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Analysis

Quantification of interdependencies between economic systems and ecosystem services: An input–output model applied to the Seine estuary

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ABSTRACT

The aim of this paper is to assess the possible contribution of an input–output model towards two of the basic principles of the sustainability strategy of integrated coastal zone management (ICZM) and Post-Normal Science. According to these principles, decision-support tools should offer a holistic perspective and handle high uncertainty. The difficulties in reaching sustainability are due partly to the prevailing use of "narrow-system-boundary" tools that are non-holistic. Consequently, they fail to capture important ecosystem services and ignore interdependencies between them. To comply with the basic principles, our method allows environmental assets to be evaluated in multiple units and integrates results from recent researches in natural sciences. Both enable coverage of interdependencies between ecosystem services. Thereby, we enlarge input–output modelling from the two conventional ecosystem services of sink and provisioning to the most vital ones: the supporting services. An application to the Seine estuary addresses the impacts of maritime transportation infrastructures on nursery habitats for commercial fish. The ecosystem services covered are life support and resource provisioning. Our results show that the restoration of a total of 73.7 km^2 of nursery areas over the period 2004–2015 would result in a stock of sole in 2015 that exceeds the "business as usual" scenario by 44.2% (uncertainty range: 35.9%–69.9%). In spite of high restoration costs, the negative macroeconomic impact is very low. However, on the sector level, a trade-off results between nurseries and three economic sectors. The quantification of such trade-offs in our model is particularly useful to public participation in decision-making.

1. Introduction

The European guidelines for the implementation of the Water Framework Directive recommend the use of cost–benefit analysis (CBA) to identify water bodies in which environmental measures present disproportionate costs (European communities, 2009). For water bodies where costs exceed benefits, decision makers can ask the European Commission to postpone environmental targets or make them less stringent. The European Commission will have to consider such requests carefully as it seems that the difficulties in reaching sustainability are due partly to the prevailing use of "narrow-system-boundary" tools (*e.g.* CBA). Such tools are useful but they are not the panacea, because they are non-holistic, non-participative and exclude complex environmental issues with too high uncertainty. They represent only one kind of tool among others and should be complemented by other tools and approaches. This has been the problem of the recent decades. "Narrow-system-boundary" tools came in support of sector-related and individual resource-based policies in environmental management. As a result, environmental impacts have been analysed separately, whereas holistic analyses were required, as with European coastal zones (Belfiore, 2000; O'Hagan and Ballinger, 2009; Stojanovic and Ballinger, 2009). Consequently, numerous efforts have failed to achieve sustainability.

The prevailing use of "narrow-system-boundary" tools such as CBA is partly responsible for the failure to achieve sustainability in European coastal zones. Many investigations on CBA limitations might explain this issue (*inter alia* van den Bergh, 2000; Maréchal, 2007; Munda et al., 1994). One limitation is that CBA is an analytical approach rather than a holistic one (Ackerman, 2004; Gallopin et al.,

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2001; Stirling, 2001). That is to say, it considers a narrow range of causes and consequences and takes into account only a small part of the world. It restricts the scope of issues to a micro-scale and leaves out connections. Consequently, CBA fails to consider interdependencies between ecosystem services. However, interdependencies are important (de Groot et al., 2002), since the ecosystem services that directly benefit human activities and survival – resources provisioning and cultural services – depend on the existence of three vital ecosystem services: supporting, regulating and sink services (Millennium Ecosystem Assessment, 2005).

Failing to consider interdependencies is a limitation which is not only inherent in CBA but to all other approaches that use single indicators — *e.g.* green GDP, genuine saving, ecological footprint, and cost–benefit ratio in CBA. Single indicators cannot encapsulate all the complexity inherent in ecosystems (Ashford, 1981). To solve that problem, Post-Normal Science and Integrated Coastal Zone Management (ICZM) (Box 1) put at their core the basic idea of extended peer communities (*i.e.* stakeholder participation) to encompass the multiplicity of legitimate perspectives (Belfiore, 2000; Funtowicz and Ravetz, 1994; O'Hagan and Ballinger, 2009; Ravetz, 2006; Stojanovic and Ballinger, 2009). They recommend avoiding the hegemonisation of a single indicator in analyses of environmental issues and suggest complementing single indicator methods with tools that offer holistic properties (Giampietro et al., 2006). This would enable a globalising approach where various elements, usually dissected into parts, are instead gathered to be studied together with their interactions inside a system (Gallopin et al., 2001).

