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Improving science and policy in managing land-based sources of pollution

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ABSTRACT

Detailed scientific information about degraded systems and impacts of land-based sources of pollution [LBSP] including information about accelerating costs caused by degradation are readily available. Conveying and bringing this information to decision-makers and the public requires both efficient transmission of findings and institutional support for decision-making.

In 2010 the Global Environment Facility [GEF] developed a medium-sized project on ‘Enhancing the use of science in International Waters projects to improve projects results' to examine the role of science and technical analysis in transboundary water projects. This article follows up an analysis of the LBSP working group. The emphasis was on examining the science-policy interface in over forty projects dealing with LBSP. The analytical framework combined descriptive [scientific component-incorporation into project design and implementation], evaluative [extent of use of analytical tools] and prescriptive elements. Best practices for management of LBSP were identified. The prescriptive analysis discussed the importance of enhancing communication among scientists and policy makers. The authors conclude that a common framework [here the DPSIR, further developed as DPSWR approach]

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should be applied across projects to enable collective framing of the key environmental issues and working towards informal adaptive management.

1. Introduction

The general environmental, social and economic impacts of Land-Based Sources of Pollution [LBSP], including sewage, urban wastes, industrial discharge, agricultural runoff and a host of other sources are well known. Degraded coastal habitats and fishing grounds, reductions of the pleasures and economic benefits of coastal tourism, depleted fisheries, loss of species and human diseases and loss of life are among those impacts. Globally, the annual costs of these and other impacts amount to billions of dollars. Designing and implementing effective public policies and projects to address the impacts requires active stakeholder participation, huge financial investments, political will and valid technical analysis. Despite increased demand for technical analysis, there is an increased recognition that much of the analysis produced is not being effectively converted into policies, plans and projects that can prevent or reduce negative environmental, health and economic impacts [Pielke, 2007; Slaughter and Rhoades, 2005; Van Kerkhoff, 2005].

Interactions between those preparing technical analyses of LBSP and national and local policy makers and planners working on waste management or water management issues mirror relationships between technical analysts and policy makers in many different fields. While the need for improved communication is often highlighted, the more basic issue is a difference in their roles. Analysis involves the identification of various types of threats distributed over spaces based on key assumptions about short and long term environmental changes over time. Technical analysts describe a probabilistic range of possible future conditions. On the other hand, urban and coastal planners and policy makers often require real time actionable and solution-oriented knowledge. Given patterns of vulnerability, they need to know how to intervene to reduce the adverse impacts of waterway and coastal uses. Their challenge is to identify types and combinations of interventions that will have the greatest likelihood of reducing risks at the least cost and minimum social, economic and political disruption.

Successful development and transmission of technical information on land-based sources of pollution to policy makers is an important institutional issue in water management, arising out of key questions: what strategies of developing and disseminating technical information contribute to its successful use by policy makers and planners? How effectively are policy makers and planners using technical information about the impacts of land-based sources of pollution? How do they assess its validity and usefulness? How do they convert technical information about the risks, scope, and severity of potential impacts into cost-effective impact mitigation strategies? What types of policy responses and what combination of management tools are being developed and applied? How are they evaluated?

These and other similar questions motivated the development of a Global Environment Facility [GEF] research project to examine the role of science and technical analysis in transboundary water projects. The resulting International Waters [IW]: Science research project focuses on GEF-funded water projects involving underground aquifers, river basins and lakes, marine coasts, large marine ecosystems and open oceans. The overall objective of the project was to 'enhance through knowledge integration and information sharing tools – the use of science in the GEF IW focal area to strengthen priority-setting, knowledge sharing a results-based, adaptive management in on-going and future projects' [Mee et al., 2012, p. 42]. A research team composed primarily of scientists, but also donor agency representatives, planners and resource managers engaged in water management issues held an initial meeting in Macau in January 2010. Experts were subdivided into groups dealing with more specific water management issues: rivers, lakes and groundwater [aquifers], land-based sources of pollution; and large marine ecosystems and open oceans. Subsequent meetings of each group were held in early 2011. This article is based on the analysis of the LBSP team.

2. Project method and analytical framework

The role of science in GEF funded projects was analyzed following a standardized approach. For land-based sources of pollution, the emphasis was on projects addressing untreated and under-treated sewage discharged into rivers and other waterways, runoff from agricultural and aquaculture activities, urban runoff, industrial discharges and other unmanaged waste disposal activities. These pollutants lead to higher rates of biological oxygen demand, nitrogen, phosphates and total suspended solids in receiving waters.

The Land-Based Sources of Pollution [LBSP] working group analyzed over 40 research projects using a standard template developed for project review. The projects ranged from pollutants from a well-defined source with local impacts to those that included multiple sources of pollution covering a broad geographic scope. While for each project a set of documents was supposed to be available, there was considerable heterogeneity in their availability.

The analytical framework combined descriptive, evaluative and normative elements. The descriptive element included analysis of scientific components of the design and implementation of individual projects. Technical inputs were often cursorily described without any details about how and by whom they were undertaken. Discussions of the influence or impacts of scientific inputs were absent in some project documents.

In the evaluative component, the use of specific analytic tools was examined such as the formation of multi-sector technical advisory committees and institutionalization of on-going research. In the prescriptive element, the development of a decision-support system was used as the way of explicitly linking the science and knowledge sphere to the management arena to support improved decision-making.

In the LBSP report, the decision support initiative is reflected in the application of the Driver, Pressure, State, Impact, Response [DPSIR] framework concept, modified to the DPSWR [replacing 'impact' by 'welfare'], to the analysis and management of LBSP.

3. Descriptions of project features and impacts

Core questions that helped shape the project included: critical science challenges specific to each ecosystem type, significance of regional and global scale drivers, understanding and managing multiple causality, accounting for spatial and temporal scales, assessing coupling of socio-ecological systems and the availability of knowledge used to evaluate tradeoffs between response options developed by IW projects [Mee et al., 2012, pp. 42–43].

