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REVIEW

Scientific approaches to address challenges in coastal management

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ABSTRACT: Anthropogenic activity has a negative impact on many coastal ecosystems, compromising the significant direct and indirect socio-economic benefits provided in these areas. Maintaining activities that depend on coastal zones while preserving the ecological state of the ecosystems represents a management challenge. Management of coastal zones requires scientifically based knowledge, due to the complexity of the ecological processes which occur in these ecosystems and because of interaction with the socio-economic system. The effectiveness of coastal management instruments and programmes needs to be evaluated to determine the success of adopted measures and to establish improved goals. Some of the research areas that can support coastal management include marine spatial planning, ecological modelling, development of tools to communicate science to managers, and interaction between coastal ecosystems and socio-economics. This paper reviews management instruments to address coastal zone problems and of some research areas to support management.

KEY WORDS: Integrated coastal zone management · Ecosystem-based management · Marine spatial planning · Ecosystem model · Integrated environmental assessment · Differential drivers-pressure-state-impact-response approach · Ecological economics

INTRODUCTION

Coastal ecosystems generate goods and services with a high economic value (Ledoux & Turner 2002, Egoh et al. 2007, Rönnbäck et al. 2007, Koch et al. 2009). As a result of the ecological importance of coastal zones for human activities, a large percentage (around 40%) of the world population and of the world's economic activities (around 61% of the gross world product; MA 2005, Martínez et al. 2007) are concentrated in a 100 km-wide strip along the coast. Increasing human pressure on coastal zones is causing degradation (Boissonnas et al. 2002, Halpern et al. 2008a,b) and consequently a decrease in the benefits that these ecosystems deliver (Bowen & Riley 2003, MA 2005, Costanza & Farley 2007, Lester et al. 2010). The main threats posed by humans to coastal areas include loss of natural habitats, biodiversity loss, decline in water quality, vulnerability to global changes such as predicted sea level rise, increased negative impacts of coastal disasters, competition for space and seasonal variations in pressure (Ehler et al. 1997, Fabbri 1998, Humphrey et al. 2000, MA 2005, Costanza & Farley 2007, Defeo et al. 2009). Sustainable management of coastal zones thus constitutes a challenge for coastal stakeholders.

Over the past few decades, policy makers worldwide have defined policy and legislative instruments to address coastal zone problems (Clark 1996, Borja 2006, Ducrotoy & Elliott 2006). One of the more widely known and applied is the integrated coastal zone management (ICZM) approach (Cicin-Sain & Knecht 1998). A complementary coastal management approach, known as ecosystem-based management (EBM), highlights the need to (1) consider the cumulative effects within and across ecosystems, (2) use the best avail-

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able information about a given ecosystem and adapt to emerging knowledge, and (3) consider both human and natural dimensions as key aspects in the management of marine resources and functions (Fluharty 2005, Murawski 2007, Borja & Collins 2009, Douvere & Ehler 2009, Forst 2009, Queffelec et al. 2009, Lester et al. 2010, Tallis et al. 2010). The development, implementation and output evaluation of coastal management instruments and programmes must be supported by scientifically based knowledge (Martínez et al. 2007, Lester et al. 2010). Managers and policy makers require analytical and assessment methodologies to (1) generate understanding about coastal ecosystems and their interaction with the socio-economic system, and (2) synthesise research outcomes into useful information in order to define effective responses and evaluate previously adopted actions (McNie 2007, Stanners et al. 2008).

The objectives of the present paper are to review (1) the main management instruments, such as ICZM and EBM, used to address coastal zone problems and (2) some of the research areas that can contribute to coastal management, namely marine spatial planning, ecological modelling, tools to communicate science to managers, and interaction between coastal ecosystems and socio-economics.

