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Coping with complex and dynamic systems. An approach to a transdisciplinary understanding of coastal zone developments

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Abstract. Complexity and uncertainty play important roles in coastal management. Economic development may push the coastal system beyond its resilience thresholds as a result of interactions between environmental and socio-economic processes. The concepts in this paper link processes of system change, natural evolutionary processes observed in coastal zones, to processes of social evolution. An indicator based on calculating an ecological footprint for coastal zones is presented to guide decision-making in spatial and economic planning. The suggested indicator may support a range of methods linking economic valuation and environmental impact analysis.

Keywords: Decision-making; Ecological footprint; Environmental planning; Socio-economics.

Introduction

Coastal zones are complex in their environmental structure and functions. They have a high biological diversity and can provide self-sustaining functions and resources needed for human use. Humans are faced with multiple opportunities in using parts of the coastal zone ecosystems as resources, for settlements and for the services of these systems. Coastal zones have always attracted people to live in or close to them and economic activity has affected their environmental quality by sewage discharge, application of pesticides to adjacent farmland, and a variety of other industrial, agricultural and municipal pollutants. Increasing population densities of coastal regions reinforce these threats. On the other hand, coastal zones are highly dynamic and capable of adapting to changing circumstances.

Located at the edge of land and marine waters, coastal zone ecosystems are subject to evolutionary processes. How can we safeguard such processes? A related question is; How do natural ecosystem disturbances and economically induced changes interact and how do they change the natural system's resilience? These two basic questions will influence every management strategy applied to coastal zone regions.

Decision-making in a complex world

Resource use decisions are always made in a society context, and this may affect policies at different hierarchical levels such as:

- The individual, the household, the group or the firm level within a specific economic sector or in the interface between different sectors.
- In local communities, within regions, nations, continents or at the global scale in a specific socio-economic, socio-political, cultural or environmental context.

Environmental impacts can either be reinforced or buffered through the economic or social systems. For instance, society may emphasize mitigation strategies or not. It may regulate waste discharges by banning substances or by introducing an ecological tax. The nature of the primary environmental impacts will be different depending on which mitigating system is used. The interactions between the system levels may lead to a series of direct and indirect effects that operate on different spatial and time scales. Decision-making, therefore, needs to be based on a methodological framework that allows observation of direct and indirect effects.

An example of this is the regulation of PCBs (polychlorinated biphenyl) in the Baltic Sea. PCBs were unregulated until the 1970s because their impacts on aquatic life were unknown. The Baltic Sea environment suffered because PCBs caused seals to become infertile and the top predator in the Baltic Sea came close to extinction. The recovery of the seal population after the ban of PCBs in 1985 (Helsinki Commission, Recommendation 6/1) clearly showed the relationships between the economic, political and environmental systems.

Decisions of individual consumers may also influence other levels in ways that are not always immediately obvious. An example is the demand for diapers. If everyone switched from disposable to cotton diapers, the pulp and paper industry would suffer from a serious drop in the demand. This does not, however, necessarily mean that the overall economic output would decline.

Diaper services (such as loundering) may compensate for jobs lost in pulp and paper industries. Moreover, this change in consumer behaviour would surely reduce the social costs of clear cutting old growth forests and the subsequent erosion in watersheds.

It is also important to remember that not all economic decisions take place within the market system. Transactions in the informal economy do not show up in economic measures that register transactions of goods with established prices. The sectors of an informal economy may cover almost 50-60% of all economic activities in industrial countries (Biesecker 1996) and even more in developing countries. These sectors are more relevant in coastal zones in which a substantial part of the economy is still subsistence orientated.

The economic theory of decision analysis uses the concepts of 'state' and 'acts'. States describe the knowledge-based perception of a present or a future situation. Acts describe the move from a preceding state to the succeeding state. The preceding state predetermines the options to move and some of the parameters of the future state. The latter assumption holds, as long as a system stays resilient. Although social actors may expect a succeeding state to be a desirable outcome of decision-making, not all moves will necessarily result in a desired future state. 'Drifting' in the implementation process is a property which arises from system complexity and system resistance to change. In this context, it is necessary to distinguish between 'resistance' and 'resilience'. Whereas resistance describes the property of a system to resist change, resilience is the capacity of a system to absorb fluctuations. Further, one may distinguish internal or external fluctuations challenging the system's capacities. Whereas a decision is mainly an event internal to the system, other changes are external to the system in which the decision is made. Examples within the natural environment might be the eruption of a volcano or climate influences on floods and drought. However, this process can also go in the other direction. A decision could influence the environmental system in a way that flips it from a preceding resilient state into another state. The succeeding state in most cases is also resilient but has different constitutional parameters.

