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Ecological Status of Segara Anakan, Indonesia: A Mangrove-fringed Lagoon Affected by Human Activities

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Abstract: Segara Anakan is a mangrove-fringed shallow coastal lagoon in south central Java, Indonesia, which is of high ecological and economic value because of its richness and diversity in living natural resources. The economic demands of a growing population, however, strongly alter environmental conditions which affect the ecology of the living resources and ultimately the ecological balance and economic potential of the region. Preliminary results of recent investigations in conjunction with available information from the past decades indicate an increasing deterioration of environmental conditions, particularly through high riverine sediment inputs in the western part of the lagoon, oil pollution in the eastern part and inputs of effluents from agriculture particularly in the western part of the lagoon. The destruction of mangroves mainly through illegal logging leads to habitat changes which affect the ecology of organisms, particularly of economically important species. Benthic organisms are as diverse as in other tropical regions. Abundances are extremely high in the central lagoon, but lower by two orders of magnitude in the eastern part which is affected by the effluents of an oil refinery. Developing measures for the sustainable management of the lagoon's living resources requires an integrated understanding of ecosystem functions and their changes related to human activities and climate change. The multidisciplinary German-Indonesian SPICE (Science for the Protection of Indonesian Coastal Marine Ecosystems) research programme is designed to obtain the necessary information in high temporal and spatial resolution.

Key words: Mangroves, rivers, lagoon, Indonesia, environmental change, benthos, biogeochemistry, human impact.

Introduction

In the past decade, tropical coasts came into focus because they are harbouring a wealth of ecologically as well as economically important ecosystems, but which are, at the same time, threatened by the growing demand of an ever-increasing population. Indonesia is of major importance in this context because it is among the regions with maximum water and sediment inputs, high diversity of coral reefs, seagrass meadows and mangroves and maximum human modifications of the coastal zone worldwide (Elvidge et al., 1997). About half of the Indonesian population of 235 million live on the island of Java and depend on its natural resources to a large extent. Consequently, natural environmental conditions of its coastal ecosystems have been modified by human activities in many places. Segara Anakan, a mangrove-fringed shallow coastal lagoon in south central Java

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(108°46′ E–109°03′ E, 8°35′ S–8°48′ S) is a prime example in this respect.

The lagoon with its extensive intertidal mudflats provides shelter and nursery grounds for numerous finfish and crustacean species forming also major part of its economic potential. Fishing made up 90% of occupation of the rural population in 1983 (Ecology Team, 1984) and nowadays provides the economic basis for about 13,000 local fishermen. Other major income sources are agriculture, mainly cultivation of irrigated rice and the use of mangrove wood. In the past century increasing inputs from the sediment-laden rivers, mainly the Citanduy, due to unsustainable land-use practices in the hinterland have led to dramatic changes in the distribution of water- and land-covered area. These affect vegetation and habitat distribution for the pelagic and benthic flora and fauna. Moreover, urbanisation and cultivation of the land at the expense of natural land cover resulting from continuous migration into the area are considered responsible for increased inputs of nutrients and pollutants harming ecosystem health. Illegal logging of mangrove wood and the operation of aquaculture ponds are other threats to the ecosystem. This, in turn, affects the economic potential of the lagoon. The underlying processes, however, are not well understood and fluxes have hardly been quantified so far. This is one major reason for the failure of management programmes in the past decades.

Here we summarize existing knowledge on the ecological status of the lagoon including preliminary results from a dry season expedition conducted within the frame of the joint Indonesian-German research programme SPICE (Science for the Protection of Indonesian Coastal Marine Ecosystems). Its major goals are (i) to understand how changing environmental conditions due to human activities affect the ecology of the living resources of the lagoon and (ii) to use this knowledge to develop management strategies for their sustainable use.

Study Area

Segara Anakan is a mangrove-fringed shallow coastal lagoon located in south central Java (108°46′ E–109°03′ E, 8°35′ S–8°48′ S; Figure 1). It is separated from the Indian Ocean by the rocky mountainous island of Nusakambangan. The tropical humid climate is governed by the monsoons. Major part of the annual precipitation of 3,000-3,500 mm falls during months November to March (White et al., 1989; Whitten et al., 1996). The hydrology of the lagoon is governed by seasonally varying river runoff mainly of the Citanduy River in the west and tidal exchange with the Indian Ocean through two channels in the western (Plawangan) and eastern parts of the lagoon. It is responsible for the seasonally

