REGIONAL COORDINATING UNIT
EAST ASIAN SEAS ACTION PLAN

UNEP UNITED NATIONS ENVIRONMENT PROGRAMME

SEAGRASSES OF EAST ASIA:
Environmental and Management Perspectives

By

Miguel D. Fortes

RCU/EAS TECHNICAL REPORTS SERIES NO. 6

Prepared in cooperation with:

MARINE SCIENCE INSTITUTE

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"...a fisherman and gleaner, paddling his small firewood-laden boat down a muddy creek, ties it 'round a tree trunk and, with a small net in hand, wades his way through a thick seagrass bed to catch fish, glean shells and grass fruits -a pitiful sight, perhaps, but one most desirable if we want to sustain seagrasses in perpetuity."

INTRODUCTION

Seagrasses are the only group of submerged flowering plants in tropical and temperate marine environment. Thriving mostly in shallow-water coastal habitats, they are adapted to live submerged in saline medium, with an anchoring system that withstands wave action, and to be capable of hydrophilous (by the agency of water) pollination (Arber, 1920). Thence, they perform a wide spectrum of biological and physical functions which are the bases of their environmental and economic roles, making seagrasses an essential link in the energy dynamics of coastal and marine environments.

Countries of the East Asian Seas region[1] which are participants in UNEP's Regional Seas Programme (here, referred to as East Asia) include Indonesia, Malaysia, the Philippines, Singapore and Thailand. They have an extensive combined coastline of 99,092 km and a present population of 312.7 million, about 75% of which live in coastal villages (Chou, 1994). Much of the growth along these areas comes from using renewable resources (i. e., crops, seaweeds, water, crustaceans, fish). The bulk of the fish catch is taken in the nearshore half of the coastal zone where seagrasses abound. This feature alone justifies a strong research effort on the ecosystem in particular, and on the region's coastal zone in general. The marked dependence of coastal Asian countries upon their marine resources makes the improvement of marine environmental quality a policy objective common to the countries of the region (Fortes, 1991). Unfortunately, its seagrasses are being threatened largely from loss of mangroves, coastal development, and mining (Lean et al., 1990) and from natural perturbations (Fortes,1989; 1991). It is thus imperative that we first know what their functions are and how they best manifest these functions, so that we could better understand and translate them into uses for the improvement of the quality of the region's marine environment.

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[1] In October 1994, the membership of UNEP's East Asian Seas Regional Seas Programme expanded to include five new countries (Australia, Kingdom of Cambodia, People's Republic of China, Republic of Korea, and Socialist Republic of Vietnam). This book was prepared when the East Asian Seas region included only the 'original' five countries. Where mentioned, East Asia will refer to the geographic area of the original five members.

This book is designed primarily to highlight significant and up-to-date information on the environmental and management aspects of seagrass ecosystems in East Asia. This is an advancement of a previous work of the author (Fortes, 1989) which focused on the seagrass systems as a resource yet unknown in the region. To put the topic in its proper perspective, a brief discussion on the biogeographic affinities of seagrasses in the Indo-West Pacific, the status of research on the ecosystem, and some relevant aspects of its structure and dynamics have been included. 'Grey literature', preliminary or cursory information, as well as observations by reliable sources have been included to augment primary information and fully document and substantiate the objectives of the book. Their inclusion reflects the true state of knowledge on seagrass ecosystems in the region. Certain claims are supported by results of primary investigations and similar or related studies from other regions of the world.

Seagrass Biogeography in the Indo-West Pacific

The Indo-West Pacific region is the center of generic richness and diversity of seagrasses in the world (Heck & McCoy, 1978). There are, however, large discontinuities in the distribution of the region's seagrasses, reflecting more the lack of data resulting from unsystematic studies and incidental collections than the true pattern of distribution of the species. Only five major accounts on their species composition, biogeography, and distributional affinities have been made (see den Hartog, 1970; IUCN/UNEP, 1985; Fortes, 1988a,1993; Mukai, 1993). The highest number of species is found in the coastal waters of Malesia bounded by Indonesia, Borneo, Papua New Guinea and northern Australia (Mukai, 1993). Fig. 1 shows that East Asia belongs to Province A, the area of second highest number of seagrass species and numerical similarities in the world (Fortes, 1988a). This bio-geographic area exhibits characteristic patterns of climate, habitat conditions, and productivity. The genus Halophila represents a major connection between most of the seven provinces, strongly influencing the clustering of the seagrasses.

Clustered in terms of presence or absence of species, the seagrasses of East Asia show a pattern that may reflect their true ecological requirements. Halophila spinulosa and Thalassodendron ciliatum were generally found in deeper (2-17 m) clearer waters of the eastern part of Indonesia and southern and western shores of the Philippines. The materials of T. ciliatum collected from Cuyo Is., Philippines (10°51' N lat.; 121°00' E long.) represents the northernmost limit of its distribution in the Pacific. Local populations of Halophila beccarii and Ruppia maritima, on the other hand, have been reported only from brackishwater habitats, while the materials of the new variety of H. minor (den Hartog, personal communication) was collected from a sandy bottom off Lubang Is., Philippines at 17 m depth. The distribution of H. decipiens in the region is limited to the shores of Indonesia, Thailand and deeper waters (10-23 m) of Brunei Darussalam and the Philippines. The specimens of the species dredged from Eman cove, Bataan, Philippines, (14°21' N lat.; 120°30' E long.) represent the northernmost limit of its distribution in the Pacific.

In terms of zonation and depth distribution, certain patterns in the local seagrass communities are evident. Halophila ovalis, Enhalus acoroides, Thalassia hemprichii, Cymodocea rotundata and Halodule uninervis are all widely distributed, co-dominating in communities in a greater number of instances. On the other hand, Syringodium isoetifolium, C. serrulata, Halodule pinifolia and Halophila minor are relatively restricted to specific microhabitat conditions.

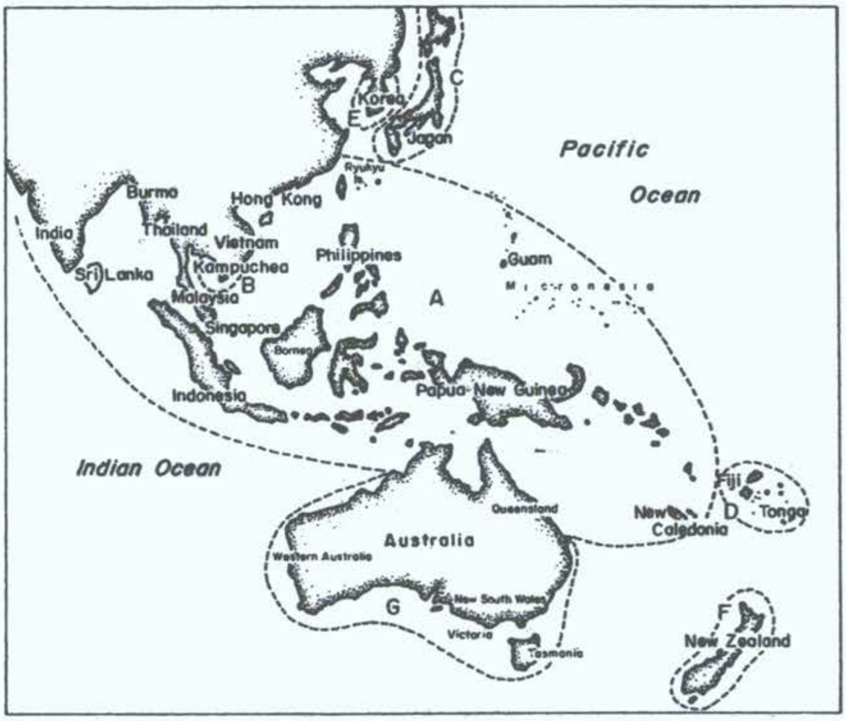


Fig. 1. The seven seagrass provinces in the Indo-West Pacific region (A through G) delineated by cluster analysis (After Fortes, 1989)

The high variability in seagrass species abundance at the study sites in East Asian countries is probably influenced by site-specific factors. Highest numbers of seagrass species at a site (5-6) are consistently recorded in areas characterized by sandy-muddy substrate, and moderately protected from wind and waves. On the other hand, lowest number of species (1) is recorded from areas either highly exposed to waves with hard or shifty bottom, or from those protected from waves in muddy substrate.

In terms of the more common and frequently collected seagrasses, their zonation along the upper littoral is generally inconspicuous. In strong contrast to that in temperate regions, those parts of the eulittoral zones along East Asian coasts uncovered by most tides, is characterized by the complete absence of seagrasses. Johnstone (l982) attributed this absence of the species to their inability to withstand exposure and the associated desiccation factor. However, the site-specific and infrequent occurrence of the narrow-leaf variety of Halodule uninervis along these zones is an exception (Fortes, 1986).

In general a well defined zonation pattern exists in the lower littoral and adjacent sublittoral portions in many parts of the region. Three main zones are recognizable. They are named with reference to the most abundant species in the zone:

Zone I: Halodule uninervis
(narrow-leaf) Zone

A pure but sparse and narrow (ca 0.5-3 m wide) meadow of the narrow-leaf variety of the parvozosterid, H. uninervis is commonly seen in this zone, frequently exposed to air by most tides. Zone I ranges in depth from ca -0.4 to 0.7 m with respect to spring tidal marks, although this range could be more considerable. Here, the substrate is stable, predominantly fine to very fine sand, sometimes interrupted by small solid coralline or rocky patches, overlying soft to compacted mud. Excessive "browning" of the seagrass leaves commonly occurs due to their prolonged exposure to air and sun.

Zone 2: Halophila-Halodule uninervis
(wide-leaf) Zone

Smaller-leafed forms of the halophilids, Halophila ovalis, H. minor, and the wide-leaf variety of the parvozosterid, Halodule uninervis, normally compose this more extensive, 5-l0 m wide zone. It forms the upper fringe of the main seagrass bed. Depth range in this zone is ca 0.2-2 m with respect to the spring tides, and here, scouring and active sand movement is considerable. In other areas where the depth gradient is steep, this zone replaces Zone I, but its extent is restricted to only about 5 m, and the leaves of the component Halophila spp. become much broader. Small patches of the syringodiid, Syringodium isoetifolium, the magnozosterid, Thalassia hemprichii, and the enhalid, Enhalus acoroides sometimes add to the species diversity in this zone, particularly in clear water, moderately wave-exposed areas where coarse gravelly sediments overlie soft, bluish muddy bottom.

Zone 3. Thalassia-Cymodocea-Enhalus Zone

Most of the extensive seagrass beds in slightly sheltered reefs and bays are characterized by the discrete association of the magnozosterids, Thalassia hemprichii and Cymodocea serrulata, and the enhalid, Enhalus acoroides. Den Hartog (l977) considers these species as representing the terminal stage in seagrass succession. Extending from about five to more than 500 m in width, they form the bulk of the meadow. At times, the first two species co-dominate, resulting from the seasonal disappearance of C. serrulata. In this zone, other seagrass species may be present but their occurrence is highly variable, depending upon the substrate. Where the substrate is sandy, S. isoetifolium co-dominate, but where it is muddy, H. ovalis and the wide-leaf variety of H. uninervis may produce considerable biomass. In this zone, stands of C. rotundata occur when the other bulkier species have low density and as depth increases.