Theories of decision-making

Fig.1 shows a hierarchy of theories of decision-making. The narrowest approach is cost-benefit-analysis. This approach uses market or pseudo-market prices to judge impacts on society and/or the environment (see Hanley & Spash 1995). Cost-benefit studies reflect a unique and static situation that may help to choose between different technological alternatives, but its narrow approach may be inappropriate when non-market considerations are important.

Another approach, derived from expected utility theory (von Neumann & Morgenstern 1944), is game theory. Players have relatively good knowledge about their own opportunities within a settled agenda and also those of the other players. They may use knowledge, experiences as well as cost-benefit studies from previous moves as well as those they are making during the game. Game theory is a rather mathematical approach where decisions are made within a fixed agenda. The relevance of game theory to real decision-making situations is controversial.

Decision analysis (Raiffa 1968) may expand the scope of game theory to a more comprehensive system. Although previous moves play an important role, the

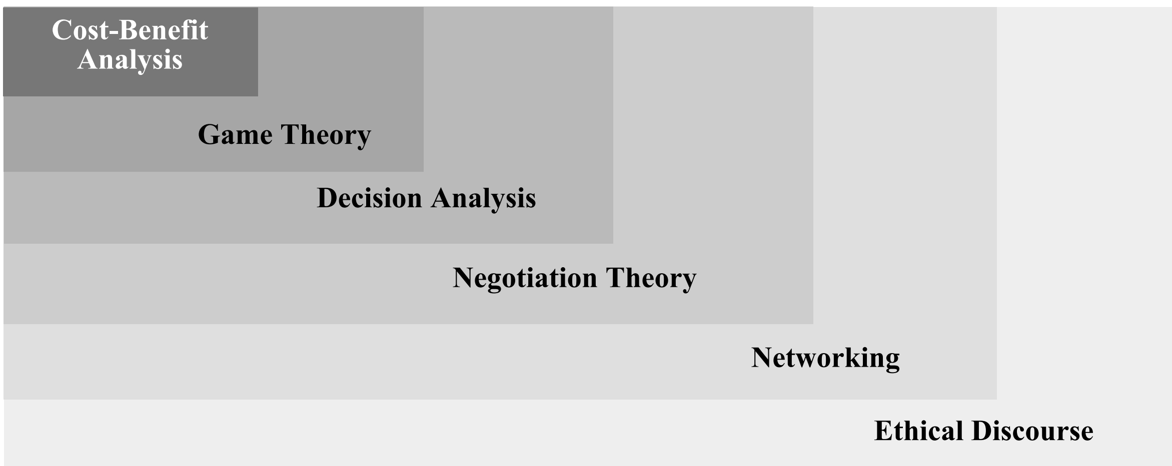

Fig. 1. Theories of decision-making.

decision-making process ranks different calculated outcomes or pay-offs in a matrix quite similar to the game theory. However, decision analysis is extended to include concepts of risk management which partly allow the examination of 'if-when' scenarios.

The outcome of decisions depend upon the context in which the decision is made. Social theory goes beyond the economic calculus inherent in the above methods, although decisions made using this approach may include cost-benefit studies, game theory or decision analysis. Negotiation theory includes the analyses of the positions of the actors involved in a negotiation. It is a less mathematical approach and may, therefore, include more than two actors who may make decisions separately. Negotiation theory also takes into account the context in which decisions are made. Often, it has no fixed agenda. It allows the transfer of experiences from other conflict resolutions into the present one (Lang 1989). The approach, however, focuses on a specific conflict that should be resolved. It does not necessarily deal with future opportunities.

Networking is a procedure often applied to planning processes. The planning process often brings together politicians, planners and scientists. Rarely are all affected stakeholders involved in these procedures, which may lead to conflict with some stakeholder interests in the succeeding implementation stage.

The broadest concept, ethical discourse, relates to stakeholder approaches in which all affected actors are involved. The aim of ethical discourse is 'cooordinating communicative action (or action oriented to reaching understanding)'. Ideally, discourse follows these principles:

- the inclusion of all those potentially affected;
- mutual acceptance;
- the equality of the rights of all participants;
- the possibility of revising each position as well as the results;
- the open-endedness of the discourse;
- equal access to information;
- the absence of power ('formal equality').