Highlights of scientific best practices recognized in some of the projects were elaborated as case studies and analyzed by the LBSP working group as 'Lighthouse Projects'. 'Scientific Best Practices' were also classified as [a] technological best practices and [b] science-outreach, in order to highlight the major contributions of science to the project and communicating this science into outreach programs.

3.1. *Results of the case study approach*

This approach critically addressed the current and emerging science challenges, regional and global scale drivers of change, multiple causalities, multiplicity of spatial and temporal scales, coupling of social and ecological systems and the evaluation of tradeoffs.

Science challenges in the future of International Waters [IW] will more likely be concentrated on implementing measures towards the application of scientific knowledge than on advancing technical analysis, e.g. characterizing ecosystem types and changes. Applying science-knowledge should ideally include an evaluation of where, how and by whom this knowledge should be the applied. Science-knowledge generation should be best based on the application of indicators and observations.

Transboundary problems in IW are strongly driven by patterns of change on a global scale. Despite the importance of global drivers such as climate change, regional issues such as pollution, subsidence/erosion and anthropogenic forces often have similar impacts. Global drivers can also affect regional and local developments leaving little room for communities to adapt. Analysis of projects concluded that among the overarching pressures on coastal systems, LBSP have a high impact on the regional and local level and future trends may even go up [e.g. increasing land conversion for crop based bio-fuel production has undoubtedly strong significance for nutrient fluxes through IW]. This may accelerate societal priority decisions towards renewable energy concepts both in the continental shelf or LME context (see LOICZ IMBER continental margins working group for example).

In the future of transboundary waters multiple causalities leading to uncertainties are challenges of major concern. They were recognized in many of the IW projects. Analysis of causes and effects are key analytic tasks. By examining scenarios in light of different socio-political priorities and global developments, science can influence IW projects. One project evidently addressing multiple causalities is the Partnerships in Environmental Management for the Seas of East Asia [PEMSEA, 2006, LaRoche and Wilkinson, 2013; http://www.pemsea.org, accessed 23.01.14].

Transboundary Diagnostic Analysis [TDA] and legal instruments are addressed within the Western Indian Ocean Land Based [WIOLAB] [see http://projects.inweh.unu.edu/inweh/report.php?ListType=ProjectDocument&MenuItemID=3&ID=80, accessed 23.01.14]. The project features multiple causalities on a regional scale. In both approaches, PEMSEA and WIOLAB, the social-science perspective needs to be improved. Twinning systems [e.g. catchments] in the cross-continental context served as cases studies to improve knowledge transfer within the DeltaAmericas project in Latin America. Continental scale approaches enable international learning about multiple causalities.

Different scales within IW projects [here within PEMSEA and DeltaAmerica] are often addressed along the water continuum. Institutions have been established or reinforced addressing multiple scale approaches along different temporal and spatial scales [e.g. regional monitoring programs and assessments] particularly in Asia and, to a lesser extent, in Latin America. The Ecosystem Services is a notable approach that has the potential to ensure a variable scale consideration for management purposes and for application within necessary institutions and user communities of practice.

Multiplicities of scales and coupled system approaches [as e.g. coupled social–ecological system analysis] are not explicitly used in IW projects. Within such approaches indicators need to be developed and applied. They were used in PEMSEA, WIOLAB or by the ‘Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles’ project, executed by Land–Ocean Interactions in the Coastal Zone [LOICZ]. For further examples see Kremer et al. (2012a, p. 9).

Evaluating tradeoffs in the management of increasing pressures and response options in the context of LBSP is an emerging task for science. An evaluation of different options and likely changes in socio-ecological systems and tradeoffs was carried out by the EU funded project KnowSeas [http://www.knowseas.com, accessed 15.04.13].

3.2. *Preliminary conclusions*

Reflecting on evaluations of different options for response to environmental pressure and changes in socio-ecological systems together with other observations made in the IW portfolio, allows the following summary of key aspects and recommendations for the application of analytical tools.

The development of scenarios can help in social–ecological system analysis by building pathways for management and future development alternatives and expected outcomes. Outcomes should be structured along the lines of different orders such as reflected in the ‘orders of outcomes’ framework for coasts developed by Olsen et al. (2009). Scenarios can help in evaluating tradeoffs and supporting decision-makers and stakeholders to set long-term goals. This could go along with studies on public awareness being carried out by human dimensions research. Exploring developments of value systems and changes of values might help to influence social choices and address high priority goals. Seeking public awareness is even more important when it comes to widely accepted solutions and decisions related to climate change on a regional scale.

Most IW projects did not address climate change as a driver and regional dimensions of hazards and risks in spite of the fact that knowledge is widely available and climate change has strong impacts for future developments.

Other priority tools to be emphasized include risk assessments for natural hazards [e.g. probability analysis of a storm surge; projections for the next 12 months], resilience and risk research analysis, disaster management tools, improved predictions and measures for community preparedness towards hazards, and the issue of governance [benefits of informal networks and structures].

These research issues emphasize the integration of social and natural science-based methods and results into public awareness and the decision-making processes. There is substantial overlap with related questions of the global Earth system science organizations and initiatives. They are also reflected in the ICSU GRAND CHALLENGES of Earth System Science for Global Sustainability [Reid et al., 2010; http://www.icsu.org/publications/reports-and-reviews/grand-challenges, accessed 18.03.13] which namely are Forecasting, Observing, Confining, Responding and Innovating.

Research issues addressed above are also mirrored in the three Research Themes of the new 10-year international research initiative **Future Earth** [see Future Earth draft initial design report, http://www.icsu.org/future-earth/media-centre/relevant_publications/FutureEarthdraftinitialdesign report.pdf, accessed 3.09.13] supported by the Alliance for Science & Technology [UNEP, UNU, UNESCO, IGFA (Belmont Forum), ICSU, ISSC, WMO and Observer]. Themes aim at observing, explaining and projecting the *Dynamic Planet,* providing knowledge for a sustainable use of goods and services in the *Global Development* and understanding strategies for managing the global environment and society interventions towards *Transformation towards Sustainability*. Both initiatives conclude that disciplinary knowledge needs to be coupled in an integrative manner. Future Earth, in particular, aims at implementing a co-design concept where science and user communities engage in a joint framing of critical questions and identification of knowledge products.