On reefs, Zone 3 sometimes occupies tide pools where the seagrasses form deeply rooted and wide- and long-leafed but very sparse stands. Here, C. rotundata is often found. At the deeper portions, the only other species that often occurs is E. acoroides.

The zonation of seagrass communities in many parts of the Philippines (Fortes, 1986; 1993b), Thailand (Nateekarnjanalarp & Sudara, 1992b; Chansang & Poovachiranon, 1994), Indonesia (Azkab, 1991; Kiswara, 1992), and Sabah (Norhadi, 1993) closely approximates that presented by den Hartog (1977) in relation to the distribution of the different growth forms of seagrasses in the region. In addition, they agree remarkably well with that proposed by Johnstone (1982) for the Papua New Guinea seagrass communities. However, he recognized four zones including a discrete C. rotundata zone which, in the Philippines and the western parts of Indonesia, is a seasonally transitional zone dominated by the species and co-dominated by T. hemprichii and E. acoroides (Zone 3). Furthermore, H. spinulosa forms a distinct zone in Papua New Guinea, but the species is extremely limited in its distribution in other parts of East Asia to merit a major zonal classification.

Heck & McCoy (1978) proposed to discuss seagrass biogeography in terms of evidences from associated organisms, i. e., foraminiferans, mangroves and corals. They based their claims on the intimate co-occurrence of these groups as part of the natural successional sequence in the larger coastal ecosystem and because these habitats show similar global patterns of generic richness. The distinct attenuation pattern in the number of seagrass species corresponding to an increase in the longitudinal distance from the Philippines was observed by Tsuda (1984): 16 taxa from the Philippines; 10 from Palau; 7 from Yap; 5 from Truk; 3 from Kosrae; and 1 from the Marshalls.

History and Status of Seagrass Research

Worldwide, there is a patchy geographic spread of research effort on seagrasses, the concentration being largely in the US, Caribbean Basin and Bahamas, western Europe, Australia and western Mediterranean (Duarte et al., 1994). In East Asia, seagrass beds are the least studied among the ecosystems of the coastal environment. Why little attention has been focused on seagrasses in the region is due to a number of factors. On one hand, most people consider that they are not as important as coral reefs or mangroves. For centuries, while the sea has been the primary source of protein of the greater portion of the region's population, the main interests of local marine scientists focused almost solely on the corals, seaweeds, animals, or fish that either live in coastal habitats or are associated with them. On the other hand, the traditional orientation of the region's marine science has been to view the ocean as a deep water mass, in fact, it was only in the mid-1960's that the shallow benthic coastal fringe was recognized by oceanographers as a discrete ecosystem, forming a part of the larger ocean systems (Phillips, 1978). Investigators with the interest on seagrass research are few and priorities for research and developmental activities are usually directed towards other resources with immediate economic impacts. Ironically, in East Asia where the second highest seagrass diversity in the world is found, seagrass ecosystem has been a focus of scientific inquiry only in the last 15 years and, as an object of natural resource management, only in the last 5 years. For the most part, this direction has been guided by the ASEAN-Australia Living Coastal Resources (LCR) project (Fortes, 1994a) and the other related initiatives it encouraged or supported. For East Asia, the '80s were truly the 'decade of seagrasses'.

The small emphasis the countries of East Asia place on their seagrass research and development activities is partly a function of the following interrelated factors: (1) presence/absence of sizeable seagrass habitats associated with the length and nature of the coastlines; (2) available expertise; and (3) current state of knowledge on the ecosystem. Although a positive correlation is apparent between the length of coastline and the number of seagrass species each country has (see table below), this numerical relationship reflects more the low intensity of collection than the true distribution of the plants. The islandic nature of Indonesia and the

Country	Length of coastline, km	Seagrass species
Indonesia	54,716	12
Philippines	22,540	16
Malaysia	4,675	10
Thailand	3,219	10
Singapore	193	7

Philippines has endowed the countries with a high diversity of seagrass habitats. Thailand has sizeable grass beds in Chantaburi and Trat (Nateekarnjanalarp et al., 1990) at the east and around the islands of the west coast of the Gulf of Thailand. Seagrasses are also reported from Phan-nga southward in the Andaman Sea (Chansang & Poovachiranon, 1994). On the other hand, the small size and limited coastlines in Singapore and Brunei allowed only patchily distributed seagrass communities. Interestingly, while the coasts of Peninsular Malaysia are relatively extensive, the water and substrate conditions are generally unfavorable for extensive seagrass growth. The plants are confined only to a limited area mostly at the east coast of Johore (Mui & Rajagopal, 1989). In East Malaysia (Sabah), on the other hand, nine seagrass species were found inhabiting the intertidal zone down to 2.5 m depths on various substrate types such as coral rubble, sand, to muddy-sand (Norhadi, 1991).

Expertise in seagrass research and knowledge on the ecosystem in East Asia are extremely limited. This is reflected in the number of publications which totaled only 177 for the period 1983-1994 (Fortes, 1994a). 94 publications were products of activities outside the LCR project, while 83 resulted directly or indirectly from the activities of its seagrass component. 80% of the total number came out only in 1986 when the project was initiated.

Table 1 shows that current research activities in seagrass ecosystems in East Asia fall under five categories: seagrass structure; dynamics; fisheries; environmental factors; and applied aspects. Among the member countries, these activities are largely concentrated on the structural aspects (species composition and distribution) of the seagrass plants and their associated fisheries (finfishes and invertebrates), indicating, among others, the relative novelty of the subject. With the exception of the Philippines, much less research interest has been invested by the countries on the dynamic aspects of seagrass ecology. This is one reason why the functions of seagrasses are as yet with limited applications in addressing environmental issues in the region. Among the countries, and only in the last five years, the Philippines has advanced substantially in understanding the basic biology, trophic dynamics, and broad-scale distribution of its seagrass resources. From the data, it has initiated a program of research that investigated the role of seagrasses in protected areas, their usefulness in the rehabilitation of degraded coasts, and in monitoring impacts from environmental stresses imposed by industrial activities. In Indonesia, emphasis on seagrass research is focused on the structure of the

Table 1. Seagrass and seagrass-related parameters under study in Southeast Asia; **, more intensely; *, less intensely

	PHIL	INDO	THAI	SIN	MAL	BRU
STRUCTURE						
sp composition	**	*	*	*	*	*
distribution	**	**	**	*	*	*
biomass	**	**	**	*	*	
density	**	**	*		*	
cover	**	*	**			
diversity	*	*	*			
leaf height	*	*				
affinity	*	*				
zonation	**	**	*	*	*	
epiphytes	**	*	*			
leaf area index	*					
associated fauna		**	*	*		
DYNAMICS						
productivity						
plant	**	**		*		
animal	**					
bacterial	*					
decomposition	*	**				
growth rates	**	**				
turnover	**	*				
recruitment	**					
mortality	**					
litter transport	*	*				
interaction	**	*	*			
nutrient budget		*				
mineralization		*				
reproduction	**					
feeding	**					
FISHERIES						
sp composition	**	**	**	*	*	
distribution	**	**	**			
abundance/biomass	**	*	*			
residence pattern	*	*				
diel variation	*	**	*			
interactions	*	*	*			
ENVL FACTORS						
substratum	*	*	*		*	
depth	*	*	*			
water clarity	*	*	*	*		
light regime	**	*	*			
water movement	*	*				
temperature	*	*	*			
quality criteria	*	*	*	*		
APPLIED ASPECTS						
sg as feeds	*	*	*			
remote sensing	**	*	*	*		
artificial sg	*		*	*		
transplantation	**	*	*			
pollution	**	*				
socioeconomics	*	*	*	*		
endangered species	**	**	*			

communities and the fisheries they support. In collaboration with the Dutch government, the country has initiated a study on seagrass primary production (Erftemeijer et al., 1993), sediment-nutrient interactions (Erftemeijer & Middelburg, 1993), the role of seagrass in the diet of dugong (Erftemeijer et al., 1993), and in marine heavy metal pollution (Nienhuis, 1986). Much less intensely, research activities on seagrass systems occur in Malaysia and Singapore, although a field study on the photosynthetic performance of seagrasses has recently been conducted by a graduate student from the National University of Singapore. Interestingly, its Department of Primary Industry used artificial seagrasses to improve fish production and water quality in Singapore River (Lee & Low, 1991).

In Thailand, the taxonomy and phenology of seagrasses are being investigated with help from Japan (Ogawa, personal communication). Seagrass roles in fisheries and habitat interconnection are currently in focus (Sudara et al., 1992b). The role of seagrass resources in coastal socioeconomy is under investigation by a non-governmental organization in the western part of the country.

Importance of Seagrass System Components

The fundamental ecological role of seagrasses was revealed dramatically in the 1930s when the 'wasting disease' threatened to eliminate eelgrass, Zostera marina (Rasmussen, 1977). This catastrophe killed over 90% of the North Atlantic eelgrass population. As a result, scallops, clams, crabs, and many fish species suffered from the loss of protective habitat and from the sedimentation and erosion that occurred because without the eelgrass root systems as anchors, bottom sediments became loose. In North Carolina, the commercial scallop fishery crashed (Thayer et al., 1984) and many species of ducks and geese were severely affected. The American brant nearly vanished from the North American flyway subsequent to the eelgrass decline (Buchsbaum, 1987). The adverse effects brought about by the disease on the economy of the region created renewed interest on the study on seagrasses in most parts of the world. Currently a parallel concern is in focus with the occurrence of a similar phenomenon in the southeastern coasts of the U.S. (Short et al., 1989;1991).

The applied aspects of non-tropical seagrass ecosystems, showing historical and contemporary uses, are well known (see McRoy & Helfferich, 1980). Many of these uses are applicable and have been documented in East Asia (Fortes, 1989). Hence, local seagrasses have been used as packing material, children's toys, compost for fertilizer, fodder, for direct human consumption, the habitat itself is a fishing ground, especially for the juveniles and small adults of the rabbitfish, Siganus spp.; near resort areas, low tide exposes seagrass beds and their associated organisms which are the object of curiosity of tourists and other nature enthusiasts; as important natural components in marine parks and reserves; and in many typhoon-prone areas in the region, as effective retainers of sediments due to the thick mass of their underground systems, hence, serving as buffer against waves and storm surges. The contemporary uses of seagrasses as sources of chemicals and sewage filters are anticipated or as yet potential uses.

The importance of seagrass systems primarily as a source of income and as a livelihood base of coastal populations in the ASEAN (Association of Southeast Asian Nations) region has been treated separately in another publication (Fortes, 1989) and will not be emphasized here. Hence, in this section of the book, the focus of discussion will only be aspects of the major components of seagrass beds (i.e., seagrasses, fish, reptiles and mammals, periphyton, epibenthic invertebrates, and benthic seaweeds) which make them useful in the protection of the coastal environment and which justify sound management of this valuable resource.