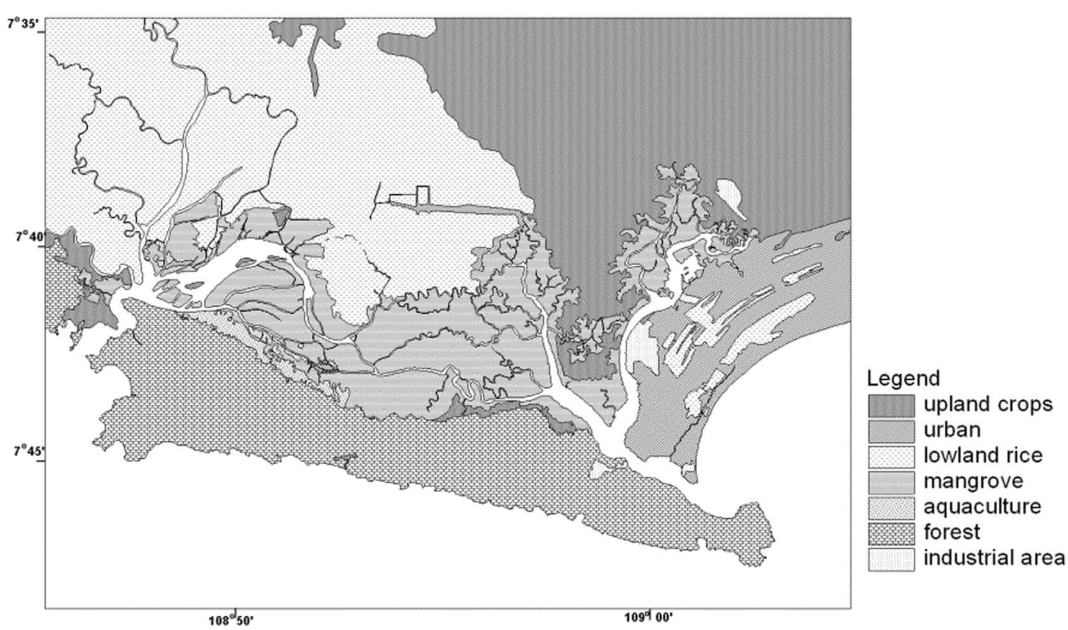

Figure 1: Map of the Segara Anakan lagoon with land use and recent areas of investigation (black rectangles). The box on the left-hand side denotes the western part of the lagoon (area 1) including the Citanduy, Cikonde and Cibereum rivers and the Plawangan channel. The middle box represents the central part of the lagoon (area 2). The right-hand side box denotes the eastern part of the lagoon (area 3) including the Sapuregel (left half) and Donan (right half) subareas.

varying salinity and turbidity of the lagoon (Figure 2). The mixed and predominantly semidiurnal tide ranges between 0.4 m during neap tide and 1.9 m during spring tide (White et al., 1989). The Citanduy is the fifth largest river of Java in terms of discharge which is estimated to 227 $m^3 s^{-1}$ (dry season 171 $m^3 s^{-1}$, rainy season 283 $m^3 s^{-1}$; Ludwig, 1985) or 195 $m^3 s^{-1}$ on an annual average (Whitten et al., 1996) resulting in an annual total of 7.2 km^3 or 6.1 km^3, respectively. The discharge of the other rivers emptying into the lagoon is lower by about two orders of magnitude. Major land use in the area is agriculture, mainly cultivation of irrigated rice which increased by 18% since 1982. Upland crops increased by 25% while the area of forest and plantations decreased by 18% in the same time span (Table 1, Figure 2).

Table 1: Changes in land use (ha) in the Segara Anakan region from 1972 to 2004.

	1972	*1982*	*2004*
Lowland rice	22,821	23,000	27,200
Upland crops	12,844	11,000	13,700
Home and garden	13,073	11,000	11,300
Forest	31,491	27,000*	22,200*
Plantation	1,563		
Others	1,733		
Total area			74,400

*incl. plantation

Numbers given from 1972 and 1982 are from White et al. (1989).

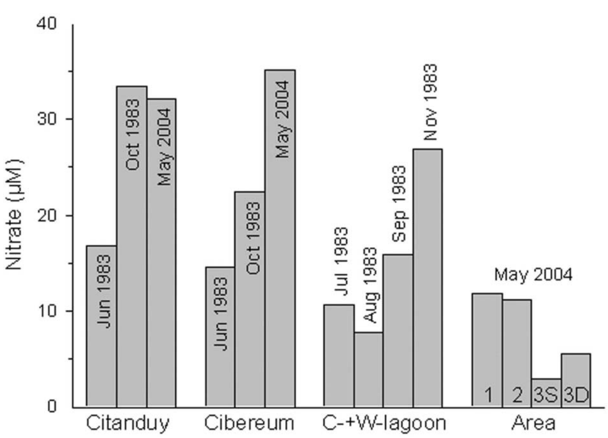

Figure 2: Concentration of dissolved nitrate (μM) in the Segara Anakan lagoon in 1983 (Ecology Team, 1984) and May 2004. The Citanduy and Cibereum are the major rivers in the western part of the lagoon (area 1). Numbers on bars on the right-hand side denote areas of investigation in May 2004 (1 – western lagoon, 2 – central lagoon, 3S – Sapuregel, eastern lagoon, 3D – Donan, eastern lagoon).

