Segara Anakan, Java, Indonesia, a mangrove-fringed coastal lagoon affected by human activities

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The demands of an increasing world population in combination with technical advances of mankind, particularly since industrialisation from the nineteenth century onwards, are challenging the natural performance of system earth. Since then an accelerating loss of biodiversity is accompanied by an overall decrease of water quality, recovery potential and stability of marine and coastal ecosystems (Worm et al. 2006). It has been shown that regional losses in biodiversity negatively affected ecosystem services in temperate estuaries and coastal seas, i.e. they led to a decline in the number of viable fisheries, the provision of nursery habitats and the filter function of wetlands, submerged vegetation and suspension feeders (Lotze et al. 2006).

This is also of particular importance in coastal regions of the tropics where a majority of people lives within 100 km of the coast and to a large extent economically depends on its natural resources. Their overexploitation is endangering ecosystem functioning. Besides providing us with living natural resources which can be directly valued by providing either humans with energy or cash via markets, ecosystems also offer a variety of other services such as, e.g., flood protection, climate and water regulation, nutrient cycling and biological control (Costanza et al. 1997), which indirectly also affect the economic potential. The removal of a resource from the system does not only

mean to decrease its directly measurable economic effects, but it may also entail a cascade of effects on the ecosystem structure and functions.

While the depletion of fish stocks, e.g., has direct economic consequences, i.e. less income for fishermen, the effect of a missing element in the foodweb on ecosystem functioning can only be seen later. This, in turn, may adversely affect those ecosystem services which are difficult to quantify in terms comparable with economic services and manufactured capital (Costanza et al. 1997). Because of the difference in timescales of realising the direct and indirect effects of resource depletion and the difficulties in valuing ecosystem services in terms of economy, the importance of these ecosystem services has long been overlooked or given little attention in policy decisions.

Only in the past decades, we have learnt that these ecosystem services in the long run sustain the economic potential of an ecosystem to a large extent. It appears that coastal systems with a high biodiversity consistently provide more ecosystem services than those experiencing a loss of diversity. This has to be taken into account with regard to the economic potential and policy decisions. Biodiversity conservation and long-term economic development can be seen as interdependent societal goals of equal importance (Worm et al. 2006). Therefore, developing management measures towards a sustainable use of natural resources requires an integrated understanding of ecosystem structure and functions and social and economic dynamics of a region, all of which are intimately linked.

In this special issue, we present results of the German-Indonesian SPICE (Science for the Protection of Indonesian Coastal Marine Ecosystems) programme which addresses the scientific, social and economic issues related to the management of the Indonesian coastal marine

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ecosystems and their resources. It is being funded by the German Federal Ministry of Education and Research (BMBF) and the Indonesian Ministries of Fisheries and Marine Affairs (DKP) and of Research and Technology (RISTEK). The Segara Anakan (“Child of the Sea”) lagoon in south central Java is the regional focus of SPICE Cluster 2 (“Mangrove Ecology”).

The natural resources and hence socio-economic goods and services of the mangrove-fringed lagoon are affected by high riverine sediment inputs, overexploitation of natural resources and effluents from agriculture, industry and households (White et al. 1989; Yuwono et al. 2007). The longstanding perception of stakeholders of the Segara Anakan region, therefore, is that sedimentation and pollution are major threats to the lagoon. This has led to the development of management programmes which are in operation for decades but seem not to have satisfied all stakeholders’ demands. The task of SPICE Cluster 2 was to address these problems with a multidisciplinary approach and to improve understanding of the ecosystem structure and functions and of its interaction with the social and economic dynamics. It shall provide the basis for the improvement of existing management schemes towards a sustainable use of the lagoon’s natural resources. This special issue reports results from the first phase of SPICE (2003–2007) which had a focus on natural science, while the second phase (2007–2010) has a stronger social science component.

The first three papers provide information on the physical and biogeochemical environment. Ardlı and Wolff report changes in land use and land cover over the past two decades. Mangrove and lagoon (water-covered) area have decreased substantially, mostly at the expense of expanding rice fields and aquaculture. High sediment input from the Citanduy River and a volcanic eruption and conversion of mangroves to other land uses appear to be the most important factors for the loss of habitat for aquatic organisms. The hydrodynamics of the lagoon which have been investigated by Holtermann et al. are another important factor for the input, dispersal and fate of substances as well as for the habitat distribution. While tidal exchange with the Indian Ocean is of major importance in the eastern part of the lagoon where freshwater input is low, high freshwater input by the Citanduy and other rivers dominates over tidal exchange in the western and central parts of the lagoon. Because of this and the shallowness of the lagoon, the residence time of water is short. This is also important for the nutrient biogeochemistry as described by Jennerjahn et al. The Citanduy River which drains an agriculture-dominated hinterland is the major nutrient source of the lagoon. Nutrients were high in the western lagoon, decreased towards the east and were lower during the dry season than during the wet season. Despite a high

population density and intensive agriculture in the hinterland, nutrient levels were moderate to low when compared to other lagoons around the globe suffering from eutrophication. It is probably mainly due to the low residence time of water in the lagoon.