Seagrasses

Seagrasses have high organic production rates which probably accounts for the high biodiversity in the ecosystem. Net production by E. acoroides in Cape Bolinao, northwestern Philippines, was l.4 gram carbon per square meter per day ($gmC/m^2/d$), while its leaf growth rate averaged l.9 cm/d. The recorded mean total turnover time in E. acoroides is 115 days, which means that the whole leaf biomass is produced every 16 weeks, forming 2-4 leaf crops annually. In Calauag Bay, northcentral Philippines, the total seagrass area make available to consumers at least 1.8 million kg (1,771 MT) of dry matter 2-14 times a year (MSI/EPAI, 1993). This value, representing only 0.2% of the total amount produced by the plants during the period, does not include the production and biomass of the rhizomes which almost doubled those of the leaves. In the bay the bulk of dry plant matter is contributed by E. acoroides and C. rotundata although the former makes its contribution only three times a year, while the latter does so nine times annually. Total dry leaf biomass of selected seagrass communities in the Philippines ranged from 8 - 132.15 gm/m^2 (Rollon & Fortes, 1992).

On an areal basis, seagrass production rates can be higher than phytoplankton production off Peru, one of the most productive areas in the world's oceans (Ryther, 1969). The production rates of E. acoroides in North Bais Bay, southern Philippines (1.08 $gmC/m^2/d$, Estacion & Fortes, 1988) and in Cape Bolinao, northern Philippines (1.4 $gmC/m^2/d$, Fortes 1986) are fairly comparable to those of cultivated crops (e.g. wheat, corn, rice, hay) on world average basis (McRoy & McMillan, 1977). Interestingly, seagrasses attain such high rates without energy subsidies like fertilizers and modern cultivation techniques. Fig. 2 shows that, compared to the other vegetation types, seagrasses of the tropics rank highest in net annual production.

At Pari Island, Indonesia, Azkab (1988a) reported a mean leaf growth rate of 0.8 cm/d for old leaves of E. acoroides and 0.6 cm/d for young leaves. Mean leaf production rate was 3.4 $gm/m^2/d$, with a biomass of 96.1 gm/m^2, and 3.48% mean turnover rate. For T. hemprichii, he (1988b) reported a mean growth rate of 0.24 cm/d for new leaves and 0.2 cm/d for old leaves. Mean leaf production was 1.8 $gm/m^2/d$ with 3.74% turnover rate.

Using bell jars, Lindeboom & Sandee (1989) measured the production and consumption rates of tropical seagrass communities in eastern Indonesia. Gross production was between 1,230 and 4,700 $mgC/m^2/d$. Consumption was between 860 and 3,860 $mgC/m^2/d$. Hence a relatively low net production of 60 to 1,060 $mgC/m^2/d$ could be calculated.

In the generally multispecies seagrass beds in East Asia, resource utilization by fauna is expected to vary considerably. The primary source of organic material comes from production by the seagrasses themselves. However, contributions from the associated epiphytes and macrobenthic algae (Fortes, 1982; 1986), and organic matter from outside the system, i.e., phytoplankton and terrestrial plants, could be considerable.

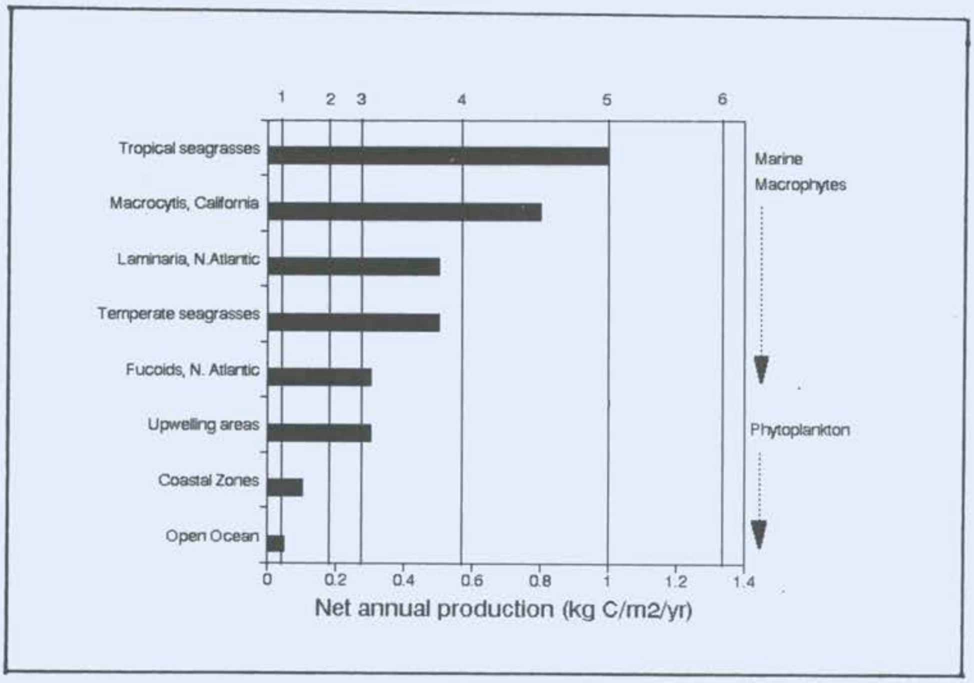


Fig. 2. Net annual production of the world's vegetation types: 1, desert scrub; 2, lake and stream; 3, temperate grassland; 4, temperate forest; 5, tropical rainforest; 6, swamp and marsh. (Sources: terrestrial, Whittaker & Likens, 1975; seagrasses, McRoy & McMillan, 1977; Macrocystis, Clendenning, 1978; Laminaria, Kain, 1979; fucoids, Brinkhuis, 1977; phytoplankton, Ryther, 1969). Redrawn from Mann (1973).

Fish

In East Asia, appreciation of seagrass beds is largely in the context of the fisheries they support and the benefits the latter earns for the economy. However, few reports acknowledge the crucial role of fishes which migrate from seagrass beds to other ecosystems. In the region, most coral reefs are in developing countries where they are associated with seagrasses. These two ecosystems potentially could supply more than one-fifth of the fish catch in these countries (McManus, 1988). Five times as many fish live over seagrass beds as over sea floors made up of mud, shells, and sand (Lean, et al., 1990). In Cape Bolinao, five of the 104 fish species found in the seagrass beds were residents (found all year round), while 23 were seasonal residents (residing only for a season or life history stage), and 59 were casual species (found only occasionally). Unfortunately, the ecological role of these fairly distinct groupings is virtually unknown. The importance of fish movement between coastal habitats is currently receiving attention particularly in the Indo-West Pacific region (Robertson, 1984; Fortes, 1988b;1991; Sudara et al., 1992b; Noor, 1993). This is largely because of its role in defining the ecological interactions between tropical coastal ecosystems which has significant implications to coastal resource management. In Calancan Bay, a copper mine tailings discharge point in northcentral Philippines, correlation analysis was made between the growth rates of E. acoroides and Cymodocea serrulata with the yield of two seagrass-associated fish species (Siganus canaliculatus and S. Guttatus) (Fortes, 1994b). There was a general similarity between the temporal patterns of growth of the seagrasses and the abundance of the fish suggesting a functional coupling of the two biological parameters. This could indicate a return or magnification of one of the primary ecological functions of seagrasses -that of being a feeding ground for the fish. The interconnections between coral reefs, seagrass beds and mangroves have been emphasized by UNESCO (1983), SPC/SPEC/ESCAP/UNEP (1985), and White (1987).

Denser seagrass vegetation was found to be inhabited by comparatively more fishes in Burung Island, Indonesia (Hutomo, 1985). In a seagrass habitat in Calancan Bay, the quarterly yield of the seagrass-dependent fish, Siganus canaliculatus was consistently the highest overall when compared to the other fish species caught in the bay (Fortes, 1994b). On the other hand, the yield of S. guttatus ranked from second to sixth among the other species caught.

Endangered Reptiles and Mammals

Some endangered species of reptiles and mammals are known to occur in seagrass beds of East Asia. Six species of marine turtles are reported from the region (IUCN/UNEP, 1985). Among these species, the green sea turtle (Chelonia mydas), the olive ridley (Lepidochelys olivacea), the loggerhead (Caretta caretta), and the flatback (Chelonia depressa), together with the wart snake (Acrochordus granulatus), are frequently found in dense seagrass meadows especially of Thailand, Malaysia, Indonesia, and the Philippines. The sea turtle at Turtle Islands of the South Sulu Sea, are known to consume both seagrasses and algae (Estacion & Alcala, 1986). From the gut contents of two adult hawksbill turtles, Alcala (1980) found seagrasses, although these may not be their main food source.

Fig. 3 shows where sightings of the sea cow or dugong (Dugong dugon) have been reported in East Asia. There appears a high coincidence between the recorded collection of seagrasses and the occurrence of the sea cow. Erftemeijer et al. (1993) reported that about 98.9% of the total dry weight of a digesta of dugong caught in South Sulawesi, Indonesia, consisted of seagrass material. The IUCN Red Data Book gives the status of the dugong as 'vulnerable'. The dugong is confined mainly in the waters of East Asia and in Northern Australia (IUCN/UNEP, 1985). It feeds directly on seagrasses especially Cymodocea and Thalassia. In the Aru Islands, South Sulawesi, and in Bangka Island, Indonesia, around 1,000 dugongs are caught annually in shallow waters, and form an important part of the coastal diet. In Calauit Island, Palawan, Philippines, more than five dugongs on average were seen per survey day in March and July, coinciding with seagrass peak biomass (Aragones, 1994). The actual population status of the mammal in the region is unknown. Soegiarto & Polunin (1982) considers Indonesia, Papua New Guinea and Australia as important refuges of the species.