Thus particular attention is required to the role science should play in the years to come. In their analysis, the LBSP working group looked at different perspectives of the science to user interface. The responses to the 'core' questions 1–6 listed above provide a general description of the role science plays or might play in the analyzed LBSP projects addressing land-based sources of pollution. Elsewhere in the reports, more specific analytic tools, scientific insights and findings, useful processes for better developing and incorporating scientific input, strategies for developing analytic capacity and more effective strategies for institutionalizing technical analysis are described. As the authors of the LBSP Synopsis Report [2012b] note:

> '*Most of the projects stress their attempt to build marine scientific and technological capabilities in the field of coastal management to ensure that scientific requirements are integrated into development of national and regional coastal management programmes and plans. In particular, some of the projects promote, through exchange of experiences, development of scientifically based methodologies, tools and services to assist decision-making processes in the field of sustainable development and management of coastal areas. Projects used a variety of applied scientific assessments: environmental assessments, risk assessments, cause-and-effect analysis, resource assessments and monitoring and evaluation. In general, the cause-and-effect relation-ships between discharge of sewage and water quality conditions and between dumping of wastes and habitat degradation, for example, were well understood. What is needed now are well-engineered projects sensitive to local environmental conditions and governance capacity*' [Kremer et al., 2012b, p. 8].

The LBSP Synopsis Report also identifies some 'technological best practices' and science communication strategies. A sampling of 'technological best practices' include:

- 'Creation of an integrated information system [Case study of Rio de la Plata and its Maritime Front];
- environmentally-sound reservoir operation through historic evaluation and modern day modelling [Case Study: Rio São Francisco Basin];
- development of an ecological discharge model to define minimum ecological flows [Case study of São Francisco River Basin];
- application of a calibrated artificial flood model, including a fully documented technical, economical and socio-environmental framework, and a final test of artificial flood and related operation plan;

- assessment of carrying capacity and valuing ICM [Case study of the East Asian Seas – Partnership for the Management of the Seas of East Asia [PEMSE]];
- use of biofilms as a unique procedure for reduction of nutrients in wastewater streams. Use of natural systems such as wetlands for nutrient, POPs, and metal removal may be termed as environmentally friendly [Alexandria agriculture project];
- reporting of new seagrass species-Halophilaspinu-losa [Case Study: Community-based Management of Seagrass Habitats in Trikora Beach];
- Integrated Coastal Management Demonstration Sites [Case study of the East Asian Seas – Partnership for the Management of the Seas of East Asia [PEMSEA]];
- environmental impact assessment guidelines to be used for pre-feasibility studies of possible port reception facilities and waste disposal infrastructure;
- guidelines for control and management of ships' ballast water to minimize transfer of harmful aquatic organisms and pathogens [Case study: Ship's Ballast Water management];
- clean production technologies and technological options for wastewater management; and in general the
- Transboundary Diagnostic Analysis and Strategic Action Plan approach applied by the GEF projects [Pernetta and Bewers, 2012; www. http://iwlearn.net/publications/tda, accessed 15.04.13] [adapted from Kremer et al., 2012b, p. 19].

The Synopsis Report also highlights science communication strategies that were used by the projects including training workshops, websites, key newspapers, scientific publications, annual reports, program brochures, community awareness programs, workshop proceedings and other mechanisms [Kremer et al., 2012b, p. 20]. Taken together, the report describes some of the tools projects used to generate scientific and technical information, some of the processes used to assist analysis and decision-making, such as the formation of technical advisory groups, and some of the communication strategies, such as websites, used to communicate technical analysis to a wider audience. As useful as these findings are, they do not provide much context about what factors influenced the choice of analytic tools, what technical questions they sought to answer, how scientific and technical analysis was integrated into project planning and implementation processes and how communication among technical analysts and decision makers was facilitated or how it might be improved. Thus the role of communication in delivering the GEF societal objectives remains largely unclear.

However the report also includes more fully developed sketches of science-policy linkages in 11 projects. These projects were selected on the basis of several criteria including significant scientific components, design and use of science networks, scientific best practices and science/management implications. One of these 11 projects, a long-term effort to reduce pollution in the East Asian Seas undertaken by the Partnership for the Management of the Seas of East Asia [PEMSEA] is shown in Box 1.

These and other project sketches in the report provide a bit more descriptive detail about the types of scientific analysis undertaken in some land-based sources of pollution projects, although it is not always clear from this and other project sketches what management decisions or practices were ultimately informed by the analysis.

4. Evaluative analysis: identifying best practices for managing land-based sources of pollution

A second purpose of LBSP working group analysis was evaluative by identifying those actions that are likely to improve the quality of analysis and the integration of science with policy and management. In the overall Report, *Science-Policy Bridges over Troubled Waters*, the activities leading to improved science intensive management were described in terms of specific ‘best practices’ [Mee et al., 2012]. In the reports from the land-based sources of pollution, the ‘best practices’ are implicit in the findings and discussion. Some of these implicit best management practices are identified below.

Box 1–East Asian Seas Region: Prevention and Management of Marine Pollution in the East Asian Seas – PEMSEA [GEF: 396].

The primary vision of the project is to strike a balance between prevention of marine pollution and economic development in the region. The project targets both local and transboundary marine pollution impacts through participatory management involving the stakeholders.

The role of science in the project can be classified as:

- Ambient water quality monitoring [including standardization of field and laboratory methods];
- creation of an integrated database composed of [a] spatial and temporal databases for ICM, [b] a legal information database, and [c] an environmental information system for the Straits of Malacca;
- use of modelling to determine transboundary pollution by oil spills and damage assessment; dose response relationship, etc;
- development of a pollution index;
- development of tools for assessing natural resource conditions [including extent of damage], risk assessment and risk management;
- assessment of ecological effects, by exploring measured environmental concentrations for hydro-carbons and hydrocarbon composition, and their impact on the ecosystem; and
- economic valuation of the coastal marine resources.

