptual model. Whereas the ecosystem model is very likely to become a mathematical model, this may not be true of the socio-economic components. But these have to be understood to make sense of system behaviour. The local income resulting from visitors is in our example one of the agreed management indicators (and thus a 'system output'), so it will be necessary at some stage to have a means to estimate this as a function of simulated

[12] part of the freeware package OpenOffice.org: http://www.openoffice.org/

[13] The symbols were proposed by Odum., H.T. 1994. Ecological and General Systems: An Introduction to Systems Ecology. University Press of Colorado. They can be copied from: http://www.emergysystems.org/symbols.php.

[14] isee systems: http://www.iseesystems.com/

[15] IHMC Cmap Tools: http://cmap.ihmc.us/

changes in transparency. Finally, the two EC directives mentioned here may be treated as boundary conditions for governance: they influence what happens in the 'virtual machine' but are not influenced by it.

Remember that the SAF started and will finish with stakeholders and environment managers. Thus, although the task of making a conceptual model - of formalizing understanding or hypotheses about system function - is engrossing for scientists, the purpose of the modeling work is to return some information to stakeholders. So, keep clearly in mind what the virtual machine is supposed to make or indicate!

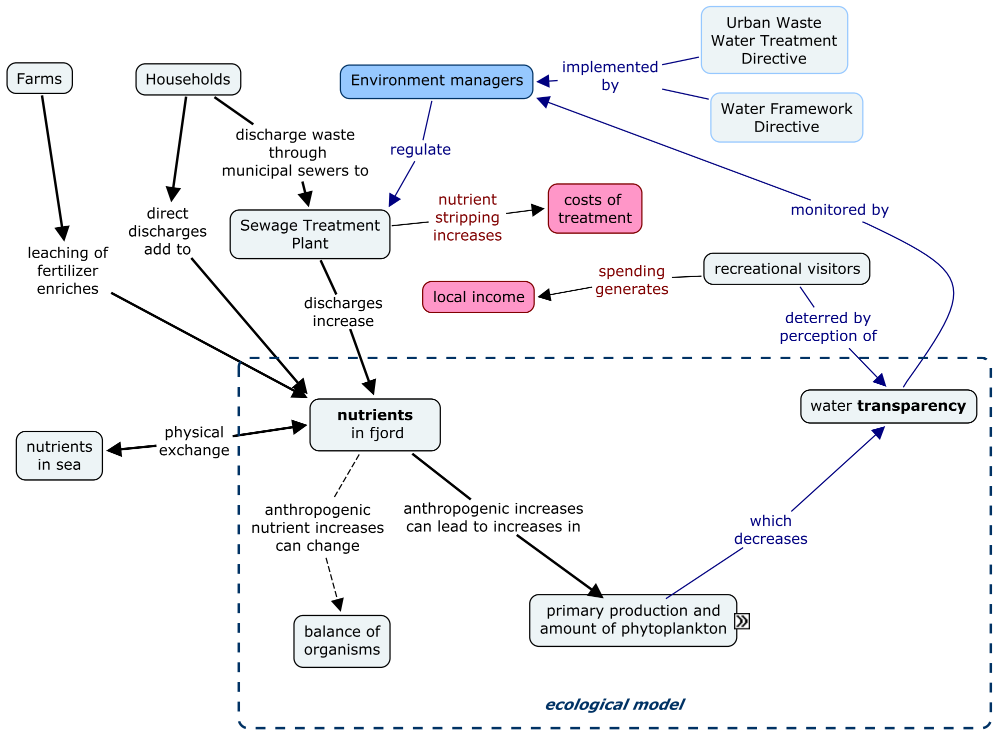



Figure 6: Example conceptual model, based on Eutrophication as an 'Issue' (Table 3). This example uses Cmap Tools to show ideas about the contents and causal relationships of the 'virtual system' as they might emerge from a preliminary discussion; it is not yet a full specification for the mathematical model, although suggests that 'nutrients' and 'transparency' might become *state variables* in this model. An attempt has been made to distinguish actual flows of nutrients (thicker lines) from less well-defined cause-&-effect relationships or information flows. Cmap allows a hierarchy to be set up within the conceptual model, with complex low-level objects collapsing into simpler objects when viewed at a high level. The tab on the 'phytoplankton' box indicates that it can be expanded in this way, to show a subsystem dealing with the effect of light and nutrients on micro-algal growth.