These principles are consistent with Wilson's (1998) call for 'consilience' between the sciences. That is, the findings and basic principles of one science should be consistent with the basic understanding of the others. Concilience requires, however, the condition of equal access to information and communication between sciences. This implies that economists should understand how natural sciences could support decision-making in the economic sphere and *vice versa*. The communication medium in negotiations, networking and discourse is not necessarily a price system.

Other approaches to conflict resolution will not be value-free and they may focus on social commitments beyond price regulations. Conflict resolutions are part of the process in which humans generate information, which under certain circumstances supports institutions that try to cope with uncertainty as an inherent constitutional parameter of systems.

Input-output analysis as a method to link natural and social sciences

Input-output analysis is a tool which makes cooperation of natural sciences and economics and spatial planning feasible. One has to bear in mind that this methodology is a simplification of both the natural and social realm. This analysis, however, may make the results readable for both natural and social sciences, to support decision-making and to improve the understanding of systems interference. Since the tremendous increase in the power and convenience of computers in the last 20 years, input-output analysis has become a major tool of analysis in regional and environmental economics. Extensions such as social accounting matrices (SAM), natural resource accounting and structural analysis have made input-output analysis a flexible and tractable way to examine the interactions in economic and environmental systems (Duchin 1998; Miller et al. 1989).

Some advantages of applying input-output tables in coastal zones are:

- the inclusion of direct and indirect impacts into the pressure and response system;
- the possibility of developing scenarios;
- the applicability to decision-making;
- the estimation of a measure of sustainability.

A disadvantage of the methodology is that we still need indicators that are measurable and allow comparison on a similar basis. Other weaknesses include:

- Applying the input-output concept is a simplification of a system to its structural parameters which are assumed to be quantifiable;
- System properties such as self-organisation and self-regulation are not fully covered by this method;
- System resistance and resilience are properties which are not quantifiable;
- Systems are open with respect to space and time;
- Systems change over time by absorbing or exchanging energy and matter;
- Input-output tables require the reduction of complexity which is conceptually intertwined with uncertainty (Ayres 1988) to make decisions feasible.

However, no other formal method used in economics has the flexibility of input-output analysis. Again, this methodology represents a step beyond traditional economic valuation practices since it does not require pricing of goods, commodities, amenities and environmental services.

In economic analysis, input-output tables may be based on the first law of thermodynamics; the law of material and energy constancy. If there is a difference between inputs and outputs, this may mean that it is added to the funds of the system within the black box. It also may mean that it is added temporarily to the funds and will be released later and added to the outputs in another period. This methodology also allows the analysis of capacities of the system in the black box as well as some but not all properties of the system and its dependencies on energy and matter transfers. The application of the rules of thermodynamics to social systems has been pioneered by Nicholas Georgescu-Roegen (1971).

In some, but not all, cases one can measure energy and material flows in quantitative terms. This does not necessarily mean, however, that we can measure all the flows in such terms. Ecologists simplify the relationships between systems in a way that separates a part of a system from its environment in order to measure the inputs and outputs at the boundaries of the artificially separated systems. What occurs within the boundaries cannot be analysed unless the boundaries are redrawn. This methodology allows the comparison of inputs to a system to its outputs. The relationship may be expressed as the ratio of flows through the system and the funds supporting the system.

A major advantage of the input-output approach is that one may design input-output tables using non-monetary quantities. This allows the application of the method to non-market economies as well as to market economies. This may help to reduce the errors inherent in cost-benefit analyses, which are based exclusively on monetary values. Moreover, it makes it possible to directly use data from natural sciences under certain circumstances for further analysis. However, the method requires that the figures are quantifiable on a comparable basis.

We start with a flow table for a hypothetical regional economy. Table 1 is a traditional input-output (IO-)table indicating monetary transactions between sectors. Sectors I-IV are i ndustry, agriculture, tourism and transportation or other services. The final demand column includes accumulation, exports and public expenditure. This definition of final demand makes that total input equals total output, e.g. the columns and rows of the table have the same sums. Within the transaction table, the output of one industry is always an input into another industry.

The flow-table is transformed into the technical coefficient matrix, or A-matrix, by dividing each column by the total output of that sector. This table shows the direct input requirement per dollar of output of each sector. The next step is to generate a [I – A] matrix by subtracting the matrix of direct coefficients from the identity matrix I. The [I–A] matrix is then transformed into the Leontief-inverse $[I–A]^{-1}$. This matrix shows the direct and indirect requirements from each sector from an increase or decrease in final demand.

Input-output tables are appropriate tools to measure the effects of increasing pressures in coastal zones, since they can support decision-making with alternative scenarios.