Highlights of the project are the two Integrated Coastal Management Demonstration Sites: Xiamen Demonstration Project [People's Republic of China] and Batangas Bay Demonstration Project [Philippines]; and one site that demonstrates transboundary marine pollution, the Malacca Straits Demonstration Project, which assesses and manages pollution in the Straits of Malacca. These demonstration projects helped launch efforts in addressing marine pollution problems in the Straits of Malacca and Straits of Singapore.

Success of the regional program can be classified in terms of scientific, management and outreach components. Results from the scientific component are quite impressive with emphasis on GIS and database creation, which is an extremely important initiative serving as a foundation for the various management and outreach objectives. Other highlights of the scientific aspects include environmental impact and risk assessments; monitoring of ambient water quality; economic evaluations of the coastal resources; and development of models and tools.

Management initiatives are captured best in the report[s] in the discussion of the success of the two ICM Demonstration Sites in Xiamen and Batangas; the case study on transboundary pollution management under- taken at the demonstration site of the Straits of Malacca; zoning schemes developed for the Xiamen and Batangas coastal areas; the establishment of a water quality index and standards for the region; and the legislative framework and the ICM framework. All of these are evidence of significant and successful outputs. The project contains documented evidence of 'outreach' components by way of newsletters, 'Bay Watch' programs organized to create awareness among the local public, and preparation of brochures.

This project has a good blend of natural and social science components, which is important for Integrated Coastal Management and for prevention of marine pollution. Combating transboundary marine pollution, using appropriate tools such as GIS, modelling and risk assessments, is a significant natural science effort. Various legal measures to prevent marine pollution deserve special mention. Economic analysis of coastal resources, oil spill cleanup costs and zoning of coastal waters is also included.

The social science focus of this project is demonstrated through the various continuing outreach programs and outreach materials. Also, for the first time [as mentioned in the report] participatory management involving various stakeholders has been undertaken. Networking and capacity building in ICM is a unique venture, which is now being taken up by many nations. In conclusion, PEMSEA is a success story, comprehensive in its objectives and can be considered successful in its implementation.

Source: Kremer et al., 2012b, p. 28–29.

4.1. *Effective management of land-based sources of pollution:*

4.1.1. *Socio-ecological systems*

In order to manage land based pollution the integration of natural and social and scientific analysis is necessary. The inherent complexity in dealing with ecological and societal challenges in pollution management means that decisions are always challenged by a lack of accurate knowledge. Socio-ecologic systems [SES] have been defined as a bio-geo physical territory along with associated stakeholders and institutions situated within a particular problem context. Specific features of coastal and marine social–ecological systems [CM-SES] include catchment-to-coast and open sea regions, specific ecosystem types, specific coastal actors, institutions and problems. Systems operate at varying temporal and geographic scales, are inter-connected [often across very large distances as a result of human activity], are often non-linear, have memory [and learning] and choke points [restricting connectivity], apart from having emergent properties [such as resilience]. Thus, the SES approach enables addressing the drivers of the problems as in exploring societal response options towards a sustainable future [Glaser et al., 2012]. This then feeds into linking governance and science in coastal regions.

A working definition for social–ecological system [SES] as used in LOICZ includes:

- A bio-geo-physical territory [e.g., ecosystem];
- associated social agents [stakeholders] and institutions; and
- a particular problem context [e.g., coral, mangrove, sea grass or macro algae degradation, marine pollution, poverty of ecosystem users, climate change].

Obviously, trans-disciplinary research is a useful means of bridging different ‘world views’ and languages of science, policy and coastal users to provide a broader understanding of the complex issues and processes. Natural sciences, social sciences, engineering sciences, and the humanities provide such knowledge and users are actively involved from the beginning [transdisciplinarity in co-design process]. Policy is understood in an abstract sense as a principle or guideline for action in a specific everyday-world context [Kremer et al., 2012a, 2012b]. In recent times, substantial efforts are made in addressing the challenges between science and policy communities in an attempt to relate science, experience and insight to policy. This is the key underlying motivation of the Future Earth Programme inspired by various UN and research organizations [http://www.icsu.org/future-earth/who, accessed 3.09.13].

4.1.2. *State of the art scientific appraisal*

The direct as well as indirect degradation of waters by chemical and nutrient pollution results in eutrophication and human health hazards. The Millennium Ecosystem Assessment [MEA] assessed the consequences of ecosystem change for human well-being, providing a state-of-the-art scientific appraisal of the condition of and trends in the world's ecosystems and the services they provide, as well as the scientific basis for action to conserve and use them sustainably.

Studies on the Mediterranean, Black Sea and north western Gulf of Mexico suggest that a critical step in improving the way ecosystems are managed is to take stock of their extent, their condition, and their capacity to provide the goods and services that will be required in the future. Coastal waters are degraded directly by chemical or nutrient pollution, and indirectly when land-use change increases soil erosion or reduces the capacity of ecosystems to filter water. Nutrient runoff from agriculture is a serious problem around the world, resulting in eutrophication and human health hazards in coastal regions, especially in the Mediterranean, Black Sea, and north- western Gulf of Mexico. Water-borne disease caused by faecal contamination of water by untreated sewage is also a major issue [Kremer et al., 2012b]. Therefore determining scientific priorities to address the most pressing coastal pollution management issues is essential. In addition, it is equally important to develop scientific tools and products to inform policy and decision making.