Table 8: Action Points for **Conceptual Modelling** task. This task continues the work of formalizing the Virtual System. It can be rewarding in itself, in that it is likely to bring about a greater understanding of differing conceptualizations of the Virtual System by scientists of different disciplines as well as by members of the Reference Group. But it is also part of the development of simulation models, and so it is useful to begin to think about the data the model will generate in later steps of the SAF application.

| *Sub-task* | Action Point | |
|---|---|---|
| *1. Construct conceptual models.* | | |
| | – Choose a method for representing the Virtual System according to consistent rules: select a set of graphical symbols and connectors and a means for assembling these - either by drawing or by using software.<br>– Prepare conceptual models of the Virtual System, which should centre on the cause-&-effect chain from Human Activity to Impact on ecosystem goods and services. Several models may be made, either showing different disciplinary or heirarchical parts of the social-ecological system or displaying different opinions of how the relevant part of the real coastal zone system is thought to work. Models should show the main social, ecological and economic compartments and variables, primary cause-&-effect relationships; key forcings; external inputs (mass, energy, and information), internal inputs.<br>– Involve the Reference Group : depending on how much discussion took place during the 'System Definition' step, consider further discussion with stakeholders and environment managers in order to represent their knowledge within the conceptual models. | |
| → | →→ `Conceptual models as diagrams and software` | |
| *2. Specify model outputs.* | | |
| | – Identify the Virtual System variables that might be used to demonstrate reliable simulation of the coastal zone system during 'System Appraisal'. Typically, these will be time series of state variables, or rates, that can be compared with observations.<br>– Specify the system outputs for both qualitative and quantitative analyses: Ensure that the conceptual model diagram(s) contain(s) marker(s) for the information that is expected to be output from the simulation model(s), corresponding to or leading to the indicators used to evaluate the effects of various scenarios in the 'System Appraisal' and 'System Output' steps. | |
| → | →→ `result of this sub-task will be included in the conceptual model diagrams.` | |

# 15 Thinking about modeling tools and data needs

The next task is to think about what will be needed to make models, to run numerical simulations, and to appraise or interpret the results, in later steps of the SAF. The contents of the task concern decisions about whether existing models can be used or new models developed, what software should be used, and what data will be needed (Table 9).

This task overlaps with those described in the next step, 'System Formulation'. However, experience has shown that it's best to begin data gathering as early as possible. Some of the kinds of data that you need to think about getting are shown in Figure 7. Start by querying public data bases (such as those of meteorological information). After this, consult other sources, including the scientific literature and your stakeholders. If needed data can't be found, can you simulate them with an accessory model (e.g. to calculate sunshine as a function of latitude and year-day), or adapt information from a similar coastal zone? Only if all else fails, should you consider the expensive and time-consuming process of measuring what you need.

You may also need to revisit the economic aspects of the Virtual System and to think about methods for economic assessment of the results of simulation modelling.

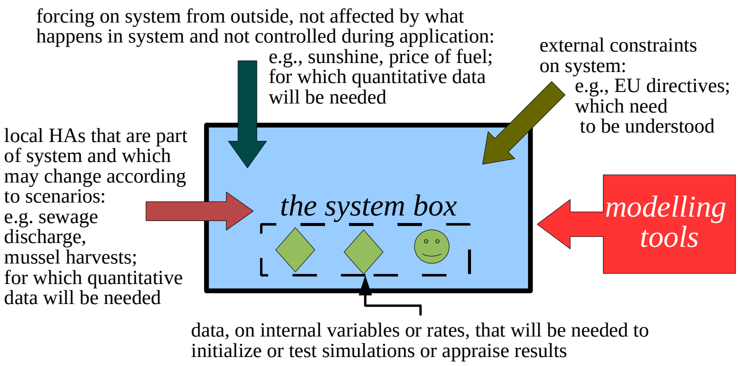



Figure 7: Illustrating data and methods needed

Finally, your choice of modeling 'tools' is crucial. On the one hand, there are programming languages such as Fortran, C++, or Matlab [16], in which state variable equations can be coded. You may have to write numerical integration and graphics routines, or may be able to draw on a library. On the other hand there is specialized modeling software, containing built-in integration routines and graphics, in which models are made by connecting ikons. Examples include Stella and ExtendSim.[17] If possible, adapt existing

[16] Matlab (http://www.mathworks.com/) is expensive but widely used
[17] ExtendSim (http://www.extendsim.com) was the standard tool in Spicosa.

models and use familiar software. Making a simulation model from scratch is time-consuming.