ADDRESSING EMERGING COASTAL ZONE PROBLEMS

Integrated coastal zone management

ICZM is defined as a dynamic management process that brings together the human and the ecological dimensions to promote the sustainable use, development and protection of coastal zones (Clark 1996, Olsen 2003, Forst 2009). Managers worldwide have adopted ICZM in different contexts: (1) either at national or local levels, as exemplified by NRMMC (2006) and Lewis et al. (1999), respectively; (2) following a top-down approach or based on a community-based initiative (Cicin-Sain & Knecht 1998, Lewis et al. 1999, Belfiore 2000, Kearney et al. 2007); (3) to address specific environmental problems in coastal zones or to manage coastal vulnerability to natural hazards and climate change (Clark 1996, Krishnamurthy et al. 2008).

Table 1 presents an overview of worldwide coastal management initiatives. Although such a synthesis is reductionist with regard to coastal management efforts, it illustrates that ICZM initiatives appeared about 4 decades ago and that some countries are currently adopting new programmes. Clark (1996), Kay et al. (1997), Cicin-Sain & Knecht (1998), Hale (2000), Eremina & Stetsko (2003), PEMSEA (2003), Lau (2005), Cao & Wong (2007) and Krishnamurthy et al. (2008) provided detailed ICZM case studies developed worldwide, and Cruz & McLaughlin (2008) compared different marine policies across different countries. The early USA-concerted coastal management efforts are stable and in a mature stage (Hershman et al. 1999, Hale 2000, Gibson 2003). Hershman et al. (1999) and Humphrey et al. (2000) described the key features for its success and its shortcomings. Coastal management programmes on a European scale are more recent (Humphrey et al. 2000, Shipman & Stojanovic 2007). The various European Union (EU) policies and directives emerged as complementary instruments, the most important being (Borja 2006, Ducrotoy & Elliott 2006, 2008, Borja et al. 2010) the Water Framework Directive (WFD) of 2000, the ICZM recommendation of 2002 and the Marine Strategy Framework Directive (MSFD) of 2008. Rupprecht Consult & IOI (2006) provided a synthesis of some of the EU policy application in each member state. Table 1 shows a brief sample of the programmes adopted within the EU at 3 scales: (1) legislation and policies applied at the EU level, (2) programmes to be implemented at transnational level for joint management of European seas (not exclusively within EU member states), and (3) legislation mainly developed at the national level, not necessarily to address EU programmes. The individual EU member states have different approaches to coastal management with a variety of coastal management initiatives and legislations (Gibson 2003, Shipman & Stojanovic 2007). In Spain, for instance, complementary to the Coastal Law, several autonomous communities have specific regional programmes of action (Sardá et al. 2005). In the UK, ICZM is characterised by local and regional coastal management programmes, corresponding to a number of administrative bodies with interest in coastal management (Stojanovic & Ballinger 2009). Several initiatives are being taken for the development of an ICZM programme for the UK in response to the EU ICZM Recommendation of 2002, namely the Marine and Coastal Access Act of 2009 (ATKINS 2004, Stojanovic & Ballinger 2009, DEFRA 2010). For detailed coastal management initiatives within and across EU member states refer to van Alphen (1995), Barragán Muñoz (2003, 2010), Pickaver (2003), Veloso-Gomes & Taveira-Pinto (2003), Anker et al. (2004), Taveira-Pinto (2004), Scottish Executive (2005), Enemark (2005), Smith & Potts (2005), DOENI (2006), Rupprecht Consult & IOI (2006), WAG (2007), Deboudt et al. (2008), DEFRA (2008, 2010) and Stojanovic & Ballinger (2009).

For individual ICZM programmes to evolve, comprehensive evaluations are required. It is important that ICZM programme output evaluation is combined with 'state-of-the-coast' information to show, for instance, whether new programme goals may be needed as well as to allow an ICZM programme to evolve to an

Table 1. Overview of major integrated coastal zone management (ICZM) initiatives worldwide