Water and Sediment Biogeochemistry

Water quality and biogeochemistry display temporal as well as spatial variability as shown by salinity and turbidity variations (Figure 3) and preliminary results of the ongoing research programme SPICE. The western part of the lagoon is strongly governed by the seasonally varying discharge of the Citanduy and the tidal exchange with the Indian Ocean through the Plawangan channel. River discharge is highest during the rainy season resulting in minimum salinity and maximum turbidity between November and February (Figure 3). The central part of the lagoon is governed by tidal water movement and indirectly by the discharge of the Citanduy, Cibereum and Cikonde rivers whose plumes are pushed towards the centre from the incoming flood current during high tide. Tidal exchange with the Indian Ocean is governing the eastern part of the lagoon which additionally receives considerable freshwater runoff only during the wet season.

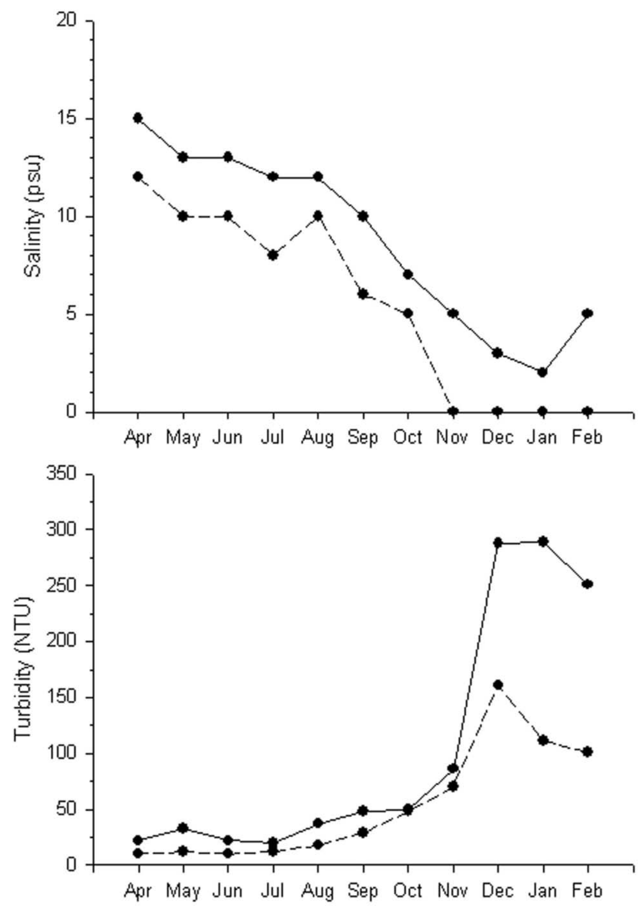

Figure 3: Seasonal variation of salinity (upper panel) and turbidity (lower panel) in the Segara Anakan lagoon between April 2001 and February 2002. Maximum (solid line) and minimum (dashed line) represent the variation between neap and spring tide.

Nutrient concentrations displayed a W-E gradient during the dry season in May 2004. The maximum concentration of dissolved inorganic nitrogen (DIN), about three quarters of which were nitrate, was measured in the western rivers of the lagoon and decreased towards the East (Table 2). Nitrate concentration varied between 1.7 and 39.5 µM and phosphate was always <0.01 µM. These concentrations are almost in the same range as those measured in the 1980s (Figure 2; Ecology Team, 1984; White et al., 1989) and 1990s (24.3 µM nitrate; Sastranegara, 1996). It is much lower than in the Brantas River estuary in eastern Java, for example, which receives high inputs of nitrogen from intensive fertilizer application in agriculture (Jennerjahn et al., 2004). Because of the very low phosphate concentration the N/P ratio was extremely high, much higher than the Redfield ratio of 16, particularly in the Citanduy and Cibereum rivers pointing to almost complete consumption by phytoplankton production (Figure 4, Table 2).

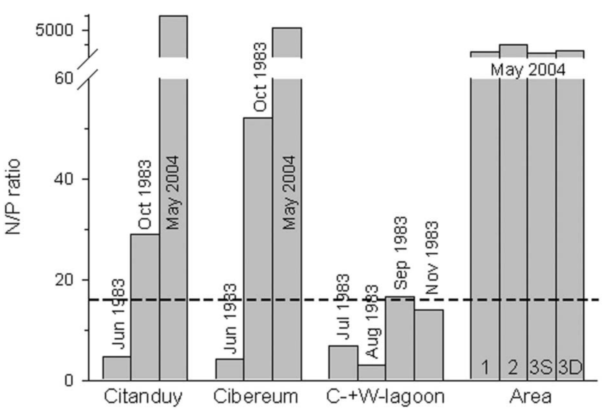

Figure 4: Molar ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus (N/P) in the Segara Anakan lagoon in 1983 (Ecology Team, 1984) and May 2004. Legend as in Figure 2. The dashed line denotes the Redfield ratio. Productivity is P-limited when the N/P ratio is above this line and N-limited when it falls below the line.