### Box: the choice of software and the use of modelers

At the start of the Spicosa project we had thought that conceptual modelling was (merely) a step on the way to the making of simulation models during 'System Formulation'. We further thought that the subject specialists who learned to use the ExtendSim software would be able to create a library of validated 'model blocks' - for example, containing algorithms for simulating phytoplankton growth or decision making in water supply - which could be drawn on by other modellers, so that an Issue-related Virtual System model could be assembled quickly. In effect, the software was chosen to support 'collective rationality' in model-building.

There was such rationality in model building, and it was aided by the use of a common software tool, but, we learned, it mainly involved two things that we had not expected: the use of conceptual models to bring the disciplines together with each other and the Reference group, and the swopping of modeling experience between skilled and trainee modelers. The task of drawing up a complete library of validated and user-friendly blocks proved beyond the resources available to the project, although example blocks are available from the Spicosa model library. (You will need the ExtendSim software, and familiarity with Extend 'library files' to view them, and also will require to be registered with the site.) If you want to explore ExtendSim, the suppliers ( www.extendsim.com) provide a demonstration version of the software, and the Spicosa-related manuals by Maes (2009a, 2009b) introduce its use in the context of coastal zone systems.

This is what we learnt from the project, and now recommend:

- think about the modellers as well as the software and the model; if your SAF application is stand-alone (i.e. you don't need to swop model code with other groups), use software with which your modelers are already familiar;
- you need someone with generic skills in systems theory and conceptual modelling as well as generic modellers who are (if possible - they take a long time to train) already skilled in mathematics, programming, and running and testing models;
- the strategic software choice - between programming languages and ikon-based modelling software - is best dictated by existing skills and by cost issues concerning licenses;
- ikon-based models are easier for non-modellers to understand - to some extend they explicitly represent the conceptual model in the simulation model;
- the chosen software should include a library of routines for numerical integration, handling data-sets, graphing output and comparing it with observations;
- try to avoid reinventing wheels: once the Virtual System has been conceptualized, review the relevant discipline-based literatures for appropriate mathematical formulation of each process that you want to include in the simulation model, and seek code libraries containing well-tested algorithmic implementations of these formulations.

Table 9: Action Points for **Methods & Information** task

| *Sub-task* | Action Point | |
|---|---|---|
| *1. Identify software, methods and formats.* | | |
| | – Decide on strategy for simulation modelling, including whether to adapt available existing models, or develop new sub-models, as components for the Virtual System simulation model.<br>– Identify software tools for building the simulation model, deciding between the use of familiar software and the acquisition of new and perhaps more systems-oriented software.<br>– Specify auxiliary models that may be needed to link with the main simulation model (for example, to provide boundary conditions): they should be available, and feasible to use with available resources.<br>– Identify other software or analytical tools needed (e.g. Geographical Information Systems, tools for time-series or statistical analyses).<br>– Identify data format (and any Intellectual Property issues) for existing data sets, and decide how these data sets and model outputs will be stored. | |
| → | →→ `Documented decisions about strategy, tools, formats and existing models.` | |
| *2. Analyse the economic dimensions of the Coastal Zone system and identify suitable economic assessment methodologies.* | | |
| | – If economic dimensions of your models are not clear from previous tasks, go through the 'step-by-step' approach in Mongruel et al. (2011).<br>– Identify appropriate assessment methodologies to explore the future states of the Coastal Zone system, and agree these with the Reference Group. | |
| → | →→ `Decisions about approaches and methods for economic assessment.` | |
| *3. Begin to acquire data.* | | |
| | – Identify the relevant Human Activities and set in motion actions to acquire relevant 'pressure' or 'forcing' data.<br>– Identify existing economic data relating to these HAs and set in motion actions to acquire these data.<br>– Identify existing demographic and social attitude data relating to these HAs and set in motion actions to get them.<br>– If Coastal Zone Governance structure relative to HAs is not clear from previous tasks, set in motion actions to identify relevant laws and governance institutions.<br>– List ecological, social and economic data (for initial conditions, forcing or boundary conditions, and testing) that will be needed for simulations and tests, identify sources, and set in motion actions to acquire these data.<br>– Where possible, identify model parameter values that will be needed, identify sources, and set in motion actions to acquire these data.<br>– Decide what to do in the absence of existing data: interpolate, simulate with auxilary models, use expert judgement, or (bearing in mind expense and time requirements) commission observations or experiments. | |
| → | →→ `Actions taking place to get data` | |

# 16 Reflecting on progress so far

'System Design' is a tool like a microscope or telescope; the sequence of tasks in this guide can be likened to the process of bringing the object of attention more sharply into focus. That object is the Virtual System that includes the connection from the Issue-related Human Activity to its impact on ecosystem goods and services and their contribution to the 'well-being needs' of stakeholders. Seen in the light of this analogy, the 'Problem Scaling' task is simple: it is to consider whether the designed system, in the form of the conceptual model, is too simple or too complicated. You do this so that you can scale - i.e. adjust the number of model components and the data requirements - for relevance (to the Issue), for resources (of skills and time available to you), and in terms of scientific understanding.