First initiatives			Recent initiatives	
Australia			2003	Framework for a National Cooperative Approach to ICZM
South Australia	1972	Coast Protection Act	1994	Environment Protection (Marine) Policy
			2000	Environment Protection (Water Quality) Policy
New South Wales	1979	Coastal Protection Act		
Queensland			1995	Coastal Protection and Management Act
Tasmania			1996	State Coastal Policy
Victoria			1995	Coastal Management Act 1995
Western Australia			2001	CZM Policy
Brazil	1988	Law 7661, establishes the National CZM Plan	2004	Decree 5300, regulates the National CZM Plan and other instruments for ICZM
Canada			1991	Atlantic Coastal Action Program (ACAP)
			1997	Oceans Act
			2002	Oceans Strategy
PR China	1982	Marine Environment Protection Law of the PR of China	1995	Measures of management of marine natural reserves
			2001	Measures of management on utilisation of sea areas
			2002	Marine functional zonation scheme
European Union			1996	Demonstration programme on ICZM
			2000	Water Framework Directive (2000/60/EC)
			2002	ICZM Recommendation 2002/413/EC for member states to adopt a national strategy on ICZM.
			2008	Marine Strategy Framework Directive (2008/56/EC)
Baltic Sea			2003	HELCOM ICZM Recommendation 24/10
			2007	HELCOM Baltic Sea Action Plan
France	1975	Coastal Conservancy (Law of 10 July)	2002	Reform of the Coastal Conservancy's mission (law of 27 February)
	1983	Marine Area Zoning Plan (SMVM) (law 83/8)		
	1986	Planning, protection, and development of coastal space		
Poland			1991	Poland's Act on Marine Areas and on Maritime Administration
Portugal			1993	Coastal strip management plans (POOC) (Decree-Law 309/93)
			1998	Portuguese Coastal Strip Strategy (Minister Council Resolution 86/98)
			2001	National Strategy for Nature Conservation (Minister Council Resolution 152/2001)
			2006	National Strategy for the Sea (Minister Council Resolution 163/2006)
			2009	National Strategy for the ICZM (Minister Council Resolution 82/2009
Spain	1988	Coast Law	2007	Strategy for the Sustainability of the Coast
Wadden Sea	1978	Trilateral Wadden Sea Cooperation	1997	Wadden Sea Plan
	1982	Joint declaration		
IOC member states			1997	Integrated Coastal Area Management (ICAM) programme adopted by the Intergovernmental Oceanographic Commission (IOC)
New Zealand			1994	Coastal Policy Statement (NZCPS)
			2008	Proposed review of NZCPS
USA	1948	Federal Water Pollution Control Act	2000	Oceans Act
	1972	CZM Act		
	1972	Clean Water Act		
	1987	National Estuary Program (NEP), established by the Water Quality Act		

improved version (Olsen et al. 1997, Hershman et al. 1999, Stojanovic et al. 2004, Billé, 2007). However, most of the evaluation efforts focus on measuring the evolution of the ICZM process outputs (Olsen 2003, Pickaver et al. 2004, Stojanovic et al. 2004, Billé 2007, Gallagher 2010). Worldwide and independent of the degree of maturity of the ICZM process, measurements of its effectiveness are lacking, i.e. of the consequent changes in the state of the coastal systems, its resources and associated benefits (Knecht et al. 1996, 1997, Kay et al. 1997, Olsen et al. 1997, Hershman et al. 1999, Humphrey et al. 2000, Billé 2007, McFadden 2007). Among other reasons, the difficulty involved in selecting criteria to measure the system's performance stands out. The difficulty stems from (1) an unclear set of ICZM objectives, (2) the complexity of coastal ecosystems and (3) data requirements (Burbridge 1997, Stojanovic et al. 2004). Problems defining a specific set of indicators for all coastal systems are greater at the national or broader level due to the different susceptibility and resilience of ecosystems, the pressures these are subject to and the issues to be tackled (Pickaver et al. 2004). The diversity of coastal systems and of the pressures on them requires flexibility in the development and implementation of ICZM programmes, which in turn calls for flexible assessment approaches (Humphrey et al. 2000, Olsen 2003). Table 2 presents a synthesis of some studies that evaluated the effectiveness of ICZM programmes.