In a next step one may apply input-output tables to show the relationship between the economy and the environment (Miller & Blair 1985). Table 2 shows the basic input-output connections between ecological and economic flows. The economy extracts resources from the environment and discharges waste into some parts of the environment. On the other hand, some parts of the environment may remain unchanged in some of their functions. The important point here is that not the whole environment serves the economic system. There has to be space for recovery and for providing the resource supply and waste assimilation services described above.

Input-output tables are also an important tool for forecasting since they allow the simulation of input factors in different sectors and develop from these scenarios on a system response. As early as 1951 Walter Isard used input-output tables to compare interregional development. Miernyk (1965) described processes of indicative planning using input-output tables. He also recommends applying input-output tables for impact analysis since they:

Table 1. Hypothetical IO-table, including a 4 × 4 transaction table (or flow table)in arbitrary monetary units for a regional economy (adopted from Miernyk 1965).

	Regional economy					
	Sector I	Sector II	Sector III	Sector IV	Final demand	Total output
Sector I	10	15	1	2	15	43
Sector II	5	4	7	1	18	35
Sector III	7	2	8	1	8	26
Sector IV	11	1	2	8	10	32
Payments sector	10	13	8	20	12	63
Total output	43	35	26	32	63	199

Table 2. An input-output-table showing the relationship between the economic system and the environment.

	Economy		Environment
Economy	Economy	➡	Waste assimilation
	⬆		
Environment	Resource extraction		Environment

- may be based on monetary or non-monetary indicators;
- allow interregional comparative studies;
- simultaneously cope with direct and indirect impacts;
- may guide decisions on a firm, sector, community, regional or national level;
- may measure the impact of an increasing final demand caused, for instance, by population growth.

The 'ecological footprint'

The 'ecological footprint' describes the *per capita* area of land use for economic activities in a region or on a national level. William Rees has developed this concept and Mathis Wackernagel applied it to individual uses of space (Rees & Wackernagel 1994). The concept uses regional or national data on consumption and relates these figures to the amount of land needed to support that consumption (Fig. 2). The concept also allows the inclusion of non-market economic activities.

We propose to use ecological footprints as a physical, non-monetary factor in input-output tables. The ecological footprint should describe the specific use of land of a specific economic process in the region that includes land uses within and outside the region. The 'ecological footprint' of a coastal region can be added to the input-output table. The sum of all the footprints may give a rough estimation of the sustainability of a region. However, its inclusion in an input-output table may also show direct and indirect impacts of growth in one or another sector of the economic part of the table, including final demand by households and demand for residential space and food. Advantages of using 'ecological footprints' are:

- compatibility with spatial planning;
- integration of environmental factors that are seen as the most crucial in coastal zones when discussing overpopulation;
- possibility to include tools such as Geographic Information Systems to specify regional data;
- possibility to expand the approach to self-sustaining capacities in coastal waters, for instance to rock beds, sandy bottoms, seagrass beds, mangrove swamps, etc., in which one may find the critical environmental funds and flows in physical terms that support the sustainability of coastal zone ecosystems.

We propose to apply the national data to watersheds or regions by using data from a GIS. This method combines planning tools with economic analysis. It is assumed that it is possible to break down national data with the assistance of GIS for a better understanding of regional change and economic pressures.

In a next step we include an environmental indicator in the Leontief-inverse by adding land use by the different sectors. Vertically integrated (Gowdy & Miller 1990) ecological footprints of each sector's demand represents the land use: FPx = column sums of [(land use per dollar of output) * (Leontief coefficients)]. The vertically integrated footprint by economic sector for a regional economy is presented in Table 3. The column sums show the direct and indirect land equivalent required for each sector's economic output. Similar studies have used

Fig. 2. The city of Hongkong. The ecological footprint of densely inhabited coastal zones is much larger than their spatial extension.

Table 3. Vertically integrated ecological footprints for a regional economy.

	Sector I	$[I-A]^{-1}$ Sector II	Sector III	Sector IV
Sector I	$FP_I *V_{11}$	$FP_I *V_{12}$	$FP_I *V_{13}$	$FP_I *V_{14}$
Sector II	$FP_{II} *V_{21}$	$FP_{II} *V_{22}$	$FP_{II} *V_{23}$	$FP_{II} *V_{24}$
Sector III	$FP_{III}*V_{31}$	$FP_{III}*V_{32}$	$FP_{III}*V_{33}$	$FP_{III}*V_{34}$
Sector IV	$FP_{IV}*V_{41}$	$FP_{IV}*V_{42}$	$FP_{IV}*V_{43}$	$FP_{IV}*V_{44}$
Vertically integrated footprint	Sum sector I	Sum sector II	Sum sector III	Sum sector IV

energy (Casler & Wilbur 1984; Gowdy & Miller 1987), pollution emissions or water (Miller & Blair 1985).