4.1.3. Assessments of the value of ecosystem goods and services

Careful assessments of the value of ecosystem goods and services can provide an important rationale for management of land-based sources of pollution. A critical step here is to understand the total goods and services provided by ecosystems. Broadly defined, 'ecosystem services' refers to the dependence of economic wealth and human well-being on natural systems [Cramer et al., 2008]. Within ecology and economics, assessment of ecosystem goods and services is a growing area of inquiry. While the promise of a cohesive framework for assessing all types of damages is not yet realized, many projects are working toward this goal through more rigorous conceptualization and communication of the links between changes in natural systems and effects on human welfare. It is estimated that the total ecosystem goods and services derived from coastal zones worldwide equates to about half of the global total of all ecosystems [Costanza et al., 1997, p. 253; Boyd, 2010; Burkhard et al., 2010; Busch et al., 2011]. However, calculating the lost ecological wealth with any precision is an enormous scientific and economic undertaking [Barbier et al., 2011].

Just to give an example: marine vessel, terminal, and harbour operations can generate a range of damages arising from liability for response and clean-up costs, damages to private property, and damages to public natural resources. Thus, there is a clear need to measure, conceptualize and communicate the links between changes in natural ecosystems and effects on human welfare in future projects as well.

4.1.4. Analysis of the factors affecting the behaviour of resource users

This is a critical component of designing strategies for effective management of ecosystems. Unplanned development can result in socioeconomic polarization which increases vulnerability. It is also important to recognize that the most economically marginal local people are also often the most vulnerable, and thus require explicit support. Local coping strategies, such as adaptation strategies to address sea level rise, must be informed by science. Appropriate socio-ecological governance institutions should match ecological scales [Kremer et al., 2012b; Langmead et al., 2007].

Community level social dynamics and people's perceptions and behaviours related to coastal resource management by the people [termed co-management] are becoming more common in recent times. A basic understanding of the perceptions and support by the community for marine management provides a context for implementing management activities. Focus on people's perceptions of the marine environment and coastal management efforts, needs scaling up. It is therefore necessary to ensure a balance between stimulating economic growth at the coast while maintaining environmental quality. This balance should be made with the focus on reducing poverty among the coastal communities [Sesabo et al., 2006]. Management activities can and should be about improving environmental quality while simultaneously reducing poverty.

4.1.5. Effective interventions to reduce or mitigate land-based sources of pollution

Causal analysis of both the immediate sources of pollutants and social and economic behaviours help assess the inadequacies in pollution management. Causal chain analysis as part of the transboundary diagnostic [TDA] helps in the identification of the root causes of physical and natural aspects as well as the socio-economic and ecological impacts resulting from prioritized issues and concerns. This is necessary to ensure development of appropriate policy interventions which can be focused where they will yield the greatest benefits for the region [Chen et al., 2013]. Causal chain analysis has been employed in a few well-studied projects involving the most important causal links between the coastal environmental and socio-economic impacts, their immediate causes, the human activities and economic sectors responsible, and, finally, the root causes that determine the behaviour of those sectors. Casual chain analysis has been successfully employed in the case of Integrated Coastal Zone Management [ICZM] [Olsen et al., 2009], Integrated Water Resource Management [IWRM] and Integrated River Basin Management [IRBM].

4.1.6. Evaluation and communication

Improvements in learning from the science analysis in LBSP projects will require more effective tools for evaluation and communication. Diverse methods of communicating science were employed by different projects. However, some were more effective than the others in terms of evaluation and communication tools. For example, a major effort to update a national assessment of US estuaries was undertaken as part of the National Estuarine Eutrophication Assessment [Bricker et al., 2007].

Evaluative research shows that some of the projects with communication in their objectives seem to have achieved little, and, for the interested reader, it is challenging to find background or information on results. Thus, the strategy for cross-project learning and best practice communication has huge potential for improvement. As this brief list of best practices and weaknesses illustrates, identifying practical lessons from project experience that have relevance for the design of new projects can be valuable. However, identifying specific best practices with sufficient precision to indicate the contexts in which they are likely to be most relevant can be quite challenging.

5. Prescriptive analysis: applying a decision support system

Decision support systems are required to facilitate communication, knowledge transfer and interaction among scientists and policy-makers, facilitating engagement among stakeholders in a process and enhancing the perceived legitimacy of the decision-making process. The discussion of a decision support system in the context of the overall review of LBSP noted that a joined-up approach to engage the combined skill and energy of natural and social scientists working within a common framework is required. It must be noted that that while ‘environmental management’ refers to managing human activities, those who provide advice are trained in natural science.

The DPSIR approach […] was modified to incorporate welfare instead of impact in a move to balance natural and social sciences as the DPSWR approach [Cooper, 2012]. Fig. 1 is a schematic diagram that helps to frame a problem and to understand the scale in which it operates. Each element of DPSWR has associated space and time scales [Mee et al., 2012, p. 26]. This move has been suggested as the term ‘impact’ can cause confusion since it is applied differently by natural and social scientists. Avoiding the term can provide for greater clarity for environmental accounting and policy development [Mee et al., 2012; Cooper, 2012].

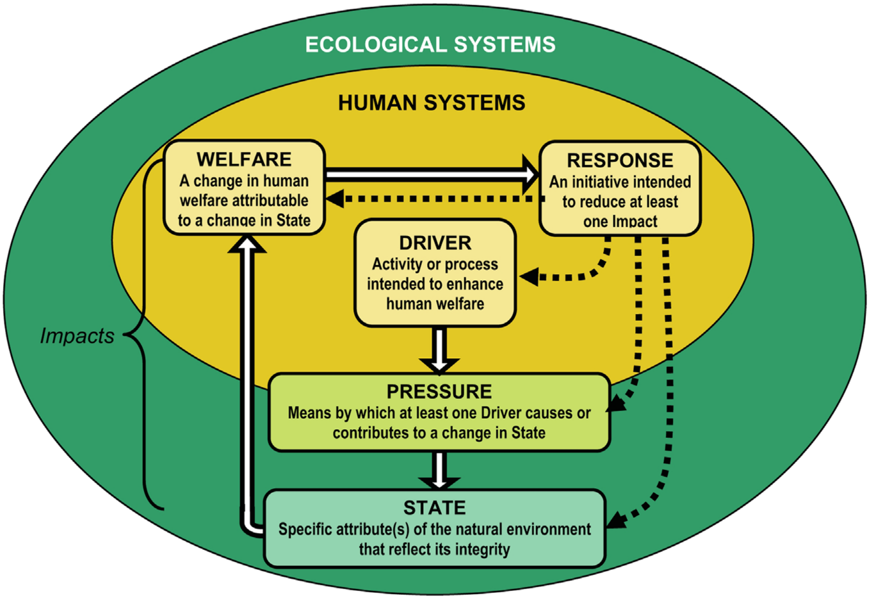

Fig. 1. The DPSWR model conceptual diagram [taken from Mee et al., 2012, p. 27].