The development of indicators and tools to evaluate ICZM at different levels is ongoing, as analysed by Hoffmann (2009). For instance, Cordah Ltd (2001) and Belfiore et al. (2006) consolidated a suite of indicators developed worldwide for ICZM. At the European level, assessment tools are also being developed in a collaborative effort between managers and the research community (Bowen & Riley 2003, Ehler 2003, Ducrotoy & Elliott 2006, Kiousopoulos 2008, Diedrich et al. 2010). An important feature of this effort is the inclusion of measurable indicators as common tools to quantify both the progress of implementation of ICZM and the sustainable development of the coastal zone (Breton 2006). These worldwide efforts are valuable contributions towards making the assessment of the evolution of coastal zones the standard rather than the exception in the ICZM process.

Ecosystem-based management

Complementary to ICZM, EBM emerged recently as a scientific consensus that highlights (1) the importance of considering the interactive and cumulative impacts of the range of activities that act on the coastal ecosystems and (2) the definition of strategic objectives across those activities for their sustainable management (Browman & Stergiou 2005, Murawski 2007, Halpern et al. 2008a, Forst 2009, McLeod & Leslie 2009). The concept of the ecosystem-based approach first appeared in the 1970s, not specifically related to coastal zones (Slocombe 1993). Grumbine (1994) and Slocombe (1998) reviewed the origins and principles of EBM and provided lessons for implementing it. An important feature that both authors highlighted is that EBM is about integrating environment and human activities. They emphasised that in the real systems, humans are within, rather than separated from, nature. Slocombe (1998) suggested that an effective EBM (1) starts with a synthesis of information for future research and management, (2) monitors features to fol-

Table 2. Examples of evaluation of the effectiveness of Integrated Coastal Zone Management (ICZM) programmes

Programme/domain	Description	Source
Perceptions of the performance of 24 state CZM programmes in the USA (1993–1995)	Evaluation was based on a survey of perceived performance on 4 major coastal management issues: (1) protection of coastal resources; (2) management of coastal development; (3) improved public access; and (4) reduction of losses due to coastal hazards.	Knecht et al. (1996)
US National CZM effectiveness study (1995–1997)	Objective is to determine success of 5 of the core objectives of the USA CZM Act of 1972: (1) protection of estuaries and coastal wetlands; (2) protection of beaches, dunes, bluffs and rocky shores; (3) provision of public access to the shore; (4) revitalisation of urban waterfronts; and (5) accommodation of seaport development. Although based on limited data, it evaluates programme success based on 'on-the-ground outcomes'.	Hershman et al. (1999)
Tampa Bay Estuary Program (USA)	The programme includes the definition of specific goals to address the identified issues to be managed. Quantitative criteria were selected to evaluate the programme outcomes. These include e.g. areal extent of seagrasses and populations of birds.	Lewis et al. (1999)

low changes, (3) uses local knowledge and (4) is practical, i.e. if resources are limited it needs to focus research on knowledge that is meaningful to management. The definition of operational goals is an important challenge for EBM implementation, according to Slocombe (1998). In one of the first references to EBM for coastal zones, Imperial & Hennessey (1996) identified the US National Estuary Program (NEP) as a promising ecosystem-based approach to manage estuaries. The particularity of NEP is to focus on solutions for problems identified in each estuary (Imperial & Hennessey 1996). For each estuary, a comprehensive conservation and management plan is implemented which contains an action plan to address the identified problems and a monitoring programme to measure the effectiveness of activities. Furthermore, the plan sets the funding and the institutional context for the implementation of the estuarine programmes. At the European level, there are also several examples of EBM, for example for the Baltic Sea, North Sea and Wadden Sea (Enemark 2005, HELCOM 2007, Ducrotoy & Elliott 2008). In Canada, the Atlantic Coastal Action Program (ACAP) is an ecosystem and community-based approach to integrate planning and management of the environment, which has unique features such as power sharing among stakeholders (McNeil et al. 2006). Environment Canada launched the programme in 1991, and the process consists of development and implementation of management plans, partnership building, local involvement and action and scientific research to improve and maintain the environmental integrity of coastal communities (McNeil et al. 2006). The ACAP established an alternative process to environmental and socio-economic management of coastal zones involving, at the beginning of the process, interested stakeholders in identifying problems and solutions. The evaluation of ACAP focuses on the environmental results and appraises the measures adopted and the pressures avoided, e.g. area of enhanced wildlife habitat or weight of mercury eliminated from waste streams. According to Environment Canada, the ACAP is effective on an ecosystem basis (McNeil et al. 2006).