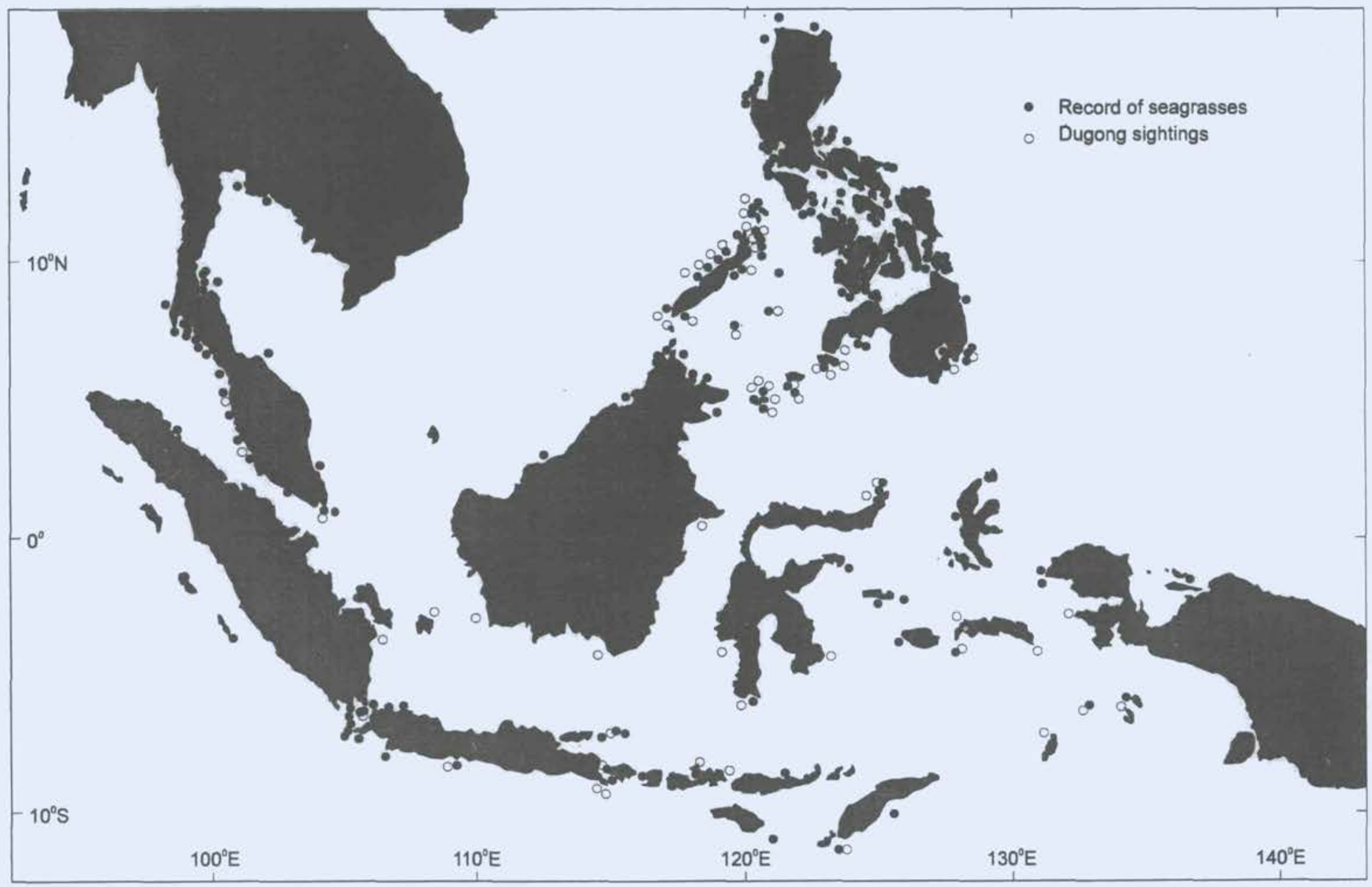


Fig. 3. Records of seagrass collections and sightings of dugong in the East Asian region. Note the high coincidence between the two parameters.

The dugong has provided subsistence and commodity goods (meat for food, skins for leather, blubber for oil, etc.) for coastal peoples in the Indo-Pacific region. Sea turtles have been hunted around the world for both subsistence and commercial trade. Its eggs are used as a protein source for both people and livestock in many coastal regions, the meat is consumed by humans, the cartilage of the green sea turtle is the source of the green turtle soup, and the scutes of the carapace, especially those of the hawksbill are the only natural source of 'tortoise shell' used for jewelry, eyeglass frames, Japanese ceremonial combs, etc. However, as with marine mammals such as whales and manatees, sea turtles are becoming increasingly valuable alive in a growing tourism industry based on viewing their nesting and hatching (Norse, 1993). The fact that they bear few young and, in general, are slow to reach reproductive age makes dugongs and sea turtles especially vulnerable to exploitation. Thus they are species of special concern by virtue of their evolutionary persistence, their values to humans, and their vulnerability and current rarity. As a result the dugong and sea turtles are listed on Appendix I under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Periphyton

Periphyton is a community of microbiota (algae, bacteria, fungi, animals, inorganic and organic detritus) that is attached to substrata (Wetzel, 1983). To date no clear evidence exists of any beneficial effects of a dense periphyton cover to a macrophyte. Protection from grazers (Hutchinson, 1975) and shading from too intense irradiation have been suggested (Sand-Jensen, 1977; Hootsmans & Vermaat, 1985; Silberstein et al., 1986). Periphyton grazing by snails prolonged tissue life of the macrophyte by reducing invasion of necrotrophic bacteria (Silberstein et al., 1986) while exchange of nutrients with seagrass leaves have been reported (McRoy & Goering, 1974). Klumpp et al. (1992) found that epiphytes account for a significant fraction of the total carbon flux in seagrass meadows.

Hootsmans et al. (1993) also found that light extinction coefficients (mean 0.8/m) and periphyton light attenuance (up to 25%) are not likely to affect seagrass leaf growth. As photon flux densities increase, however, algal assemblages exhibit greater rates of primary production and become dominated by filamentous chlorophytes and xanthophytes (Steinman & McIntire, 1987). On the other hand, dense periphyton cover that reportedly develop under eutrophic conditions may adversely affect photosynthesis and growth of the macrophyte through shading or competition for inorganic carbon and/or nutrients (Bulthuis & Woelkerling, 1981).

While the few studies on seagrass periphyton in East Asia has suffered from the "bits-and-pieces" approach, the results indicate significant contributions of the community to the ecology of tropical coasts. Among the species identified from the region, there was a consistently high dominance of the rhodophytes in the epiphytic communities. Lower dominance was shared by the chlorophytes, phaeophytes, and cyanobacteria, although pronounced co-dominance was expressed by each group depending upon site-specific conditions, with the bluegreen algae more common on seagrasses in brackishwaters, while the other groups, on those in more open waters. None were found exclusive to a particular species of seagrass. There are indications that the presence of a seagrass simply increased the surfaces on which they could grow, thereby increasing their abundance. At highly eutrophic sites, there was a remarkable growth and abundance (hence, low diversity) of communities of epiphytes. Eminson & Moss (1980) found that with increasing eutrophication, specificity for substrates disappeared.

Epiphytes contributed significantly to the energy pool in a shallow reef flat in Cape Bolinao. Total daily energy intake of the juveniles of the rabbitfish (Siganus fuscescens) was 204 cal and epiphytes made up 141 cal (Salita-Espinosa, 1991). On the other hand, seagrass ingestion rates by the fish translated to energy intake of 61.3 cal/fish/d. 2% and 20% of seagrass and epiphyte productivities, respectively, were channeled to the juvenile fish. In addition 47% of the total seagrass and epiphytic materials were 'given back' to the system as fecal materials. These imply that the epiphytic community plays a major role in the energy dynamics of a shallow tropical coast.

In Cockburn Sound, Australia, increased epiphyte load 2-8 times higher than normal reduced the area of seagrasses during the discharge of nutrient-rich effluent (Silberstein et al., 1986). This resulted from the negative log-linear relationship between leaf production and epiphyte load. Enhanced epiphyte growth in nutrient-rich waters reduce the amount of light available for seagrass photosynthesis (Cambridge et al., 1986). Sand-Jensen (1977) found that epiphytes reduced the photosynthetic rates of eelgrass leaves by acting both as a barrier to carbon uptake and by reducing light intensity. In the eelgrass, nitrogen and carbon absorbed by the roots were translocated to the epiphytes, thereby reducing the amount for use by the plant (McRoy & Goering, 1974).

In eelgrass, the contribution of the autotrophic epiphytic community to total photosynthesis per dm^2 was between 27 and 50% and between 10 and 44% per mg chlorophyll (Mazella & Alberte, 1986). These levels of epiphyte photosynthesis can double the primary production of the seagrass leaves. Non-epiphytized leaves and leaves from which epiphytes were removed showed similar photosynthetic features. Light intensity and age gradients along the leaf axis control both the photosynthetic performance of the leaves and epiphyte biomass and photosynthesis. Rapid turnover rates of host seagrasses could also reduce the growth of epiphytes (Tomasko et al., 1993).

Epibenthic Invertebrates

Large and common epibenthic invertebrates in seagrass beds of East Asia include shrimps, sea cucumbers, sea urchins, crabs, scallops, mussels, and snails. Since most of these species are economically important and they abound in seagrass beds, the latter are usually the object of unsustainable practices such as overharvesting of sea cucumbers for food, sea urchins for their gonads and sea hares for their eggs, raking the beds to get shells for the shell ornament trade, use of push nets to get rabbitfish (Siganus spp.) and shrimps, and trawling. Chong & Sasekumar (l98l) have shown that the highly priced prawn, Penaeus merguiensis feeds mainly on other crustaceans and macrophytes (seaweeds and seagrasses), the latter comprising the highest percentage (64.4%) in the gut contents of nursery populations of the species. Fortes (l988c) found that of the l,49l taxa trawled from seagrass beds, fish comprised 28.6%, while prawns, 7l.4%. Staples and his colleagues (personal communication 1988) found that E. acoroides supported the greatest numbers of Penaeus esculentus and P. semisulcatus, followed by Cymodocea, Thalassia, Syringodium, Halophila and Halodule.

Macrobenthic Seaweeds

In East Asian seagrass systems, relatively few seaweeds grow. This is due partly to the reducing condition of the sediments under which seagrasses outcompete seaweeds. However, these few species exhibit great seasonal abundance and are harvested from the beds either as food or as a rich source of chemicals for industries. In summer, for instance, biomass of the associated green 'sea vegetables' Enteromorpha intestinalis, Ulva lactuca, U. reticulata, and Hypnea spp. apparently exceeds those of the seagrasses themselves. Early developmental stages of many of the macrobenthic seaweeds are epiphytes on seagrasses, only to detach from the substrate when they reach mature stages and settle on the bottom. In the Philippines and in Indonesia, farms of the red seaweed, Eucheuma, are established mostly in association with seagrasses. While the socioeconomic impact of this activity is well known, its effects on coastal ecology are poorly understood.

Biochemical expressions of algal community structure in benthic ecology may be relevant, especially when trophic level interactions are under consideration (Steinman et al., 1988). Theoretically irradiance can influence the biochemical structure of algal communities by altering the chemical components of individual cells or by changing the taxonomic structure of the community, which in turn may result in a different chemical composition. Information on algal chemical composition provides an additional set of criteria for the assessment of community structure and indicates the food quality that in turn relates to patterns of herbivory by benthic invertebrates.

DETERMINANTS OF BIODIVERSITY

There is a high diversity of plant and animal life associated with seagrasses in East Asia. This is a product of niche partitioning and ecophysiological adaptations of species. Niche partitioning includes habitat heterogeneity, nutrient richness, and the roles of organisms in the food chain, which leads to various degrees of specialization. In seagrass ecosystem, this is shown by periphyton, epibenthos (those on sediment surfaces), infauna (those living buried in the sediments), nekton (those that live in or above the plant canopy), birds, reptiles and mammals. Biological interactions and processes can have a powerful local influence on the structure and diversity in seagrass communities. Although physical factors are largely responsible for defining habitat characteristics and limits of the community, biological factors largely determine its specific structure (Livingston, 1984). Other influential biological factors include predation, competition, habitat selectivity, migrations, reproduction and recruitment.