The concentration of total suspended matter (TSM) of 1114.4 mg l^{-1} was extremely high in the Citanduy. It was higher by a factor of 3 to 5 compared to previous measurements resulting in TSM concentrations of 193 mg l^{-1} in June 1983 and 326 mg l^{-1} in October 1983 (Figure 5; Ecology Team, 1984). Major part of the Citanduy sediment load which was estimated to 6×10^6 m^3 annually and consisted of 63-95% clay, 2-4% silt and 1-24% sand (LPPM, 1998) is discharged into the Indian Ocean through the Plawangan channel. This is illustrated by the high TSM concentration of the Citanduy decreasing by an order of magnitude each to the western part and then to the central part of the lagoon (Table 2).

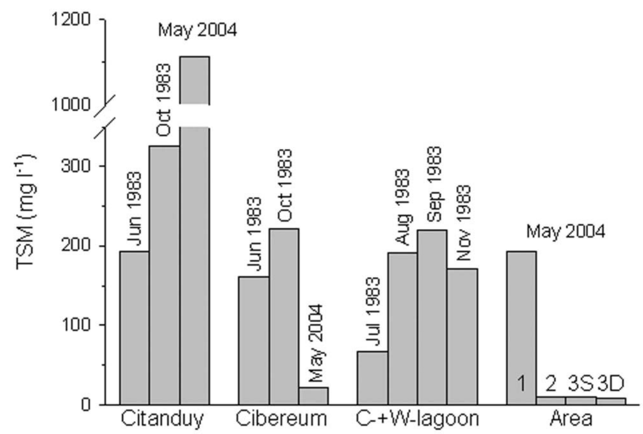

Figure 5: Total suspended matter concentration (TSM, mg l^{-1}) in the Segara Anakan lagoon in 1983 (Ecology Team, 1984) and May 2004. Legend as in Figure 2.

A high chlorophyll-a (*Chl a*) concentration particularly in the central and eastern parts of the lagoon indicates high biomass resulting from primary productivity. Despite high nutrient, input from the Citanduy reduced light penetration resulting from the also high TSM input probably limited primary productivity in the western part

Table 2: Physico- and biogeochemical data of the Segara Anakan lagoon in May 2004.

Area	*Salinity (psu)*	*pH*	*DO (mg l^{-1})*	*NO_3^- (µM)*	*NO_2^- (µM)*	*NH_4^+ (µM)*	*DIN (µM)*	*DIP (µM)*	*Chl a (µg l^{-1})*	*TSM (mg l^{-1})*
Citanduy	0	7.9	3.9	32.2	3.8	4.4	40.3	<0.1	1.8	1114.4
Cibereum	5.7	7.5	5.4	35.2	2.1	3.9	41.2	<0.1	3.4	22.1
Western part (Area 1)	12.4	7.7	5.7	11.8	1.1	3.1	16.0	<0.1	2.8	193.2
Central part (Area 2)	15.7	7.6	5.8	11.3	2.1	2.6	15.9	<0.1	4.6	10.5
Eastern part (Area 3): Doman	29.4			2.9	0.7	2.2	5.9	<0.1	8.4	10.8
Eastern part (Area 3): Sapuregel	25.5	7.8	6.2	5.6	1.0	2.4	9.0	<0.1	3.8	8.6

DO – dissolved oxygen, DIN – dissolved inorganic nitrogen = sum of the single species nitrate (NO_3^-)+ nitrite (NO_2^-) + ammonium (NH_4^+), DIP – dissolved inorganic phosphorus, N/P – molar ratio of DIN and DIP, *Chl a* – chlorophyll a, TSM – total suspended matter. For areas see legend of Figure 1.

of the lagoon as indicated by a lower *Chl a* concentration. The ammonium and nitrite concentrations ranging between 1.9-6.0 µM and 0.5-5.2 µM, respectively, both displayed a gradient from high concentrations in the Citanduy River and western part of the lagoon towards lower concentrations in the East. An opposite pattern was observed for the concentration of dissolved oxygen (DO) which amounted to 3.9 mg l^{-1} in the Citanduy River and increased towards the eastern part of the lagoon (Table 2). These contrasting patterns in combination with the high *Chl a* appear to result from decomposition of the high organic matter (OM) inputs derived either from primary productivity or the rivers. In general, the DO concentration is only slightly higher than 5 mg l^{-1} in most parts of the lagoon, a concentration below which many fish species are getting under stress. In the Citanduy River DO falls even below this threshold (Figure 6; Table 2). The high concentration of dissolved nitrate in the western rivers Citanduy and Cibereum probably results from intensive fertilizer application in agricultural areas in its hinterland. This input fosters primary productivity in the central part of the lagoon where productivity is not light-limited by the high sediment load of the Citanduy. This, however, may impede nutrient uptake by phytoplankton in the river itself and the western part of the lagoon. Consequently, export to the Indian Ocean through the Plawangan channel may be a significant nutrient source for the productivity of adjacent coastal waters.