As in the original framework, the Drivers [D] are the economic and social forces that result from government policies, markets and the activities of private industry, as well as demographic changes. These lead to Pressures [P] – the ways these drivers place demands upon ecosystem services, including additional pressures caused by larger scale human induced climate change and extreme natural events. Pressures are the interface between the social and ecological components of the system. State changes are the changes in the ecosystem resulting from the pressures [i.e. ecosystem impacts which could be on the environment, ecology, economy or society]. Seen today, the first two directly or indirectly affect society and economy and hence the welfare [W] of people. Response to a particular problem may be directed towards any of the other elements [D, P, S or W] in an effort to achieve a balance between the benefits of economic and social development and the ecosystem costs, usually determined by real or potential changes to human welfare. Welfare changes do not need to be dramatic in order to trigger a response; the current response to climate change is not driven by a huge change in the state of today's ecosystems but by the perception that the level of change that is likely to occur could be catastrophic to humanity [Mee et al., 2012, p. 27].

To oversimplify, in the case of land-based sources of pollution the *Drivers* may include processes such as population growth, urbanization and industrialization. The *Pressure* resulting from these processes may include untreated or undertreated human waste, urban runoff, and industrial discharge, to name a few. The resulting *State*, to continue with the DPSWR framework refers to impacts on the natural environment such as low levels of dissolved oxygen caused by high nitrogen loads or smothered corals resulting from high sediment loads from urban runoff. Changes in *Welfare* might originate from loss of fish stock because of degraded near-shore habitats and resulting loss of income to fisheries communities. *Response* in the DPSWR framework refers to interventions designed to reduce the negative impacts of *Drivers* or *Pressures*. A sewage treatment plant designed to gather and treat human waste is one simple example of an intervention. For tracking and assessing short term and long term trends, *Drivers*, *Pressure*, *State* and *Welfare* carefully developed indicator systems are essential as the reports make clear [Kremer et al., 2012a, p. 1–23].

The DPSWR framework is presented in project reports often indirectly and without much elaboration of its intended use or how it supports decision-making or its usefulness is assumed to be obvious. At a minimum, it is a useful heuristic approach for framing of social–ecological contexts of a changing, threatened environment. Detailing a DPSWR framework for a specific LBSP such as urban runoff can serve to enhance mutual understanding of the links among waste dumping into drains and canals, environmental conditions such as contamination of shellfish, socio-economic impacts on communities and possible interventions to improve the quality of waste management. In that sense, it can help communicate linkages to broader audiences, to demonstrate the significance of the problem and to build awareness of the need for interventions.

The DPSWR framework can also be used more explicitly for discussion and analysis of the potential for adaptive management. Adaptive management is a theme throughout the reports indicating its importance. While in its simplest form, it is ‘learning by doing’, it represents an important paradigm shift that is closely linked to the ecosystem approach to management. It can be considered as a cycling process and requires careful monitoring of each intervention and evaluation to ensure that the progress is towards the agreed vision. If not, required adjustments in interventions have to be made to proceed towards the agreed goal and the entire process repeated. Occasionally, the vision itself may require re-evaluation as new data and information flow in.

The application of the DPSWR framework – and the indicators associated with each element – should harmonize the tracking and assessing of changes in *Drivers*, *Pressure* and *State* conditions. Because the *Response* [intervention] is so central to the logic of the DPSWR framework, the importance of evaluating both the quality of the implementation of the *Response* and the impact of the intervention, particularly on the *Driver* – *Pressure* context must be emphasized. For example, to address the issue of near-shore waters polluted by dumping of household wastes in drains and canals, one neighbourhood organizes a community-based waste management program that relies on education of residents, organized community clean-ups and a network of waste disposal facilities provided by the city. Determining how effectively this community based *Response* works requires a system for monitoring the volume and types of waste entering streams and drains, assessing the quality and level of participation in community waste management training programs, coastal water quality and the health of specific indicator species and the rates and types of use of the community waste facilities. Also required is an analysis of community satisfaction with the program and an assessment of program strengths and weaknesses.

There are multiple interpretations of adaptive management, but in short it can be understood as follows:

Adaptive management puts a premium on understanding what is working well, what is not and how to 'adapt' or modify interventions in ways likely to improve impacts and outcomes. Technical analysis is central in this process of adaptive management. First, analysis of water quality and the health of indicator species are required. Second, evaluation of community engagement, the impact of education efforts on patterns of use of waste facilities is also required. Taken together these types of studies provide the analytic basis for 'adaptive management'.

To conclude, the DPSWR framework can be a useful aid to decision making, but more attention needs to be paid to how it is used and in what contexts it would be most useful.

6. Observations and conclusions

In view of development and globalization it is imperative that research on management of system changes and global sustainability is policy relevant. In the context of IW science and related to LBSP this means that scientists need to account for policy priorities (in economic and environmental terms) set for all management levels including global change issues that affect LBSP. IW science points in this direction by linking scientists from natural and social sciences and policy-makers.