Nature of the Determinants

The factors which determine diversity in seagrass communities may be categorized into biological and environmental. The biological factors include productivity, growth and turnover rates, biomass, density, variations in plant morphology, nature of associated biotic components, and interactions within and between these components. The environmental factors, on the other hand, include factors such as temperature, salinity, light regime, nutrients, and natural and man-influenced activities that change the levels of these parameters.

In East Asia, seagrass beds support higher faunal (Vergara & Fortes, 1991; Sudara et al., 1992a,c) and bacterial (Boto et al., 1991) densities and a richer species diversity than adjacent unvegetated areas. This is largely due to their high productivities, apparently approaching the theoretical maximum for natural ecosystems (McRoy & McMillan, 1977; Zieman & Wetzel, 1980). In the region, during the peak months of the monsoon season or when they are exposed to sun and air in summer, many of the leaves of seagrasses break away from the base of the shoots. Some of these leaves float away, carried by the currents; others fall to the bottom where they decompose. Detritivores break down the leaves into smaller particles, which are consumed by bacteria and fungi. In this detrital process, many invertebrates also consume the decaying seagrass. The adult and larval forms of these invertebrates become food for larger life forms such as fish and crabs. In the Mediterranean, about 30% of the net production of P. oceanica beds is carried annually towards greater sea depths as allochtonous materials mostly in the form of dead leaves, providing energy for the trophic chain composed of bacteria, fungi, and protozoa at the bottom, and by predators, among them fish, at the top (Augier, 1986).

Seagrass biomass is a primary factor in the organization of marine macrofaunal communities (Stoner, 1980). Likewise, seagrass meadows control the habitat complexity, species diversity and abundance of associated invertebrates, shaping the structure of marine communities (Heck & Wetstone, 1977; Middleton et al., 1984). It is this ecological role of seagrasses that links them directly to the stability of the environment and the socioeconomic well-being especially of the coastal inhabitants of the East Asian region.

Vegetation cover in many seagrass habitats in the region is markedly heterogeneous due to variations in seagrass species composition, biomass, density and the presence of several kinds of macrobenthic algae which are either coarsely or finely branched, or filamentous. Variations in seagrass species composition and the amount of drifting, coarsely branched algae account for the large difference in the composition of fauna associated with seagrasses (Schneider & Mann, 1991a,b). The invertebrate assemblage differs among seagrass species (Lewis, 1984; Virnstein & Howard, 1987a) and between seagrasses and clumps of macroalgae (Virnstein & Howard, 1987b). This numerical response is correlated with the variations in plant form which are related to their suitability as a food source and as a living space, especially as a refuge from predators. Lewis (1984) found that in terms of the epifauna, species richness was generally higher on seagrasses than on any of the macroalgae. Abundance of total crustacean per plant biomass or per plant surface area, on the other hand, were greater on all macroalgal species. Although abundance per plant biomass and plant surface area were greater on macroalgae relative to turtlegrass, densities (individuals per meter square of bottom) of animals associated with Thalassia testudinum were significantly greater than those with macroalgae primarily because of the greater abundance of turtlegrass in the grass bed. Neither structural feature is an adequate predictor of faunal abundance and species richness among plant species, especially when macrophytes with very different morphologies are compared.

Correlation tests between seagrass and seagrass fish parameters showed that a high seagrass biomass supports highly diversified fish communities (Vergara & Fortes, 1991). On the other hand, seagrass beds with a high number of seagrass species create a condition wherein a low fish diversity and low numbers of fish species could be found. This is perhaps because a large number of seagrass species in an area suggests a shorter aboveground part population (in contrast to pure Enhalus or Thalassia meadows) hence, does not favor cover or camouflage for small fishes from predators. This would also suggest that most fishes in seagrass beds come for shelter or refuge.

Worthington et al. (1992), on the other hand, found that seagrass shoot density explained very little of the large-scale variation in abundance in associated fish and decapods. However, the abundance of animals among separate seagrass beds will follow the supply of new individuals to them. Other authors have noted correlation between biomass and density of shoots and abundance of animals (Heck & Wetstone, 1977; Orth & Heck, 1980; Williams et al., 1990). The correlation has been attributed to variations in predation (see reviews by Heck & Orth, 1980), and habitat selection (Williams et al., 1990). However, many of these studies have been concerned with documenting patterns within individual seagrass beds, not at larger spatial scales.

Morphological variations in seagrasses are partly responsible for the high biodiversity in the system. This is brought about by differences in the amount and quality of surface (shelter) available for occupancy or colonization by species. Recruitment of many fishes appears to be influenced by the amount of shelter and the complexity of shelter or substrate also influences competitive interactions (Jones, 1988) and as a result, species composition.

In the Philippines, Indonesia, and Thailand, distinct intraspecies variations in gross morphology were observed in five seagrasses, namely, Halophila ovalis, Enhalus acoroides, Cymodocea serrulata, Halodule uninervis and H. pinifolia. These variations, attributable to differences in site-specific conditions, could similarly enhance biodiversity in seagrass systems. In H. ovalis, at least five ecomorphs, differing in foliar characteristics, were observed. While their blades were all ovate-elliptic, and more or less auriculate at their bases, the tips varied markedly from obtuse, rounded, to slightly emarginate. The number of cross-veins emanating from the midrib ranged from 8 to l8, slightly below the ranges reported by den Hartog (l970) (l2-25) and Menez et al. (l983) (l2-22). Petiole lengths varied from 2-6 cm.

In E. acoroides, the smaller, thick-leafed plants that make up sparser populations inhabiting open reefs, appear directly related to the stress imposed by high wave energy, coupled with its effective removal of sediments bearing nutrients. In these populations, organic matter is produced faster but is channeled to the above-ground parts as fast as it is utilized in the development and maintenance of anchorage systems on predominantly consolidated rock and coralline substrates (Fortes, 1986). This is in contrast to the longer, thick-leafed plants that make-up denser populations in low-energy, muddy coves. Here, nutrients accumulate and shoot production, not root-rhizome production, is better emphasized. The frequent absence of the species from coral cays in Papua New Guinea (Johnstone, l982) and its occasional patches in coarse coral sand in Philippine reefs, but pure stands in areas adjacent to mangroves (Menez et al., l983), suggest that the morphological variations in E. acoroides are a function of topography and its attendant conditions.

In Cymodocea serrulata, the two variants differed only in the presence or absence of the long, leaf-bearing branches. The latter results from the rapid elongation of their internodes. This condition is exhibited by plants in murky conditions with dense population of the species. As McMillan (l983) suggested, the rapid internodal elongation is directly related to low light conditions.

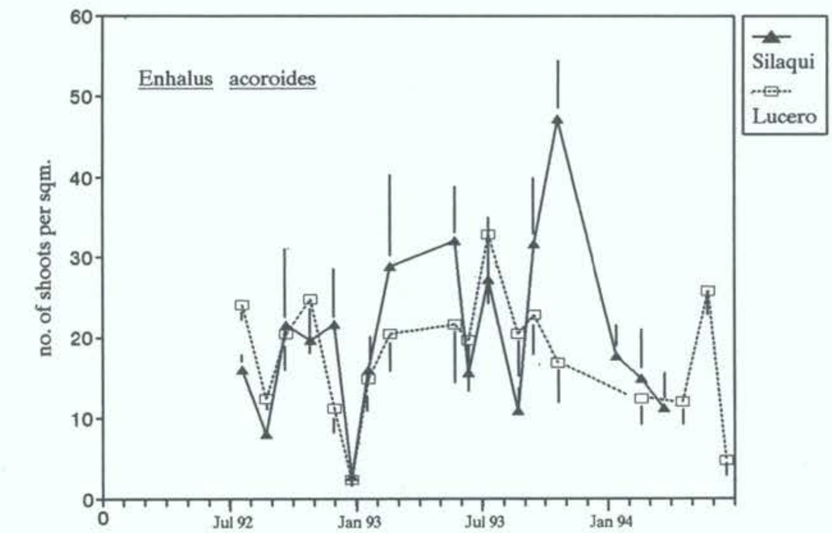
In Halodule uninervis, three environmental modifications of the same species are observable: (I) small plants with narrow leaves 0.5-I mm wide, occupying the uppermost, oftentimes exposed shore portions; (2) bigger plants with long or short stems, the leaves 2.5-4.7 mm wide, occupying similar but slightly deeper, protected habitats; and (3) intermediate sized plants, linking by gradual transitions in leaf length and diameter, the first two ecological variants. Such phenotypic alterations in the species had been considered as a generalized response to extreme salinity fluctuations (den Hartog, I970) and light conditions (Lipkin, I977; McMillan, I982).

The organic materials in seagrass beds are utilized by the fauna either through grazing of the living plant tissues, or consumption of the detritus. Which of these two pathways is more important under local conditions is still unknown, since studies on the initial linkage between plant production and animal consumption are few and based largely on direct field observation of feeding behavior and, to a very limited extent, under laboratory conditions (Salita-Espinosa. 1991). Many linkages within the trophic structure remain vague, unquantified, or largely unknown. More recently, Klumpp et al., (1993) reported that annual sea urchin grazing rate of seagrass at Cape Bolinao was 24% of annual seagrass production but this is expected to vary seasonally from 0.5 to 100%. Agawin et al., (1994) reported that there is a wide variability of responses of seagrasses to grazing. The response appears to be plastic and depends on a complex set of factors that control primary productivity.

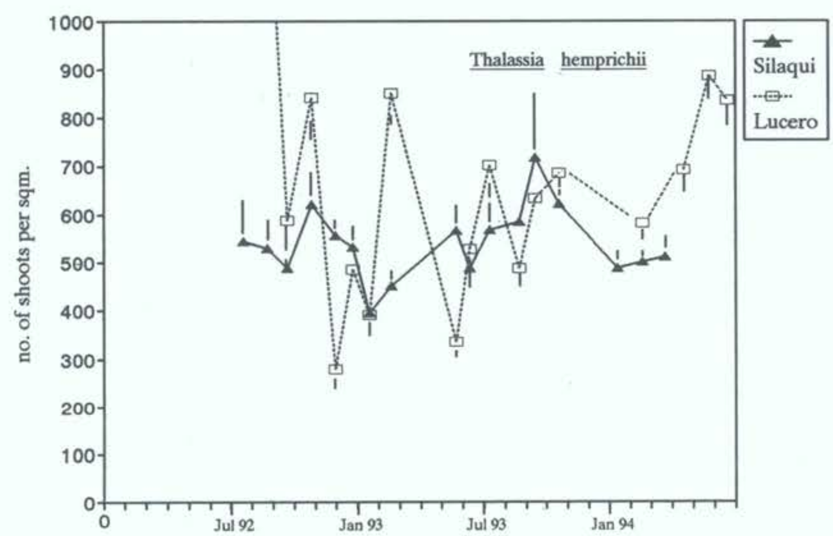
Controlling Environmental Factors

The structure of seagrass communities in East Asia varies slightly with the seasons and site-specific conditions. Seagrass density is generally bimodal, with highest values in summer (March-May) and in the wet season (July-November) (Fortes I986). In Cape Bolinao, seagrass density of the selected seagrasses monitored for 24 months (July 1992 to July 1994) showed slight changes with the seasons (ANOVA, $p<0.05$). Comparison of means revealed that E. acoroides density at both stations peaked during the rainy season (June-July) and for the rest of the months, did not fluctuate considerably (Fig. 4A). For T. hemprichii, highest density was in August and lowest in November and May (Fig. 4B). There was no consistent pattern of density maxima and minima, probably due to the heterogeneous distribution of seagrasses in response to the build-up of mounds by the shrimp-like Callianasa sp. which disturbed the sediment conditions. In the Philippines, shoot density in seagrasses is directly associated with water temperature (Fortes, 1986). T. hemprichii had the widest range of temperature tolerance. In terms of biomass, however, daylength appeared to be the most influential factor, while the number of lowest low tides during daytime played a primary negative effect on seagrass abundance, biomass, growth rate, and production. Generally, salinity and rainfall were ineffective in directly controlling the above features in local seagrasses. Unit area measures of biomass are a function not only of plant size but of shoot density. Peak biomass coincided with the wet season.