In our example the vertically integrated footprint shows the direct and indirect 'footprint' for each sector which is required for a unit increase of production. The footprint may exceed the land available in the coastal region itself. If the land use already exceeds the land available in the coastal region the region in itself may be considered as non-sustainable. An increase or decrease of land demand takes into account that land is used outside the watershed or coastal region for the economic sectors within the watershed or coastal region.

Many difficulties still remain. Input-output tables first of all describe a situation such as GIS does. Gathering and verifying data–although data needed to estimate footprints are already available–is still a formidable task, all the more so since coastal zones are in permanent change. However, because the two (black) boxes–economy and environment–are treated separately in the first steps, the relationship between them becomes more obvious. Moreover, this technique does not necessarily require putting prices on environmental goods, commodities, amenities, services and functions since a considerable part of the environmental funds and flows may remain outside the economic system.

However, it is expected that the environmental funds and flows generate indirect values to the economic system such as spawning grounds for fish and other seafood. This brings us back to the other part of the planning process–environmental planning.

Application to environmental planning

Referring to Table 3 above, the second, third and especially the fourth quadrant of the table remain without prices. Most important in this respect is the fourth quadrant, environmental funds and flows, which sustains the environmental system itself. As long as specific data for environmental functions, funds and flows in the coastal system as an entity or in parts of it are not available, these elements may be taken as black box models as applied to environmental systems by Odum in the 1960s (Odum 1971). Once internal funds and flows, e.g. in a seagrass bed, are known one may include flows and accumulation in funds – introduced as funds-flows tables in the forth quadrant. Linking economy and the environment through the second and third quadrant in the input-output table should help to enhance knowledge for each of the disciplines of natural and social sciences. However, as long as data within the environment-environment quadrant are lacking or are hard to translate into an input-output form, the table may include the first three quadrants only. It is now assumed that environmental planning requires an open process that involves most of the stakeholders causing, or being affected by, environmental damage or by a conservation strategy. Ethical discourse has the broadest conceptual base. Human-environment conflicts are, on the one hand, complex and strategies to resolve them are always processes of trial and error. On the other hand, they are embedded in institutional and organisational structures of the society that have evolved historically. The process of gathering and capturing information such as experiences, technical, technological and scientific knowledge or data is, itself, an outcome of resolving earlier conflicts. Knowledge from conflict resolution is therefore part of the set of information tools humans possess. Moreover, to safeguard societies against being trapped over and again in similar conflicts, the information generated in conflict resolution is encoded in group knowledge that passes from generation to generation and finally forms norms, rules and ethical values.

The environmental sociologists Cable & Cable (1995, p. 11) list the following barriers to sustainability that also apply to coastal zone development:

- The belief that a free-market system provides the greatest good for the greatest number of people;
- The belief that the natural world is inexhaustible;
- A faith in technology;
- The growth ethic;
- Materialism;
- Methodological individualism;
- Our anthropocentric world view.

These are institutional barriers that have to be overcome if sustainability policies are to be taken seriously.

Since these beliefs reflect normative values, sustainability policies should enable people to change their beliefs and behaviour.

Final thoughts and a concluding example

Funtowicz & Ravetz (1993, 1994) plead for a new role of science in conflict resolution and decision-making. They see the necessity of forming a post-normal science that supports extended peer discussions to encourage processes of social participation and social learning to resolve the present human-environment conflict. A post-normal science contributes to decision-making by providing information needed to make decisions to all involved or affected stakeholders. Science may also perform a mediator role in some cases.

However, science has to leave its position as only an information provider to the political system and become part of the decision-making process. Moreover, discourse is a tool in which scientists may participate and communicate with each other to reach realistic decisions.

Decision-making in planning processes via social commitments needs the cooperation of scientists. Since possessing information may generate a power factor in discourses, science has to break down information to a level that allows communication and understanding. This, however, is a step that will also facilitate communication between scientific disciplines. Therefore, ethical discourse will also provide a basis for communication and cooperation between scientists.

Conclusion

An integration of tools and concepts is provided in this paper. We see a substantial support to sustainability policies in integrating and combining methodologies from natural and social sciences. The tools we propose to characterize conflicts in coastal zones and to build scenarios for decision-making are the integration of ecological footprints, input-output tables and GIS, all in one tool. Applying this tool will show which data can be transferred and communicated between natural and social scientists.

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