However, if the advantage of holistic tools is to reflect ecosystem complexity in a better way, the disadvantage is that complexity causes high degrees of uncertainty in turn (Gallopin et al., 2001; Munda et al., 1994). The degree of uncertainty is so high that it often takes the form of "indeterminacy", which means that it is impossible to perform an accurate prediction of the future state of the system. That is to say, no statistical correlation can be established between a cause and an effect. As a result, statistic and probability theory do not apply (Giampietro et al., 2006). This is usually due to the inherent ecosystem complexity, the lack of scientific knowledge and the absence of good data. Consequently, some scientists might be tempted

Box 1
Post-Normal Science and Integrated Coastal Zone Management (ICZM).

Post-Normal Science

Post-Normal Science evolved from a criticism of Probabilistic Risk Analysis. This scientific field attempted to apply standard mathematical methods to problems where the uncertainties were actually overwhelming. The Probabilistic Risk Assessments enjoyed an initial plausibility because they were presented as a science, which is objective and certain, and free from bias and doubt. The policy agenda was clear: a risk of one-in-a-million is acceptable. Hence an installation with such a risk is scientifically proved to be safe. However, not all problems with a scientific appearance are capable of solution in orthodox scientific terms (Ravetz, 2006). There exist some problems which are in principle not reducible to "puzzle-solving" normal science in Kuhn's terminology (Kuhn, 1962). Economics applied to environmental issues does not possess the same degree of control of uncertainties as, say, analytical chemistry (Funtowicz and Ravetz, 1994). The new problems of ecological economics faced in this third millennium (*e.g.* climate change and genetically modified organisms) imply that very often scientists cannot provide any useful input to the social debate without interacting with the rest of the society (*i.e.* stakeholder participation). These new problems call for a Post-Normal Science (Funtowicz and Ravetz, 1994; Giampietro et al., 2006).
Giampietro et al. (2006) and Funtowicz and Ravetz (1994) illustrate the need for interaction between scientists and the rest of society with the example of the surgeon. The possible outcomes of a surgical operation are not completely determined by scientific facts. In this situation, the patient must have a say in the choices of the surgeon since its choices will determine the final outcome and imply rather important stakes (*e.g.* possible physical incapacity) and uncertainty (*e.g.* the surgeon is not sure of the level of incapacity). When uncertainty or stakes are even higher and affect not only a patient but also the rest of society, inferences will be conditioned by the values held by numerous stakeholder groups. In such situations, partisan discussion and a defensive tactic will involve challenging every step of a scientific argument by taking sides (*e.g.* denial of the existence of the global warming by petrochemical firms). We are now in the realm of Post-Normal Science (Giampietro et al., 2006).

Integrated Coastal Zone Management (ICZM)

The practice of integrated management extends back at least to 1965 with the first integrated coastal management programme by the San Francisco Bay Conservation and Development Commission. But it spread progressively all over the world and in 2002, 145 countries and semi-sovereign states had initiated integrated coastal zone management efforts (Sorensen, 2002). In Europe, it started in 1992 with the Convention for the Protection of the marine Environment of the North-East Atlantic (the «OSPAR Convention»). This was followed by 35 demonstration projects implemented between 1996 and 1999 in European coastal zones which set the basis for the implementation of ICZM in the European Union (Belfiore, 2000; Shipman and Stojanovic, 2007).
ICZM reflects the movement towards a broader, more holistic perspective from more sectoral and individual resource-based approaches (O'Hagan and Ballinger, 2009; Cheong, 2008). ICZM consists in a strategy that encompasses the whole process of data collection, planning, decision making, implementation management and follow-up. It seeks to achieve sustainability by setting into practice an "integrated" approach to planning and management of human activities. The term "integrated" corresponds to bringing together the components of five main areas inside a single strategy: intersectoral integration, intergovernmental integration, spatial integration (land–ocean integration), interregional and international integration (transboundary issues), and science-management integration (Cheong, 2008). Such a strategy must involve all stakeholders in a participative way (Belfiore, 2000; O'Hagan and Ballinger, 2009; Stojanovic and Ballinger, 2009).