The aim to link scientific knowledge to policy decisions is not only reflected science and policy fora of the year 2012, such as the Rio+20 [http://www.uncsd2012.org/] or the 'GEF International Waters Science Conference' [GEF IWSC 2012] [see conference report http://iwlearn.net/iw-projects/3900/project-documents/gef-iwsc2012-final-conference-report/at_download/file, accessed 23.01.14]. It is a central rationale for the new Future Earth initiative launched at Rio+20. Furthermore this summit launched a process aimed to develop a set of Sustainable Development Goals [SDG]. The GEF IWSC was the pioneering platform for sharing views and study experiences with the wider IW science audience with the objective to propose best and sustainable resource management options for transboundary water bodies.

Future Earth focussing on initial Integrated Research Themes [Transition Team for Future Earth, 2013] is supposed to 'develop the knowledge for responding effectively to the risks and opportunities of global environmental change and for supporting transformation towards global sustainability'. The programme supported by UN and scientific entities as well as national governments strongly emphasizes the integration of social and natural science-based knowledge products into public decision-making [see http://www.icsu.org/future-earth, accessed 23.01.14].

Research themes listed below reflect current priorities as a living agenda aimed to map global change research flexibly also onto issues that are relevant for the management of LBSP.

6.1. Dynamic planet

The aim of this research theme is to understand how socio-environmental changes relate to natural phenomena and human interventions. LBSP can be seen as an expression of global change that occurs dynamically. Observing drivers and processes and their interactions is critical to enable early warning of emerging LBSP. Analysis has to be built upon existing knowledge jointly provided by physical/natural and social scientists and the public. Within IW science projects, focus should be on developing early warning measures, based on local vulnerability assessments and identifying institutions and networks (including informal ones) that are needed for preparedness.

Conclusions of the LBSP WG related to Future Earth Research Theme 'Dynamic Planet'

- The links among industrial pollutants, sewage, urban and agricultural runoff and eutrophication, harmful algal blooms and other impacts that degrade water quality, reef communities other coastal habitats in general are well-understood. Technical inputs may be required on project level to

analyze specific local sources of pollution and to insure that interventions are engineered in ways insuring effective treatment of urban wastes.
- Resilience and risk need to be integrated; e.g., what makes a coastal community resilient in dealing with global environmental regional and local pressures?
- Social research is required in terms of what the benefits of informal networks are and how prediction and forecasting can be improved?

6.2. *Global development*

Providing knowledge for using ecosystem goods and services sustainably is seen as a major goal of this research theme. Underlying are sound scientific descriptions of ecosystem functions and processes of a certain socio-ecological system. Understanding human-environmental change should include impact on human well-being and point out pathways for improved management. An assessment of local drivers of water pollution is closely related to global drivers of change, such as climate change. They have a strong impact in the long term and have to be considered carefully in the development of scenarios.

Progress in the improvement LBSP management can also be made through investments in economics, engineering and education:

- At the project level, improving the management of LBSP requires increased emphasis on the economics, engineering and urban as well as river-basin planning in a connected ecosystem based thinking. This includes appropriate technologies such as drainage, sewage collection and treatment, dam construction and water fertilizer usage. Designing sewage collection and treatment systems that serve all sections of the city and insuring operating funds for their operation and maintenance can do much to reduce adverse impacts on coastal waters. Agricultural policy in awareness of their influence on water quality from source to sea is an important example.
- Progress in the improved management of LBSP could also be accomplished by investments in the continued education of urban residents, farmers and other resource users including river management authorities. Urban and agricultural runoff can be reduced by means of better road design, household, village and municipal waste management practices and education of farmers about the applications of herbicides, pesticides and erosion management.
- In a scientific context, improvement of informal adaptive management would very much rely on appropriate delineation of the physical and socio-political scales of the system under consideration. Water bodies interact and so do the drivers and pressures – water and material as well as economic flow is the trajectory. The regional scale is of critical importance.
- Anticipatory planning including trend analysis and scenario development can help predict emerging conditions contributing to degrade action of coastal waters and habitats.

6.3. *Transformation towards sustainability*

An analytical issue and task for research is to provide knowledge for understanding of transformation processes within society and individual human behaviour for governing and managing change. These processes emphasize the integration of social and natural science-based methods in delineating pathways to sustainability. Combined with socio-environmental scenarios this psychology and behavioural research will enable comprehensive appraisal of community resilience.

- Significant social–ecological system-based scenarios are required to evaluate tradeoffs, to help decision-makers and stakeholders to set long-term goals by comparing different management alternatives and their outcomes [new concepts of integrated modelling and conceptualizing of social dimensions are critical];
- application of scenario techniques to envision alternative futures and pathways of future development; and

- there are scientific tools to explore development and change of value systems that may influence social choice. Those should be addressed with high priority;
- Underlying is a thorough investigation of environmental psychology and human behaviour in priority setting.

Several factors impede improved management of LBSP:

- Relatively small investments have been made in institutional arrangements to monitor trends in resource use patterns, resource conditions [including water quality], environmental stressors and other variables. Creating institutional arrangements for continuing applied research and monitoring could provide a strong information basis for improved management.
- Weakness or the absence of communication channels linking scientists and resource managers with regulators and decision-makers who could take enforcement actions to respond to deteriorating resource conditions. In addition, many resource managers lack the authority and political will to engage in effective science-based regulatory actions.
- Weak institutional mechanisms for counteracting coordinating responses to environmental deterioration. Joined up thinking and cooperation between public works, environmental and land use planning agencies could improve the quality of management of LBSP.

The work of the LBSP working group concluded that disciplinary knowledge needs to be integrated. Future Earth, in particular, aims at implementing a co-design concept in which science and user communities engage in a joint framing of critical questions and identification of knowledge products. Both strands should therefore closely be linked with each other in the future of managing International Water related issues in general and LBSP in particular.

The current development of the Future Earth Programme, the global framework and knowledge platform for sustainability research is seen as an emerging enabling mechanism. It may assist in improving transboundary and International Waters science and informed policy intervention. The fact that it is supported by the Science and Technology Alliance for Global Sustainability (UNEP, UNU, UNESCO, IGFA (Belmont Forum), ICSU, ISSC, WMO and Observer) established a direct link to the International Waters portfolio.