'An idealization is a deliberate simplication of something complicated with the objective of making it more tractable. ... Aristotelian idealization amounts to 'stripping away', in our imagination, all properties from a concrete object that we believe are not relevant to the problem at hand. ... Galilean idealizations are ones that involve deliberate distortions. Physicists build models consisting of point masses moving on frictionless planes, economists assume that agents are omniscient, biologists study isolated populations, and so on.' [18] 'Occam's razor': *it is vain to with more what can be done with fewer*, suggests starting with a simple model, and adding extra components only when it proves impossible to get realistic results from the simple model. In the face of a complicated physical and human-social world, Occam's razor is helpful. When applied to models of systems, however, it may slice away something that appears minor but which actually plays a critical part in a feedback loop. Linear models, such as those simulating cause-effect chains, can be made simple; but most systems have feedback loops that you may want to simulate (Figure 8).

'Problem Scaling' can lead to removal of some existing parts of the conceptual model, and the addition of new parts. In ideal circumstances, such adjustment could take some time. In practice, your application will be restricted by the resources of people, skills, time and information available to you, and by the time-constraints on members of the Reference Group. So the Virtual System needs to be reconsidered in relation to those constraints, and a decision reached, in consultation, as to what can be done. If your modelers are experienced and already have portfolios of model components, then it will be possible to build, quickly, an adequately complex model. If that is not possible, do as much as you can! Our experience in Spicosa suggests that even simple models, simulating only parts of the system, can be useful, and that the business of resolving the Issue and creating a con-

[18] Frigg, R. and Hartmann, S. (2006) 'Models in Science', URL: http://plato.stanford.edu/entries/models-science/

ceptual model can help by clarifying understanding of ecological, social and economic constraints on the management solutions, even if no numerical model is built.

A SAF application is a process carried out jointly with stakeholders and environment managers or policy makers. In addition to on-going discussions with the Reference Group, there will be a need to report to the wider community of stakeholders in the 'System Output' step. It is best to start preparing for this from the start, by documenting each application step as it takes place. In addition, it may be desirable to produce a scientific output, in the form of a paper in peer-reviewed journal. This will strengthen the perceived legitimacy of the scientific results, will disseminate what has been learnt out into the wider scientific community, and may be vital for the career prospects of the scientists involved.

Now you should be ready to work through the action points in Table 10, before moving on to the SAF's next step of 'System Formulation'. In that step, what we have here called the *social-ecological system* (to emphasise its unity) becomes the *ESEsystem* to denote that models for ecological, social and economic components may be made separately, by experts in the different disciplines, before linking during the 'System Appraisal' step.

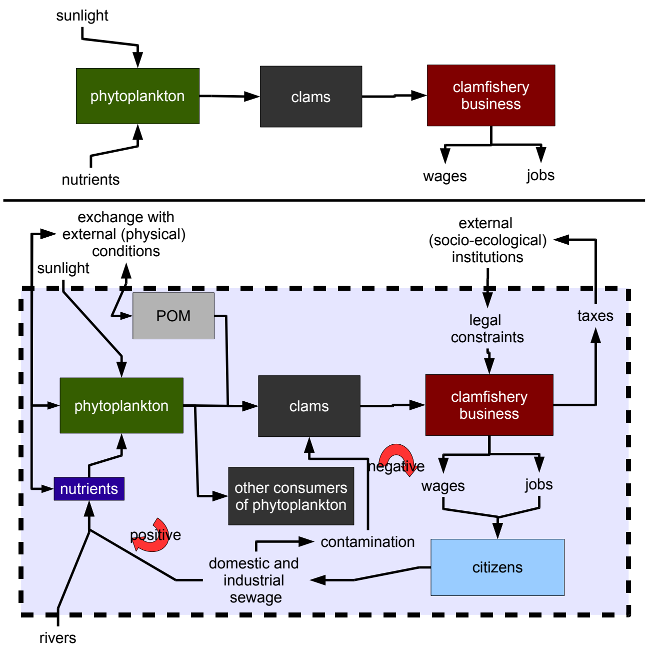



Figure 8: Illustrating Problem Scaling. On top is a simple chain from phytoplankton to a fishery in a coastal lagoon; the more complex version underneath includes several feedback loops as well as boundary fluxes.