The following four papers report on the distribution and diversity of the biota, the lagoon’s living natural resources, and ways how to use them in a more sustainable fashion. Hinrichs et al. studied the diversity and distribution patterns of mangrove vegetation in the lagoon and find it in a degraded state as indicated by, e.g., lower seedling density and stem diameter when compared to the 1980s. Tree cutting and high sedimentation rates are the major causes, particularly in the western and central parts of Segara Anakan not allowing for development of a mature forest. The distribution and diversity of benthic organisms and communities displayed distinct spatial variations and a serial shift between 2004 and 2006 as reported by Nordhaus et al. Despite the potentially harmful human activities in the lagoon area, the species richness and densities of benthic organisms are surprisingly high. They are high compared to other SE Asian mangroves and hence among the highest in the world. Rückert et al. describe the diversity of metazoan fish parasites in the lagoon in order to use them as indicator organisms for fish health, an issue which will gain importance in Indonesia with respect to its growing aqua-/mariculture business. The results of Rückert et al. indicate that the fish fauna in Segara Anakan is affected by the input of land-derived substances particularly in its eastern part which receives effluents from industry and households of the city of Cilacap. Aware of the fact that effluents from aquaculture create severe environmental problems, Edy Yuwono and Purnama Sukardi in their paper describe how an efficient feeding management may contribute to a reduction of aquaculture effluents. Jointly with local fishermen, they ran experiments in the field which showed that a partial feed reduction does not necessarily reduce fish production. This example demonstrates how a simple measure can be beneficial in terms of economy and ecology at the same time, i.e. it reduces cost for the operator of a fish farm and the release of pollutants to surrounding waters. Moreover, the collaboration between scientists and stakeholders can provide for a better understanding and acceptance of management measures.

The latter appears to be crucial for the success of any kind of management measure as pointed out in the final paper by Reichel et al. which deals with conflicts between stakeholder groups in the Segara Anakan region. They report on the conflict potential between multiple stakeholders, basically different occupational and ethnic groups. Ongoing migration into the Segara Anakan region will exacerbate the competition for shrinking resources. Reichel

et al. conclude that a management scheme aiming at a sustainable use of Segara Anakan's natural resources requires not relying only on the traditional uses, but it has to depict additional, alternative income sources.

The newly acquired knowledge reveals that the identification of environmental problems of Segara Anakan in the past was not always based on scientific findings but rather on a mixture of stakeholder's perceptions of observations and scientific data sets which were often insufficient in quality and/or quantity. For example, eutrophication related to agricultural runoff, for a long time regarded a major problem, is apparently of minor relevance at present because of the short residence time of water and/or moderate nutrient input (Holtermann et al., this volume; Jennerjahn et al., this volume). Also, high sediment input into the lagoon is probably a natural phenomenon occurring for centuries rather than a process related to human activities in the hinterland in the past decades alone, as deduced from the environmental history of Segara Anakan since the early nineteenth century (Schwerdtner Mánéz Costa et al. 2009). Resource exploitation and habitat loss were identified as being the major factors for species depletion in temperate estuaries and coastal seas (Lotze et al. 2006). Though still lacking reliable numbers particularly on resource exploitation our results so far suggest that the above factors are also among the major threats to the Segara Anakan ecosystem.

The results of SPICE Cluster 2 allow to better identifying present environmental problems and gaps in knowledge. A better understanding of direct and indirect ecosystem services and creating awareness of the value of these among stakeholders are preconditions for developing sound and efficient measures for a sustainable use of the lagoon's natural resources. An overall vulnerability assessment and the creation of scenarios of ecosystem

response to environmental change and attendant changes in ecosystem service provision like suggested for Europe (Metzger et al. 2008), e.g., can be valuable in this respect. All this requires intensive inter- and transdisciplinary collaboration between natural and social sciences and stakeholders, an approach the SPICE programme follows during its ongoing second phase.

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