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References

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B., 2011. The value of estuarine and coastal ecosystem services. Ecol. Monographs 81 (2), 169–193.

Boyd, J., 2010. Lost ecosystem goods and services as a measure of marine oil pollution. Resour. Future, RFF DP, 10–31. (accessed 18.03.13) ⟨http://www.rff.org⟩.

Burkhard, B., Petrosilio, I., Costanza, R., 2010. Ecosystem services-bridging ecology, economy and social sciences. Ecol. Complex. 7, 257–259.
Busch, M., Gee, K., Burkhard, B., Lange, M., Stelljes, N., 2011. Conceptualizing the link between marine ecosystem services and human well-being: the case of offshore wind farming. Int. J. Biodivers. Sci., Ecosyst. Serv. Manag. 7 (3), 190–203.
Chen, S., Pernetta, J.C., Duda, A.M., 2013. Towards a new paradigm for transboundary water governance: Implementing regional frameworks through local actions. Ocean Coast. Manag. 85, 244–256.
Cooper, P.W., March, 2012. The DPSWR Socio-Ecological Accounting Framework: Notes on its Definition and Application. KnowSeas Policy Briefs No. 3. Available from: ⟨www.knowseas.com⟩ (accessed 18.03.13).
Cramer, L.A., Stoms, D.M., Kennedy, C.J., Bael, D., Kappel, C.V., Perillo, G.M., Reed, D.J., 2008. Coastal ecosystem-based management with nonlinear ecological functions and values. Science 319, 321–323.
Costanza, R., d'Arge, R., de Groot, D., Faber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Glaser, M., Christie, P., Diele, K., Dsikowitzky, L., Ferse, S., Nordhaus, I., Schlüter, A., Schwerdtner Manez, K., Wild, C., 2012. Measuring and understanding sustainability-enhancing processes in tropical coastal and marine social–ecological systems. Curr. Opin. Environ. Sustainab. 4, 300–308.
Kremer, H.H., Ramachandran, R., Arga, A., Carsen, A., Etienne, M., Hart, V., Lowry, K., Ramachandran, P., Restrepo, J.D., Vermaat, J., Zoeckler, C., 2012. Land – Based Pollution Sources; A Global Analysis of the Land-based Pollution Sources Science and Transboundary Management. GEF IW-Science Project, United Nations University Institute for Water, Environment and Health [UNU-INWEH], Hamilton, Canada, 32 pp.
Kremer, H.H., Ramachandran, R., Arga, A., Carsen, A., Etienne, M., Hart, V., Lowry, K., Ramachandran, P., Restrepo, J.D., Vermaat, J., Zoeckler, C., 2012. Land – Based Pollution Sources; A global Synopsis of Land-based Pollution Sources Science and Transboundary Management. GEF IW-Science Project, United Nations University Institute for Water, Environment and Health [UNU-INWEH], Hamilton, Canada, 40 pp.
Langmead, O., McQuatters-Gollop, A., Mee, L.D. (Eds.), 2007. European Lifestyles and Marine Ecosystems: Exploring challenges for managing Europe's seas. University of Plymouth Marine Institute, Plymouth, UK.
LaRoche, D., Wilkinson, C., 2013. Terminal Evaluation Report for the Project for the Implementation of the Sustainable Development Strategy for the Seas of East Asia. Global Environmental Facility. Quezon City, Philippines.
Mee, L.D., Adeel, Z., Tujchneider, O., vd Gun, J., Munkittrick, K., Servos, M., Kremer, H., Ramachandran, R., Babel, M., Karar, E., Cabanban, A., Heymans, S., 2012. Science-Policy Bridges over Troubled Waters—Making Science Deliver Greater Impacts in Shared Water Systems. GEF IW-Science Project, Synthesis Report, United Nations University Institute for Water, Environment and Health [UNU-INWEH], Hamilton, Canada, 48 pp.
Olsen, S.B., Page, G.G., Ochoa, E., 2009. The Analysis of Governance Responses to Ecosystem Change. A Handbook for Assembling a Baseline. LOICZ Reports & Studies No. 34. GKSS Research Center. Geesthacht, Germany, 87 pp.
PEMSEA, 2006. Performance Evaluation: Building Partnerships in Environmental Management for the Seas of East Asia [PEMSEA]. PEMSEA Information Series. Global Environmental Facility/United Nations Development Programme/International Maritime Organization Regional Programme for Building Partnership in Environmental Management for the Seas of East Asia [PEMSEA]. Quezon City, Philippines.
Pernetta, J.C., Bewers, J.M., 2012. Transboundary diagnostic analysis in international waters interventions funded by the global environment facility. Ocean Coast. Manag. 55, 1–12.
Pielke, R. A., 2007. The Honest Broker: Making Sense of Science in Policy and Politics. Cambridge: Cambridge University Press.
Reid, W.V., Chen, D., Goldfarb, L., Hackmann, H., Lee, Y.T., Mokhele, K., Ostrom, E., Raivio, K., Rockström, J., Schellnhuber, H.J., Whyte, A., 2010. Earth system science for global sustainability: grand challenges. Science, Policy Forum 330, 916–917.
Sesabo, J.K., Lang H., Tol R.S.J., 2006. Perceived Attitude and Marine Protected Areas [MPAs] establishment: Why households' characteristics matters in Coastal resources conservation initiatives in Tanzania. Working Paper FNU-99, http://www.fnu.zmaw.de/fileadmin/fnu-files/publication/working-papers/FNU99.pdf.
Slaughter, S., Rhoades, G., 2005. From "endless frontier" to "basic science for use": social contracts between science and society. Sci. Technol. Hum. Values 30, 536–572.
Transition Team for Future Earth, Future Earth Initial Design: Final Report, 2013. International Council for Science (ICSU); Paris, France, 98 pp.
Van Kerkhoff, L., 2005. Integrated research: concepts of connection in environmental science and policy. Environ. Sci. Policy 8, 452–463.