SCIENCE FOR COASTAL MANAGEMENT

Management of coastal ecosystems requires interaction among managers and researchers of a range of disciplines, due to the complexity of the phenomena occurring in these systems (Fabbri 1998, Ducrotoy & Elliott 2006). Research must be problem-oriented and the outputs translated into meaningful information for managers (Nobre et al. 2005, Dennison 2008, Hoffmann 2009). The enhanced understanding that scientific methodologies provide can be particularly useful in conflict-resolution processes inherent to coastal management (Fabbri 1998, McCreary et al. 2001). The development of integrative tools requires the interaction of all stakeholders (Cicin-Sain & Knecht 1998, Van Kouwen et al. 2008) to ensure that (1) tools address relevant issues for coastal management and (2) managers can use the tools and their outputs.

Overall, ecosystem-based tools capable of providing insights into complex ecological processes and interaction with socio-economic systems are valuable to support the sustainable use of highly impacted coastal zones. The most commonly applied tools include (Cicin-Sain & Knecht 1998, Neal et al. 2003, Crowder & Norse 2008, Nobre & Ferreira 2009, Seim et al. 2009): (1) data-gathering tools such as on-the-ground water quality sensors, radar systems and satellite imagery; (2) databases, georeferenced or not; (3) modelling tools, such as catchment and coastal ecosystem modelling; (4) geographical information systems (GIS) and remote sensing, including habitat mapping and habitat suitability; (5) marine spatial planning (MSP); (6) participatory work with stakeholders; (7) integrated environmental assessment, benefit-cost studies and economic valuation. The aim of these tools is to provide information for the decision-making process or its evaluation and not to replace decision makers (Van Kouwen et al. 2008).

Among the several research areas that support coastal management, I discuss the following: (1) MSP, (2) ecological modelling for simulation of management scenarios, (3) development of tools to communicate science to managers and (4) interaction between coastal ecosystems and socio-economics.

Marine spatial planning

MSP is a decision-making tool to support EBM implementation (Douvere 2008). MSP focuses on planning the multiple uses of the coastal and marine ecosystems and resolving conflicting interests and policies, allowing for an efficient zoning of the coastal and marine areas (Douvere 2008, Ehler & Douvere 2009). The overall aim is to maintain the goods and services provided by marine ecosystems, which implies considering ecological principles for ecosystem function analysis (Crowder & Norse 2008, Foley et al. 2010). There are several MSP case studies worldwide, and among the most comprehensive and long-lasting is the zoning scheme in Australia's Great Barrier Reef Marine Park (Day 2002). Douvere et al. (2007), Douvere (2008), Ardron et al. (2008) and Douvere & Ehler (2010) have reviewed MSP case studies. At the European level, there are several drivers for MSP, primarily the EU legislation on conservation (Douvere 2008). In 2008, the European Commission published the

'Roadmap for Maritime Spatial Planning' (EC 2008b) for MSP implementation at national and European levels. The process of coastal and marine zoning involves the use of other tools, such as databases for data assimilation, and GIS for spatial data analysis and production of maps which identify conflicting and compatible water uses (Douvere et al. 2007, Cömert et al. 2008). Ehler & Douvere (2009) and Foley et al. (2010) provided, respectively, a detailed stepwise approach and the key elements for MSP implementation.