Sediments display variations in organic carbon (C_{org}) and nitrogen (N) content with minimum concentrations and the minimum C/N ratio found in the Citanduy River where the high load of mineral matter dilutes OM. Generally the strong flow of the river allows for little deposition of detrital OM which, however, makes up a considerable fraction of the transported material. C_{org} and

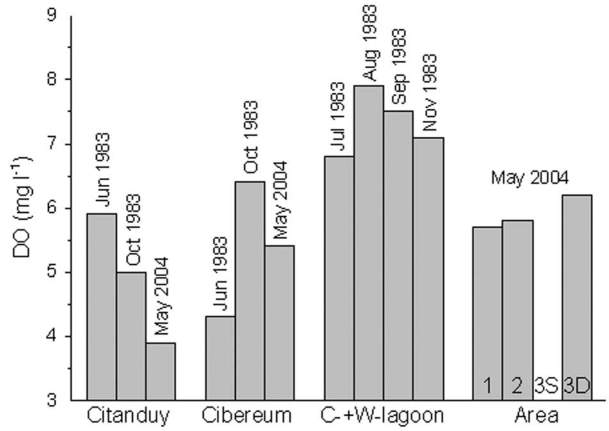

Figure 6: Concentration of dissolved oxygen (DO, mg l^{-1}) in the Segara Anakan lagoon in 1983 (Ecology Team 1984) and May 2004. Legend as in Figure 2.

N concentrations and the C/N ratio are higher in the central part of the lagoon which is less dynamic but still under the influence of the rivers as well as of the tides. Maximum concentrations and C/N ratio were found in the easternmost and least dynamic part of the lagoon, the Donan area where freshwater inflow is almost zero during the dry season.

Bordering mangroves and rice fields are the potential major OM sources of the lagoon. The C/N ratio is slightly lower and the $\delta^{13}C_{org}$ slightly higher in lagoon sediments than in mangrove sediments and rice soils indicating that these are the major OM sources on an annual scale despite fairly high primary production suggested by high nutrient and *Chl a* concentrations during the dry season (Table 3). The C/N ratio and $\delta^{13}C_{org}$ display slight gradients from the western rivers towards the centre of the lagoon. They are in the range reported for mangrove carbon in other regions (Torgersen and Chivas, 1985; Rezende et al., 1990; Jennerjahn and Ittekkot, 2002). The C/N ratio increases from 8.2 in the Citanduy to 11.4 in the central

Table 3: Biogeochemical data of surface sediments and potential terrestrial source material.

	C_{org} (%)	N (%)	C/N	$\delta^{15}N$ (‰)	$\delta^{13}C_{org}$ (‰)
Citanduy	0.1	0.01	8.2	4.3	–25.3
Cibereum	1.0	0.10	10.6	4.9	–25.4
Western lagoon (Area 1)	0.9	0.09	10.9	4.9	–25.5
Central lagoon (Area 2)	1.2	0.11	11.4	4.3	–26.1
Eastern lagoon (Area 3): Donan	2.2	0.12	17.4	3.8	–26.6
Eastern lagoon (Area 3): Sapuregel	0.6	0.04	14.7	3.4	–26.7
Eastern lagoon mangrove sediment	1.5	0.07	19.3	2.9	–26.2
Mixed mangrove leaves	42.8	2.41	17.8	5.3	–27.0
Soil young rice field	1.6	0.14	10.8	4.2	–27.9
Soil mature rice field	3.2	0.25	12.7	6.1	–24.9
Leaves mature rice plant	35.7	1.97	18.1	14.2	–29.7
Stem mature rice plant	35.2	0.86	41.1	9.0	–29.3

part of the lagoon while $\delta^{13}C_{org}$ decreases from –25.3‰ to –26.1‰. It reflects an increasing contribution of mangrove detritus to sedimentary OM towards the centre of the lagoon.

$\delta^{15}N$ varies between 3.4‰ and 4.9‰ in the rivers and the lagoon. Nitrate which is the major nitrogen source of plankton has a mean $\delta^{15}N$ of 6‰ in the ocean and ranges between 6‰ and 9‰ in temperate estuaries (Liu and Kaplan, 1989; Middelburg and Nieuwenhuize, 2001). Plankton in the Childs River estuary (Massachusetts, USA) which receives increased nitrogen inputs from fertilizers and wastewater disposal has an average $\delta^{15}N$ of 5.9‰ (McClelland et al., 1997). Plankton discriminates against ^{15}N during nitrogen uptake (Montoya and McCarthy, 1995). Preferential uptake of the lighter isotope during times of high nutrient supply may result in a low $\delta^{15}N$ of plankton. Part of the nitrogen demand of mangroves is met by bacterial fixation of atmospheric nitrogen which has a $\delta^{15}N$ of 0‰ resulting in a low $\delta^{15}N$ of mangrove OM. During diagenesis preferential removal of the lighter isotope leads to an enrichment of ^{15}N in the remaining OM and consequently a high $\delta^{15}N$. In our case, the generally low $\delta^{15}N$ in river and lagoon sediments hence indicates freshness of sedimentary OM and appears to result from fractionation during plankton uptake of nutrients and the high input of terrestrial OM.