In Lucero, Cape Bolinao, the differences in seagrass growth rates appeared to be influenced by nutrient limitation. The site is characterized by relatively higher water movement and wave exposure. These may produce nutrient loss from the system through export and inducing erosion which prevents organic matter deposition in the sediment. With the loss in nutrients, hence, in energy source, fewer organisms are expected to colonize the habitat.



A



B

Fig. 4. Density of seagrasses at the two sites in Cape Bolinao, Philippines. A, <u>Enhalus acoroides</u>; B, <u>Thalassia hemprichii</u>.

Rhizomes of Enhalus acoroides collected from Cape Bolinao and Calauag Bay in the Philippines were back-dated by analyzing their retrospective seasonal production signature (RSPS)(Fortes, 1994c). At the latter site, pooled data confirm the existence of seasonal oscillations in production in the last 14 years and five months. In general, major peaks are evident after every 22-28 months, with quasi-biennial peaks occurring after 15-18 months immediately preceding the major peaks. The response was directly correlated with the elevated temperatures coinciding with the occurrence of the El Nino Southern Oscillation (ENSO).

An instantaneous, as well as cumulative, effect of rainfall on production was apparent, the latter occurring 1.5 months after the heaviest rainfall. Lowest production rates occurred three months after the passage of the typhoons. Recovery from these major stressors appeared evident only after a period of almost five years.

Data suggest that intra-annual patterns in aboveground production in E. acoroides are a small part of a major oscillation with peaks occurring about once every two years. At both sites, the bulk of the dry plant (seagrass) matter is contributed by E. acoroides, making this available three-to-four times annually (MSI/EPAI, 1993). Data suggest, however, that this rate of organic matter production is a direct function of major environmental events (temperature regimes associated with the ENSO phenomenon, rainfall and frequency of typhoons) which occurred in the past. This would imply that the major ecological contributions of the habitat which are dependent upon its productivity could be much more substantial under more favorable conditions.

Fig. 5 shows the set of phenological indices plotted against the gradients in the environmental factors at Puerto Galera (northcentral Philippines). It is probable that daylength, temperature maximum, and rainfall, interacting independently or in combination, make up the critical and primary environmental cues that control the reproductive periodicity, abundance and production of E. acoroides at the site. Identifying the influence of these cues would be useful in solidifying the ecological basis of seagrass management in tropical coasts.

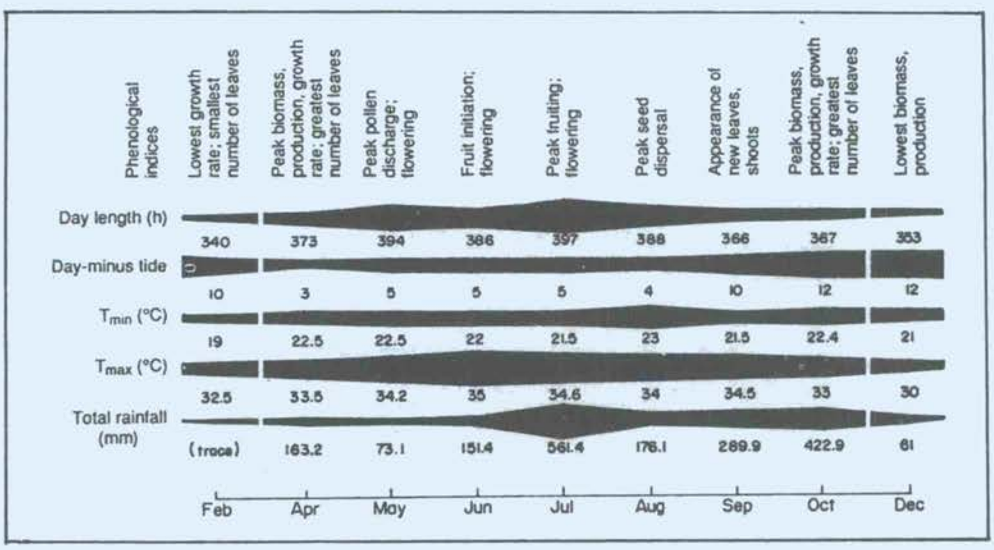


Fig. 5. Phenological indices of E. acoroides plotted against prevailing environmental gradients in Puerto Galera, northcentral Philippines (After Fortes, 1989)

SEAGRASS-CORAL REEF-MANGROVE INTERACTIONS

In the next decade, one of the challenges critical for seagrass ecological science is its understanding and application in the management of the environment and its resources in the face of environmental change. Coral reefs, seagrass beds and mangrove forests are major life support systems of the tropical coastal and marine environment. They are known to be interconnected by high-order interactive processes which maintain their stability and structural and functional integrity. UNESCO (1983) and SPC/SPEC/ESCAP/UNEP (1985) identified some interconnections among these ecosystems and these are: physical, nutrients (dissolved and particulate organic matter), animal migrations, and human impact. Our current knowledge about these interconnections, however, are yet so meager and the rate we acquire more information about them cannot cope with the rate the habitats are being destroyed or degraded (Fortes, 1991).

Seagrass beds may be linked functionally with coral reefs and mangrove forests by the high similarity indices between their associated fish and algal epiphytic communities. In the Philippines, between Cape Bolinao (a reef area) and Pagbilao Bay (a mangrove area), seagrass fish fauna had 51.3% similarity with the fish fauna from coral reefs and only 18% similarity with that from mangrove forests. In Calancan Bay where all three ecosystems are present, seagrass fish fauna had 44.4% similarity with that from mangroves and only 13.3% with that from coral reefs. For the country as a whole, the preliminary survey indicates that seagrass fish fauna is closer to that of coral reefs (46.3%) when compared to its affinity with mangroves (13%).

The high species overlap between the algal epiphytes from seagrasses and coral reefs (Sorensen's Community coefficient, CCs = 56.2%, Table 2) implies close similarity in the magnitude of the principal environmental factors and niche provisions by the two habitats (Fortes, 1994d). It is postulated that the degree of species overlap represents a high-order biological connection linking the two systems. In Cape Bolinao, the gut contents of the seagrass-dependent fish, Siganus fuscescens were mostly algae which made up the greater bulk of the epiphytic flora on the leaves of seagrasses (Salita-Espinosa, 1991). The preliminary results also indicate a possible quantification of a primary ecosystem interconnection (fish migration) and the sensitive role seagrass beds play between coral reefs and mangrove forests in tropical coasts. This sensitivity makes seagrasses useful as indicators of changes not easily observable in either coral reefs or mangrove forests. With its overlap with mangroves(CCs = 31.4%), the ecological position of seagrass ecosystems as the transition zone between two divergent but trophically related habitats is demonstrated.

The ecosystems may also be connected via export or import of drifted plant materials. In Cape Bolinao these materials were composed mostly of detached or grazed leaves of the seagrasses E. acoroides and T. hemprichii, and fronds of the seaweeds, Sargassum, Padina, and Chaetomorpha. Of the total 1,405 gram dry weight (gmDW) of the materials, T. hemprichii contributed 61% while E. acoroides, 20.3%. The seaweeds gave a combined contribution of 19.2%. 1,135 grams of dry seagrass matter came from 178.6 sq. m area of seagrass bed in the Cape.

On a monthly basis, biggest amount of exported seagrass materials was collected in May (27.67 gmDW/d), while the smallest amount was collected in December (1.71 gmDW/d). Thus, if the total observed contribution of the producers

Table 2. Algae epiphytic on the leaves of seagrass, trunks and pneumatophores of mangroves, and on coral surfaces in Calatagan, Philippines. The community similarities are also given.

Mangroves	Seagrass beds	Coral reefs
Boodless pusilla	*Acetabularia dentata*	*A. dentata*
Bostrychia binderi	*A. major*	*A. major*
B. radicans	*Acrochaetium gracile*	*A. gracile*
Caloglossa leprierii	*Actinotrichia fragilis*	*A. fragilis*
C. ogasawaraensis	*Amansia glomerata*	*A. glomerata*
Catenella caespitosa	*Amphiroa foliacea*	*A. foliacea*
Calothrix aeruginea	*A. fragilissima*	*A. fragilissima*
C. scopulorum	*Antithamnion antillanum*	*Anadyomene sp.*
Ceramium affine	*Boodlea composita*	*A. antillanum*
Chaetomorpha sp.	*Boodlea pusilla*	*Boodlea composita*
Ectocarpus indicus	*Brachytrichia quoyi*	*Bryopsis sp.*
Enteromorpha compressa	*Centroceras minutum*	*C. minutum*
E. ramulosa	*Ceramium fastigiatum*	*Ceramium sp.*
Gelidium crinale	*C. gracillimum*	*C. fastigiatum*
G. pusillum	*C. mazatlanense*	*C. gracillimum*
Herposiphonia tenella	*C. zacae*	*C. masonii*
Laurencia surculigera	*Chaetomorpha aerea*	*C. mazatlanense*
Lyngbya confervoides	*Champia parvula*	*C. personatum*
L. majuscula	*Cladophora trichotoma*	*C. procumbens*
Microcoleus acutissimus	*C. uncinata*	*C. serpens*
Murrayella pericladus	*E. intestinalis*	*C. sinicola*
Oscillatoria curviceps	*Gelidiella adnata*	*Champia parvula*
O, nigro-viridis	*Gelidiopsis sp.*	*Cladophora sp.*
O. sancta	*Gelidium crinale*	*C. trichotoma*
Polysiphonia subtilissima	*Griffithsia ovalis*	*C. uncinata*
Rhizoclonium grande	*G. tenuis*	*Cruoania sp.*
Rivularia nitida	*Herposiphonia dendroidea*	*Dasyopsis sp.*
Sphacelaria furcigera	*H. tenella*	*Dictyota sp.*
	Hydrocoleum sp.	*E. indicus*
	Jania capillacea	*Fosliella sp.*
	Laurencia obtusa	*G. crinale*
	L. surculigera	*G. ovalis*
	Lyngbya confervoides	*H. dendroidea*
	L. majuscula	*H. obscura*
	Oscillatoria curviceps	*H. parca*
	Polysiphonia savatieri	*H. tenella*
	P. subtilissima	*J, capillacea*
	Sphacelaria furcigera	*J. ungulata (?)*
	Spyridia filamentosa	*O. corallinae*
	Tolypiocladia calodictyon	*Padina japonica*
		P. minor
		P. pacifica
		P. scopulorum
		S. furcigera
		S. filamentosa
		Struvea sp.
		T. glomerulata
28	42	47

CCs (S:M) = 31.4%
(S:C) = 56.2%
(M:C) = 11.0%

to the exported materials and to grazing pressure (excluding phytoplankton) are deducted from the total production, the high energy efficiency of the seagrass ecosystem at Cape Bolinao becomes apparent. In Calancan Bay, and excluding the algae, the seagrasses contributed to the total drifted materials 0.64 gmDW/m^2/d. This amount almost equals the contribution from mangroves (0.67 gmDW/m^2/d).