Ecological modelling

Ecological modelling is recognised as an important tool for coastal management that can contribute to understanding coastal ecosystem processes and simulate management scenarios (Turner 2000, Fulton et al. 2003, Greiner 2004, Hardman-Mountford et al. 2005, Murawski 2007, Forst 2009, Nobre et al. 2010a). Scenario testing can help managers design the most effective measures for attaining their goals. An understanding of the cumulative impacts of natural and anthropogenic pressures on coastal ecosystem state, and on the goods and services these areas provide is crucial for coastal management (Halpern et al. 2008a). Modelling approaches that are able to simulate the cumulative impacts of multiple coastal activities are still at an early stage of development (Fulton et al. 2003, Ferreira et al. 2008, Nobre et al. 2010a). An example is the multilayered ecosystem model that combines the simulation of the biogeochemistry of a coastal ecosystem with the simulation of its main forcing functions, such as catchment loading and aquaculture activities (Nobre et al. 2010a). Such models are, for instance, important for the determination of ecological carrying capacity required for the sustainable expansion of aquaculture (Dempster & Sanchez-Jerez 2008, Ferreira et al. 2008, Soto et al. 2008). The outcomes of these models illustrate the usefulness of this approach for assisting the development of an ecosystem approach to aquaculture, as advocated by the FAO (FAO 2007, Soto et al. 2008).

Ecological models can be particularly useful if managers are engaged in the development process; this requires that the modelling team explains the model capabilities and limitations to managers and that the managers detail their requirements to the modelling team.

Tools to communicate science to managers

Integration and synthesis of complex knowledge from different disciplines into useful information for coastal managers and the public at large is a progressing and challenging field to environmental scientists (Harris 2002, McNie 2007, Cheong 2008). Integrated environmental assessment (IEA) methodologies can enhance communication between scientists and policy makers, since those methodologies aim to present an interdisciplinary synthesis of scientific knowledge (Tol & Vellinga 1998, Harris 2002). Ecological modelling in particular can benefit from integration with IEA methodologies to distil the outcomes of complex models into useful information for managers (Nobre et al. 2005). Because the methodology involves human interpretation, one of the IEA caveats is subjectivity and dependence on the analyst's point of view (Tol & Vellinga 1998).

The drivers-pressure-state-impact-response (DPSIR) is a well-known IEA framework (Peirce 1998) used to communicate science to coastal managers and in particular to bridge the science–management scales gap (Elliott 2002). A recent adaptation of the DPSIR, named Differential DPSIR (ΔDPSIR), provides a framework to evaluate previously adopted policies and management scenarios, in order to detect symptoms of the overuse and misuse of coastal ecosystems (Nobre 2009). The overall objectives of the ΔDPSIR framework are to assess changes in coastal ecosystems and benefits generated due to management actions or scenarios.

At the EU level, several tools are being developed, specifically to support implementation of coastal-management related legislation and policy (Ducrotoy & Elliott 2006). Specific examples include: (1) GIS as a decision support tool to be used in the development of the National Strategy for ICZM of the Catalan coast following the EU recommendation (Sardá et al. 2005); (2) GIS use for division of ecosystems into homogenous management units as required by the WFD (Ferreira et al. 2006, Balaguer et al. 2008); and (3) methods for classification of the WFD elements to evaluate ecosystem status for coastal and transitional waters (EC 2008a). Borja et al. (2008) reviewed at the global level the existing integrative assessment tools capable of supporting recent legislation developed in several nations to address ecological quality or integrity.

Interaction between coastal ecosystems and socio-economics

Understanding the linkages between natural and anthropogenic systems is crucial for ICZM and EBM (Turner 2000, Westmacott 2001, Boissonnas et al. 2002, Bowen & Riley 2003, Cheong 2008). Firstly, the aim of ICZM is to promote the sustainable development of coastal ecosystems, including both ecological and socio-economic components. Secondly, coastal management and planning must account for the 'costs' of resource degradation. Finally, the measurement of the effectiveness of coastal management initiatives must screen not only the consequent changes in the ecological state of the ecosystem but also changes in the economic benefits and social welfare generated in coastal areas. In particular, economic valuation (using market and non-market methods) is crucial to account for ecosystem goods and services in decision making (Boissonnas et al. 2002, Lal 2003, Farber et al. 2006, Costanza & Farley 2007).