Segara Anakan is a highly dynamic lagoon in which the high sediment input from the hinterland due to unsustainable land use practices is considered a major threat to the ecosystem. It has led to the formation of several small islands in the central part of the lagoon in the past years (White et al., 1989; Sastranegara, 1996). Comparison of our preliminary results on water and sediment biogeochemistry with results of previous investigations suggest that nutrient input is in the same range as in the 1980s. The "land growth" due to high sediment input of the Citanduy River, however, has led to a further reduction of the lagoon's water volume. This may lead to changes in the abundance and composition of benthic and pelagic communities which, in turn, may alter carbon and nutrient cycling in the lagoon.

The Mangrove Forest

The mangrove forest of Segara Anakan is considered to be the largest remaining single mangrove in the south coast of Java. Estimates of the total area of mangrove forest vary between 4000 ha (Ardli, 2001; Dudley, 2000) and 5000 ha (Sastranegara, 2004). The most recent estimate reported 4832 ha of undisturbed mangrove forest in the eastern part of the lagoon and 202 ha mangrove forest in the western part of the lagoon which is strongly affected by illegal logging and sedimentation. The mangrove is not only unique in terms of the area, but also consists of various species that exist in their specific habitat.

Species composition of the mangrove vegetation displays large variability. Erftemeijer et al. (1988) reported 80 species of mangrove vegetation in Segara Anakan including grasses, herbs, bushes and trees while the Ecology Team (1984) found 26 species and Yani et al. (2004) only found 17 species in northern part of Segara Anakan. The most abundant plant species are *Rhizophora apiculata*, *R. mucronata* and *Bruguiera gymnorrhiza* (Ecology Team, 1984). *Sonneratia* spp. and *Bruguiera silindrica* are also abundant. The total wood production was estimated to 33,000 m^3 (ADB, 1998). Recent estimates report that about 50% of the mangrove has been destroyed and about 470 ha have been converted into silvofishery, but only ± 10 ha of them are still in use (Sastranegara, 2004).

The Aquatic Fauna

Fish, Shrimps and Mud Crabs

Segara Anakan is home for various economically and ecologically important animal species. More than 45 fish species have been reported from Segara Anakan (Djuwito, 1985), the economically most important of which are mullets (Mugilidae), snappers (Lutjanidae), barramundi (*Lates calcarifer*), mudskippers (*Periophthalmus* spp.) and eels (*Anguilla* spp.) (Tomasick et al., 1997; Setijanto et al., 2003). Fish comprised 39% of the Segara Anakan catch that reached 250 tons per month in 1999-2000 (Dudley, 2000).

Sastranegara et al. (2003) reported the occurrence of 18 crab species in Segara Anakan with *Scylla serrata, S. paramamosain* and *S. olivacea* (Portunidae) being the economically most important. These crabs are subject to a high fishing pressure and constitute 13% of the Segara Anakan catch which is lower than the portion of shrimps (Dudley, 2000). Our recent survey suggested that economically important shrimps include *Penaeus merguensis, P. indicus, Metapenaeus elegans, M. ensis* and *M. dopsoni.*

Benthos

Our recent investigations of the benthic community in Segara Anakan included semi-quantitative sediment sampling in the lagoon (using an Ekman grab) and quantitative sampling along two transects in the mangrove forest (using corers) in the central and eastern parts of the lagoon, respectively (Figure 1). Overall, 103 taxa were recorded 67% of which were molluscs (Gastropoda 46 taxa, Bivalvia 21, Polychaeta 17, Crustacea 14, others 5).

Comparing the two transects in the mangrove forest, more taxa were found in the central (34) than in the eastern lagoon (21). This difference can be mainly attributed to the higher number of gastropod species in the central lagoon (belonging to nine families) the most abundant of which were the Thiaridae (94%, three quarters of which were juveniles). Species composition was different in the eastern lagoon. Sipunculida, not found in the central lagoon, accounted for 43% of all organisms. These differences may be related to pollution from the effluents of an oil refinery in the Cilacap port. Potamididae and Nereidae were other abundant groups in the eastern lagoon while Thiaridae were almost absent. It appears that the latter in contrast to the Sipunculida cannot thrive in polluted habitats. Species similarity (according to Sørensen, 1948) between transects was low (29.6%). The Shannon diversity index (according to Shannon and Weaver, 1949) and evenness (according to Pielou, 1988) were generally low or moderate (H´ between 0.00 and 1.85, J´ between 0.28 and 1.17) which can mainly be ascribed to the distribution and high abundance of the Thiaridae and the Sipunculida. This agrees with the typical pattern in tropical tidal flats where only few species account for the majority of individuals (Dittmann, 1995, 2002a; Wolff et al., 1993).