The expansive nature of the seagrass system has developed extensive faunal communication and material exchange with other habitats (Fonseca, personal communication). For example, Province A in Fig. 1 houses about 30% of the world's coral reefs, with which seagrasses are closely associated (IUCN/UNEP, 1985). These plants cover much more area on many fringing reefs than do corals (McManus, 1988). Vast seagrass meadows are often found between coral reefs and the coastal fringes that support most of the region's mangroves. In this transition zone, the plants have colonized all environmentally suitable areas. Here, the habitat is sensitive to fluctuations because both plant and animal components come from neighboring systems and encounter 'marginal conditions' at the extremes of their tolerance levels to environmental alterations. This sensitivity, indeed, makes seagrasses useful indicators of changes not easily seen in either coral reefs or mangrove forests.

ENVIRONMENTAL ASPECTS OF SEAGRASS ECOSYSTEMS

This section of the book emphasizes the environmental aspects of seagrass systems in East Asia, i.e., seagrass beds as coastal protective agents being threatened by both natural and man-induced perturbations. The environmental functions of seagrass systems (i. e., their capacity to provide goods and services that satisfy and sustain human needs) are best performed when the beds are intact and undisturbed (**natural functions**). However, in developing countries of East Asia and due largely to pragmatic reasons, seagrass areas may have other functions manifested not in their natural intact conditions, but as transformed habitats (**elimination functions**). In spite of their vital importance to our survival, we still know very little about the functioning of seagrass systems, and details on their operation, maintenance, adaptation and evolution are still very poorly understood. In order to better incorporate ecological information into the planning and decision-making process, it is essential to increase our knowledge on the many functions provided by both natural and semi-natural or artificial seagrass systems. These functions strongly justify a concerted effort to manage the seagrass resources in the region.

Environmental Functions

Biologically, seagrass habitats can be viewed at two levels: as a community and as an ecosystem (Thayer et al., 1984). As a community, a seagrass bed is a structural framework with plant and animal interactions. As an ecosystem, these interrelationships are viewed as discrete processes, controlled by the interactive effects of both biological and physico-chemical factors. These two levels act as the base of the environmental functions of seagrass beds. These functions are the primary consideration in using seagrasses in mariranch systems (Fortes, 1993a).

In order to provide a framework for a systematic analysis of the most relevant functional linkages between seagrasses and their users, four function categories are distinguished (modified from de Groot, 1992): **regulation**; **carrier**; **production**; and **information**. From an 'environmental perspective' regulation and carrier functions provide the preconditions for production and information functions. In assessing these functions of seagrass systems, their integrated and interdependent nature should be kept in mind. Hence, utilization of one function will most likely affect the others. In addition, it should be clear that each function results from the interactions between the dynamic and evolutionary processes and components of the marine macro-ecological subsystem of which seagrass ecosystem is an integral part.

Regulation functions

Regulation functions relate to the ability to modify essential ecological processes and life support systems which maintain a healthy environment. With seagrasses, these include:

a. Reduction of water energy and motion

The ability of seagrasses to reduce water energy and motion promotes sedimentation (Short et al., 1989). In the Mediterranean, waves and currents are damped by mattes of P. oceanica and the transient sediment is accumulated by the filtering action of its leaves and rhizomes; without the beds, there was instability and erosion of sea beds, the burying or erosion of sandy shores, and high rate of sand accumulation around harbors, and docks (Blanc & de Grissac,1984).

b. Regulation of the chemical composition of the coastal waters and sediments.

This function is accomplished by preventing resuspension of organic and inorganic matter (Blanc & de Grissac, 1984; Short et al., 1989). By filtering the waters, both suspended sediments and dissolved nutrients are removed, hence, seagrasses could be useful indicators of changes in water and sediment chemistry. The rhizomes of the long-living Mediterranean seagrass, P. oceanica, preserved a record of atmospheric caesium fallout, which closely matched that of known atmospheric loading (Pergent et al., 1983). The use of seagrasses as tracers of the chemical characteristics of environments in the past is probably restricted to non-easily metabolized and rapidly translocated compounds.

c. Regulation of runoff, trapping and stabilization of bottom sediments.

In many typhoon-prone areas in the region (e. g. upper half of the Philippines), seagrasses act as effective retainers of sediments due to the thick mass of their underground systems, hence, serving as buffer against waves and storm surges (Fortes, 1989).

Along with this function, rhizome growth and production in E. acoroides hold a potential of giving a retrospective seasonal signature of past catastrophic events as the El Nino southern oscillation (ENSO), passage of typhoons, and rainfall (Fortes, 1994c). The considerable interpopulation differences in the vertical growth of T. testudinum shoots in erosional scarps ('blowouts') could be used to estimate sedimentation rates, attributing to the species the potential to be used as tracers of sediment migration (Patriquin, 1975). The close coupling between sediment accretion rates and seagrass vertical growth has been demonstrated since for other turtlegrass meadows off the Yucatan Peninsula (Marba et al., 1994), as well as for the Mediterranean species, P. oceanica (Boudouresque et al., 1984) and C. nodosa (Marba & Duarte, 1994). The effectiveness of seagrasses to regulate runoff and trap sediments have also been reported by Thayer et al., (1975) and Blanc & de Grissac, (1984).

d. Maintenance of fertility

Through efficient fixation of solar energy and high biomass production, seagrasses are able to enhance and maintain coastal fertility. This is complemented by the efficient processing of organic material both on the leaves and at the bottom substrate. The process is facilitated by a highly diverse trophic structure and enhanced by both autochtonous and allochtonous substances. In the Mediterranean, the high productivity of P. oceanica and extensive surface it covers in the bottom are the reasons why it contributes substantially to the oxygenation of the water: 1 m^2 of the bed producing 4-20 l of oxygen within 24 hr (Boudouresque & Meinesz, 1982). Hence, P. oceanica can also be considered as suppliers of oxygen for terrestrial biotopes, at least during the most productive months of the year (Frankignoulle et al., 1984).

e. Regulation of biological control mechanisms

In East Asia, this function is manifested through trophic interactions of the macrobenthic plants with fish fauna (Robertson, 1984; Klumpp et al., 1992; 1993;), shrimps (Howard, 1984); dugong (Aragones, 1994, Erftemeijer et al., 1993), and algal epiphytes (Salita-Espinosa, 1991; Klumpp et al., 1992). The establishment of seaweed mariculture (Eucheuma) in seagrass beds in the Philippines and Indonesia have been observed to divert grazing by rabbitfish and urchins from the seaweed to the seagrasses, thereby relieving the former of the pressure. The high-order interactions of seagrass beds with mangrove forests and coral reefs in the form of fish migration and human impact are postulated to play significant role in the regulation of biological coastal control mechanisms in the tropics.

f. Maintenance of migration and nursery habitats

Seagrasses grow strategically between mangrove forests and coral reefs, or colonize areas devoid of the two other ecosystems. This feature makes them the 'stopping points' for many fishes, invertebrates, mammals, and reptiles. The low-tide exposed eelgrass beds of the North Atlantic are regular parts of the route of migrating waterfowl (Buchsbaum, 1987).

By providing refuge through the thick canopy and varied sizes and morphologies of the blades and by producing nutrients, seagrass beds serve as effective nursery grounds of important organisms. In Indonesia and the Philippines, there is a high coincidence between the areas where dugong (Compost, 1980; MERF, 1994) and turtle (Kajihara, 1973) sightings have been made and those where seagrasses are reported (Fig. 3). Unfortunately, in the recent years, there has been a significant reduction in the number of sightings of these endangered sources of biological and genetic diversity in the region (Fortes, 1989).

Enhancement and Maintenance
of Ecosystem and Genetic Diversity

By serving as essential, natural, and highly productive components of the coastal zone in East Asia, seagrass beds enhance and maintain ecosystem and genetic diversity. This is seen in the presence of a trophic hierarchy, characterized by highly diverse assemblages of producers, herbivores, carnivores, omnivores, detritivores, and decomposers (Fig. 6).