The DPSIR approach, described in the previous section as a tool to communicate science to managers, also provides a conceptual scheme of how socio-economic activities interact with natural systems (Luiten 1999, Ledoux & Turner 2002, Bowen & Riley 2003, Bidone & Lacerda 2004, Scheren et al. 2004, Hofmann et al. 2005, Cheong 2008, Nobre 2009). In simple terms, the DPSIR establishes the link between human activities ('drivers'), corresponding loads ('pressures'), resulting changes of the 'state' of the ecosystem (i.e. the 'impact') and the actions adopted by the coastal managers and decision makers ('response'). The ΔDPSIR further develops the general DPSIR approach. The key feature of the ΔDPSIR is to provide an explicit link between ecological and economic information related to the use and management of a coastal ecosystem within a specific timeframe (Nobre 2009). The application of the ΔDPSIR is illustrated by several case studies that use different datasets and scales of analysis. Nobre (2009) exemplified how this methodology can support the strategic management of natural resources in a coastal lagoon from both ecological and economic perspectives. In that case study, the ΔDPSIR was used to analyse the developments in a southwest European coastal lagoon between 1985 and 1995. Nobre et al. (2010b) illustrated the application of the ΔDPSIR for the ecological-economic assessment of aquaculture options at the farm level. A detailed dataset on the environmental and economic performance of an abalone farm located in South Africa was used. The case study consisted of assessing the ecological-economic effects of the abalone-seaweed integrated multitrophic aquaculture (IMTA) on the farm's performance and the corresponding environmental externalities.

The economic component must be included in dynamic ecological models in order to simulate the feedback between ecological and human systems (Bockstael et al. 1995, Nobre et al. 2009). Insights provided by the outcomes of such modelling tools are important for coastal management. For instance, with limited resources, it is important to prioritise actions that bring larger benefits to the public and at the same time allow the development of private activities. First attempts to integrate the ecological and economic models date back to the 1960s (Westmacott 2001). Integrated ecological-economic modelling is an evolving discipline that has increased recently (Drechsler et al. 2007). Several difficulties exist, such as the difference in scales at which these 2 systems are normally simulated or analysed (Nijkamp & van den Bergh 1997, Turner 2000, Drechsler & Watzold 2007, Nobre et al. 2009). Existing efforts to integrate ecological and economic models include the MARKET model, which dynamically couples the ecological and economic components of aquaculture production (Nobre et al. 2009). This model was applied to simulate shellfish production in a Chinese bay under different assumptions for price and income growth rates and the maximum area available for shellfish cultivation (Nobre et al. 2009). The simulation of the feedbacks between the ecological and economic systems supported the dynamic analysis of (1) the demand for aquaculture products, (2) economic production and cost-limiting factors, (3) the growth of aquatic resources, (4) interactions with environmental conditions and (5) the spatial limitations of culture in coastal ecosystems (Nobre et al. 2009). As any modelling exercise, the MARKET model has limitations; the most relevant is that the deterministic nature of the model cannot integrate the random nature of the economic agents (Nobre et al. 2009). As a consequence, the applicability of this model is limited to obtaining general trends by means of scenario simulations.

CONCLUDING REMARKS

The effective integration of science with management is important to improve policy formulation and policy making and thus for meeting both environmental and development needs and goals (Slocombe 1993, Peirce 1998, Turner 2000, Cheong 2008). It is important to define evaluation criteria in the development of management programmes and to include the relevant variables for managers and resource users in the modelling frameworks. This implies early interaction followed up by iterative communication between researchers, stakeholders with a management role and users of the goods and services of an ecosystem. Research into the ecological and economic assessment of coastal ecosystems is critical because of (1) the importance of, and high demand for, coastal zones, (2) the symptoms of overuse and misuse of these ecosystems and (3) the need for methodologies to evaluate the outcomes of coastal management initiatives and to support coastal planning. A particular area where efforts need to be increased is the development of methodologies to assess the impacts of the ICZM initiatives on coastal ecosystems (Olsen et al. 1997), including the changes in the benefits these generate.

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