Abundances of benthic organisms in the central lagoon were extremely high (17,359 ind m^{-2}/20 cm depth/1000 μm sieve) when compared to those from mangrove forests and along tidal flats of Malaysia, Thailand, Mozambique, Australia and Brazil (Alongi, 1989 and references therein; De Boer and Prins, 2002; Dittmann, 1995, 2001, 2002b; Figueira, 2002; Kober, 2004; Pepping, 1999). The mean abundance for macrofauna in tropical tidal flats ranges from 1000 to 2000 individuals m^{-2}, but variability is generally very high (Dittmann, 2002a and references therein). The high densities in the central transect are mainly caused by the high number of juvenile Thiaridae. In contrast, animal densities were low in the eastern transect (372 ind m^{-2}/20 cm depth/1000 μm sieve) most likely due to the oil contamination. Within both transects the density of benthic organisms decreased with depth (Figure 7). It is assumed that this decline is mainly caused by low oxygen concentrations below the sediment surface which is commonly found in mangrove sediments. Coinciding with the trend of decreasing animal density with depth, the number of taxa was significantly higher in the top layer than in the middle layer and the bottom layer in the central lagoon ($p = 0.001$). In contrast, the number of taxa in the eastern lagoon did not differ between layers.

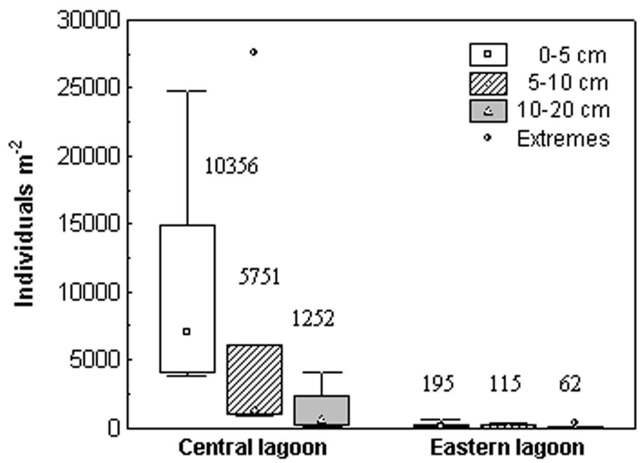

Figure 7: Density (Median, quartiles and min-max) of benthic organisms in the mangrove forest in the central and eastern lagoon in May 2004. Samples were collected from three different sediment layers (*n* =8 each). The sieve mesh size was 1000 μm. Average densities are given above the Box Whisker plots.

Biomass of benthic organisms on average was 19.36 g afdw m^{-2} (range 4.13-39.84 g afdw m^{-2}/20 cm depth/ 1000 μm sieve) in the central lagoon. In the eastern lagoon, average biomass was 6.92 g afdw m^{-2} (range 0.01-32.83 g afdw m^{-2}). Concordantly with animal density, biomass decreased with depth in the central lagoon, but displayed little variability in the eastern lagoon (Figure 8). This is due to the fact that the Sipunculida, which are relatively large and heavy, were more abundant in the lower sediment layers. Compared to macrofauna of tropical tidal flats worldwide, biomass values found for the Segara Anakan lagoon are at the higher end of the range (De Boer and Prins, 2002; Kober, 2004; Pepping, 1999; Sasekumar and Chong, 1986; Swennen et al., 1982; Wolff et al., 1993a; Zwarts, 1985). Higher animal biomasses were only reported from Malaysia (Sasekumar and Chong, 1986).

In the sublitoral, the number of benthos taxa—major part of which were gastropods—increased from the western (13) to the central (32) and to the eastern part of the lagoon (46) which may partly be due to the higher number of stations in the eastern lagoon. However, strong tidal currents and high sedimentation rates due to the sediment input by rivers which hamper colonisation by animals are probably the major factors responsible for the much lower number of species in the western part of the lagoon.