Table 10: Action Points for **Problem Scaling** task.

| *Sub-task* | Action Point | |
|---|---|---|
| *1.Adjust the complexity of the Virtual System:* | | |
| | – Adjust the complexity of the science in the Virtual System to get the best balance of simplicity and accurately, so that so far as is known, scientific understanding of the key process are represented accurately but without too many parameters, so that in each part of the model there is a balance between contribution to explanation of variability and the amount of work that will be needed to set up and run the simulation model. This may mean *scaling down*, by: removing state variables from the list; re-adjusting the Virtual System's extent to simplify boundary condition description; simplifying the representation of spatial heterogeneity; removing or simplifying subsystems; focussing on a single space and time scale, so eliminating some process descriptions. Or, it may mean *scaling up*: adding variables, feedback loops, and process descriptions. | |
| → | →→ `revised conceptual model` | |
| | – Ensure feasability of implementation for the model by adjusting the complexity of the Virtual System to ensure that it will be possible to construct and run the simulation model(s), and assess the results, with available resources. | |
| → | →→ `updated management plan for the application` | |
| *2. Begin to specify the format for results:* | | |
| | – Begin to think about the need to publish scientific results, and if necessary identify suitable peer-reviewed journals in the natural economic and social sciences, and note formats and requirements.<br>– Begin to specify the format for presentations and visualizations (for policy-makers, stakeholders, and public) recommended for use in 'System Output'. This might include thinking about a media strategy, and includes discussing requirements with the Reference Group. | |
| → | →→`notes related to the outputs, perhaps with the outline of a paper and part of a set of presentation slides` | |
| *3. 'Designed System Report':* | | |
| | – Compile, or update, a 'Designed System Report' which will be a working document, to be updated in subsequent steps, and from which information can be drawn in 'System Output' and for scientific publication | |
| → | →→ `Designed System Report` | |

# 17 Appendix: Authorship, history and citation

The original 'System Design' handbook was the responsibility of SPICOSA's Work-Package 3, which began work at the first SPICOSA meeting in Rome, 20-22 February, 2007. The handbook went through several drafts, culminating in v.1.26 of 13 November 2007, which took account of feedback received at the workshop in the University of Plymouth, 12-14 September 2007.

Further revisions were drafted in 2008, until in Brest in October 2008, it was decided to use a web-based and layered approach to the SAF handbook. Thus, the original v.1.26 was split into sections, which were worked on to a plan developed in Rome in June 2009. v.3.02 of this 'Guide to System Design', a summary of key ideas and a list of tasks and subtasks, was written by the WP3 leader, drawing on material from v.1.26 and incomplete drafts of separated sections of the handbook, and the reported experiences of SSAs. It was finished in February 2010, at which time WP3 was brought to an end. Work on modifying the guide for use on the SAF web-site continued in Spicosa WP6, and resulted in this version (v3.09) in February 2011.

Table 11: Contributors to 'System Design' handbook and Guide

| SPICOSA partner | Contributor |
|---|---|
| 1: IFREMER | Rémi Mongruel & Harold Levrel |
| 3: IAMC-CNR | Tom Hopkins (*project joint co-ordinator*) |
| 9: BUC | Audun Sandberg |
| 14: UEA–CSERGE | David Hadley |
| 17: NUE | Teresa Fernandes |
| | Paul Tett (*WP3 leader & main editor*) |
| 19: ULB | Johanna d'Hernoncourt |
| 22: SAMS | Vicki Hendrick |
| | Paul Tett ( *from March 2010*) |
| 24: KMGNE | Anne Mette ( *WP6 leader & SAF dictator*) |
| 26: IVM | Jan Vermaat & Alison Gilbert |
| 32: MU-FHRC | Loraine McFadden & Colin Green & Sally Priest |
| 51: SZN | Maurizio Ribera d'Alconà |

**SPICOSA**, Science and Policy Integration for Coastal Systems Assessment, was Proposal/Contract no. 036992 in the European SIXTH FRAMEWORK PROGRAMME, PRIORITY 1.1.6.3: Global Change and Ecosystems. Start date of contract: 1 February 2007; end: 31 January 2011.

**Cite this document as**
Tett, P., Mongruel, R., Levrel, H., Hopkins, T., Sandberg, A., Hadley, D., Fernandes, T., Hendrick, V., Mette, A., Vermaat, J., Gilbert, A., d'Hernoncourt, J., McFadden, L., Priest, S., Green, C., and d'Alconà, M.R. (2011)
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