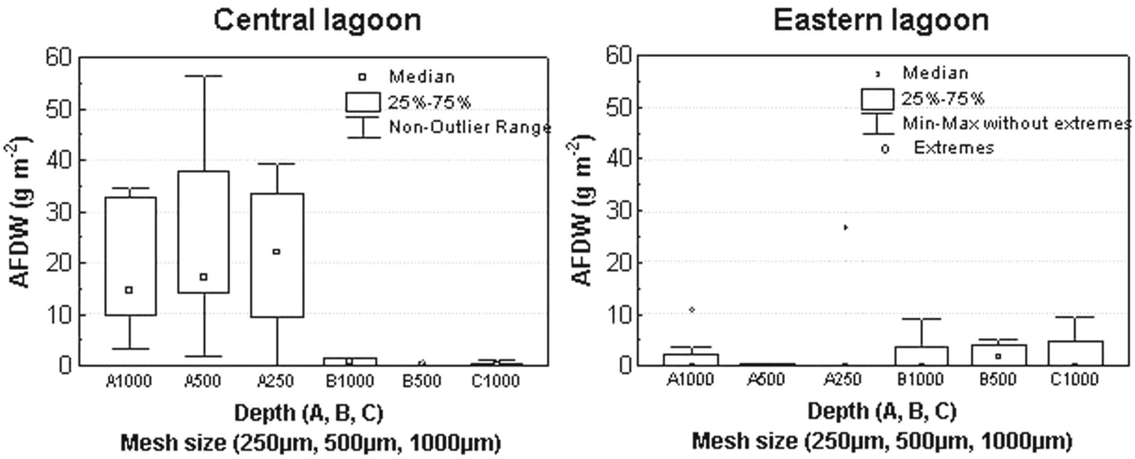

Figure 8: Biomass (ash free dry weight AFDW) of benthic organisms in the mangrove forest in the central and eastern lagoon in May 2004. Samples were collected from three different sediment layers (A: 0-5 cm, B: 5-10 cm, C: 10-20 cm; *n* = 8 each). The sieve mesh sizes were 250 µm, 500 µm and 1000 µm, respectively.

Species numbers and abundances were much higher in May 2004 when compared to previous studies. Hardjosoewarno et al. (1982) reported only 17 invertebrate taxa and two fish species sampled in the mangrove forest and Djohan (1982) found 20 epibenthic taxa. Epibenthos density varied between 8.2 and 329.2 individuals m^{-2}, without displaying any W-E trend (Djohan, 1982). Despite the potential impact of effluents from the oil refinery the Shannon diversity index (Shannon and Weaver, 1949) was only slightly lower in the eastern part of the lagoon in 1980 as well as in 2004. Interestingly, high abundances of the crabs *Macrophthalmus* sp. and *Uca* spp. were recorded close to the refinery (Djohan, 1982) which is in agreement with the higher crab densities observed in the eastern lagoon in May 2004. Because of an oil spill in October 2004 crabs disappeared in the eastern transect. However, crabs had already recolonized the area in December 2004.

In a recent study Sastranegara (2004) investigated the seasonally varying diversity and abundance of intertidal crabs in the Segara Anakan lagoon including undisturbed, crab hunting, logging and prawn pond areas between October 2000 and January 2002. In total, 13 species of Brachyura were observed (Grapsidae four species, Ocypodidae nine species) with *Metaplax* sp. being the most abundant species. Crab densities were equal in the undisturbed, the crab hunting and the logging area, where the percentage of mangrove cover was 90%, 89%, and 33%, respectively. A significantly lower crab abundance was recorded in the completely deforested prawn pond area (Sastranegara, 2004). Intertidal crab diversity displayed less monthly fluctuation in the undisturbed area than in the other areas.

A few recent studies dealt with the ecology of macrobenthos with special emphasis on the ecology of the Asiatic clam *Polymesoda erosa* (Pribadi, 2003; Suryono et al., 2003; Widianingsih et al., 2003a; Widianingsih et al., 2003b). In total 62 taxa of epibenthic crustaceans belonging to 11 families were recorded with *Perisesarma* sp. (Grapsidae), *Macrophthalmus* sp. and *Uca coarctata* (Ocypodidae) being the most abundant species in the central lagoon and *Metaplax* sp. and *Perisesarma* spp. (Grapsidae) in the eastern part of the lagoon (Pribadi, 2003; Widianingsih et al., 2003a). The average density of all crustaceans was 3.7 and 4.8 individuals m^{-2} in the central and eastern parts of the lagoon, respectively. Higher densities and a higher mean crab size in the eastern lagoon were attributed to lower sedimentation rates and less disturbance by human activities (Pribadi, 2003). A total of 29 taxa of gastropods belonging to 10 families were observed in the lagoon (Suryono et al., 2003). In contrast to the crustaceans the number of taxa (24) and the density of gastropods (26.5 individuals m^{-2}) was higher in the central than in the eastern part of the lagoon (19 taxa and 5.3 individuals m^{-2}). *Cerithidea obtusa* and *Neritina violacea* were the most abundant gastropods in the central lagoon and *Nerita lineata* in the eastern lagoon (Suryono et al., 2003). In terms of biomass, *Telescopium telescopium* was the dominant species in both areas.

Comparison of our preliminary results with results of previous studies reveals that the benthic community of the Segara Anakan lagoon shows a high spatial and temporal variability in terms of abundance, biomass and species composition. It is most likely that the species stock of the lagoon has not been fully assessed yet.

Conclusions and Outlook

Segara Anakan is a complex lagoon ecosystem which provides goods and services to the local population. The growing economic demands of an increasing population alter environmental conditions which, in turn, affect the living natural resources and as such the ecology and the economic potential of the lagoon. Preliminary results of our recent investigations indicate (i) a high temporal and spatial variability of environmental conditions and distribution patterns of the living resources and (ii) compared to former investigations no reduction in pollution and an increase of siltation and over-exploitation of resources. Management measures of the lagoon's resources applied for many years suffer from the lack of an integrated ecosystem understanding and hence had little success. Multidisciplinary investigations in high temporal and spatial resolution within the SPICE research programme are designed to obtain the information necessary for an integrated understanding of ecosystem functions and its changes with respect to human activities and climate change. It will provide the scientific basis for developing management strategies towards a sustainable use of the lagoon's natural resources.

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