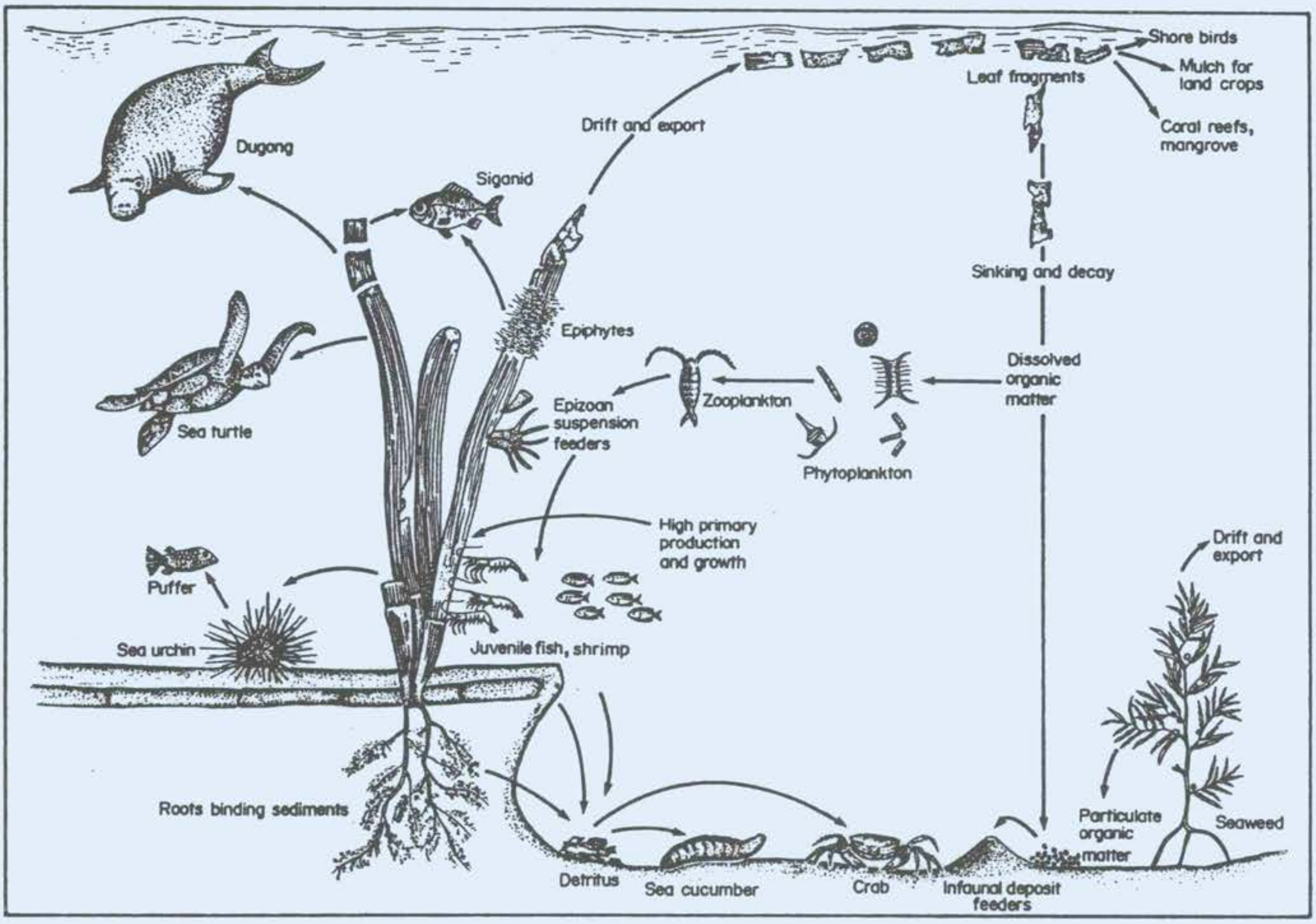


Fig. 6. Food chain in seagrass ecosystems in the Philippines and other East Asian countries showing some of their environmental functions (modified from Fortes, 1989)

Although incomplete, Table 3 shows the high diversity of organisms so far reported from seagrass beds in East Asia and Australia.

Table 3. Number of species and families of organisms reported from seagrass beds of East Asia and Australia.

	No. of Species/ Families	Data Source
Fish		
ASEAN region	318/51	Poovachiranon et al. (1994)
Philippines	172/50	Vergara & Fortes (1991)
Thailand	38/29	Sudara et al. (1992a,c)
Peninsular Malaysia	15/ 9	Rajuddin (1992)
Singapore	13/ 9	Loo et al. (1993)
Indonesia	78/ ?	Hutomo & Martosewojo(1977)
Papua New Guinea	30/14	Brouns & Heijs (1985)
Australia		
Botany Bay	103/52	Middleton et al. (1984)
Cairns; Bowen	65/35	Coles et al. (1989)
Invertebrates		
Philippines		
Bais Bay	46/>9	Onate et al. (1991)
Indonesia		
Banten Bay	15/10	Mudjiono et al. (1992)
	28/ 8	Kiswara et al. (1992)
	32/ ?	Aswandy & Kiswara (1992)
Papua New Guinea	115/36	Brouns & Heijs (1985)
Australia		
Western Port	>116/49	Watson et al. (1984)
Cairns; Bowen	17/ 5	Coles et al. (1989)
Macrobenthic Seaweeds		
Papua New Guinea	51/ ?	Brouns & Heijs (1985)
Philippines	51/20	Trono & Ganzon-Fortes (1980)
Algal epiphytes		
Papua New Guinea	83/137	Brouns & Heijs (1985)
Philippines	45/ ?	Fortes (1994d)

From Panama, 106 species of fish from 45 families were reported by Weinstein & Heck (1979). Boto et al. (1991) found significantly higher bacterial density at 6.65 cells/m^2 x 10^{13} in natural when compared to artificial seagrass beds and bare sediments at a copper mine site in the Philippines. The Mediterranean meadows of P. oceanica yielded more than 400 species of algae and 1,000 animals (Mazella et al., 1986). In the case of the penaeid shrimps, the table below shows that the Indo-West Pacific region has the highest number of species and degree of endemism in the world (After Dall et al., 1990):

Biogeographic Region	No. of species	No. endemic
Indo-West Pacific	125	124
East Pacific	16	16
West Atlantic	21	18
East Atlantic	16	3

Directly or indirectly, the high diversity of the shrimps in the Indo-west Pacific could be a function of the ecological nature of the seagrass habitats where most of them are intimately associated with.

Carrier functions

Carrier functions relate to the ability to provide space and substrate or medium for many human activities such as habitation, cultivation and recreation. Under this category, seagrass systems provide shelter, suitable substrate, breeding and nursery grounds of highly important fauna (Thayer et al., 1984; Mazella et al. 1986). The ability of seagrasses to harbor periphyton on their surfaces is well known (see Orth & van Montfrans, 1983 for review). In Indonesia and the Philippines, many seaweed farms are established in seagrass beds. In addition, the beds are now being used in marine ranching, while beds of the emergent seagrasses are partly converted into aquaculture.

The value of seagrass vegetation could also be expressed in recreational terms, hence, at low tide, children of coastal areas in the region play in exposed beds while in more developed countries, the beds are areas for hunting, fishing, crabbing. A major thrust to improve the economy in the region, coastal recreation and tourism are often developed in or adjacent coral reefs with associated seagrass beds. In East Asia, seagrass bed propagation is now considered in marine protected areas as a means of habitat enhancement and protection.

Production functions

Production functions relate to the ability to provide genetic materials, food, raw materials for industrial use, and energy. Thus seagrasses fuel both direct (grazing) and indirect (detritus) feeding pathways (Augier, 1986; Klumpp et al., 1992;1993), have high production and growth (McRoy & McMillan, 1977; Boudouresque & Meinesz, 1982). These functions of seagrass systems have been discussed under the **Section: Importance of Seagrass System Components.**

Information functions

Information functions relate to the ability to maintain mental health by providing opportunities for reflection, spiritual enrichment, cognitive development, and aesthetic experience (de Groot, 1992). Under this category, seagrass systems of the Philippines, Indonesia, Malaysia, and Thailand are known to provide aesthetic information mainly when nature enthusiasts go bird watching in wetlands where seagrasses are exposed during low tide. As earlier noted, near resort areas in these countries, low tide exposes seagrass beds and their associated organisms which are the object of curiosity of tourists. Seagrasses are also important natural components in marine parks and reserves where they provide historical, scientific and educational information and cultural and artistic inspiration.

Causes and Consequences of Seagrass Loss

Worldwide, there has been a rapidly increasing intensity of seagrass decline (Thayer et al., 1975). As natural resources, seagrass beds are subject to varied and destructive disturbances mediated by both natural and man-induced influences. In this book, 'disturbance' is defined as a discrete, punctuated killing, displacement or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established (Sousa, 1984). At the Seagrass Workshop held in Bangkok in December 1993, seagrass scientists of the LCR project have indicated that seagrass habitats in East Asia are rapidly being destroyed. In Indonesia about 30-40% of the seagrass beds have been lost in the last 50 years, with as much as 60% being destroyed around Java. In the Philippines, seagrass loss amounts to about 30-50%, while in Singapore, the patchy seagrass habitats have suffered severe damage largely through burial under landfill operations. In Thailand, losses of the beds amount to about 20-30%. Very little information on seagrass loss is available from Malaysia.

At the same meeting, the participants identified the various threats to which the region's seagrass habitats are subjected. These became the basis for the formulation of the 'Seagrass Environmental Quality Criteria' (Table 4) which could be useful in defining habitats for management purposes.

In Botany Bay, Australia, aerial photography and field observations indicated that the distribution of Posidonia australis had undergone a steady decline over the past 40 years (Larkum & West, 1990). Between 1942 and 1984, 58% or 2.57 km^2 of the beds were lost from the bay's foreshore; by 1987, the once continuous meadow became fragmented.

The 'wasting disease' of the 1930's destroyed 90% of the eelgrass populations along the east coast of the U.S.(Short et al., 1989). Thirty years after its occurrence, eelgrass in most areas along the North Atlantic coast recovered, although in some locations it never grew back (Thayer et al., 1984). Recently, there is a recurrence of the disease, affected plants being found from Nova Scotia to North Carolina, on the west coast of the U.S., and on the coast of Europe (Short et al.,

Table 4. Seagrass Environmental Quality Criteria (SEQC) based on affecting factors and their descriptors

	Factors	Descriptors
Natural		
1.	Clay	Presence/absence in substrate
2.	Coral reef	Presence/absence in- or offshore
3.	Mangrove	Presence/absence inshore
4.	Embayment	Presence/absence
5.	Dugong / turtle	Frequency of sighting
6.	Epiphytes	Degree (low to high)
7.	Grazing intensity	Degree (low to high)
8.	Monsoon exposure	Frequency
9.	Sedimentation	Degree (low to high)
10.	Sediment movement	Presence/absence; frequency
11.	Substrate type	Silt to gravel
12.	Tidal exposure	Frequency
13.	Volcanic eruption	Never; recovered; observed effects
14.	Cyclone	Never; recovered; observed effects
15.	Salinity	ppt
16.	Temperature	degree Celsius
17.	Tidal range	meters
18.	Depth maximum	meters
Anthropogenic		
1.	Disease	Degree (low to high)
2.	Management status	None; limited; some; complete
3.	Mariculture	Presence/absence
4.	Population pressure	Density relative to distance
5.	Blast fishing	Location relative to beds
6.	Boat scour	Presence/absence; degree
7.	Eutrophication	Degree (low to high)
8.	Fishing damage	Degree (low to high)
9.	Fishing intensity	Low to high
10.	Fish poisoning	Location relative to beds
11.	Gleaning	Degree (low to high)
12.	Oil spill	Never; recovered; observed effects
13.	Pollution	Degree (low to high)
14.	Reclamation	Never; recovered; observed effects
15.	Trampling	Degree (low to high)

1988). More than 40 km^2 of seagrass beds have been completely lost in recurring episodes of mortality since summer 1987 and an additional 230 km^2 have been affected to a lesser degree (Robblee et al., 1991).

The cause of the 'wasting disease' has never been unequivocally established, although suggestions have pointed to abnormally high water temperature, recent reduced frequency of hurricanes, high salinity, and chronic hypoxia of the seagrass roots and rhizomes. Other reports of regional declines in abundance of submerged aquatic vegetation (SAV) have indicated the possible influence of human activities (den Hartog & Polderman, 1975; Phillips et al., 1978). But because die-off is occurring in areas far removed from surface-water pollution sources, anthropogenic contaminants may not be involved. The causal agents of the disease are currently under investigation.

Causes of Seagrass Loss

The causes of seagrass habitat degradation and loss are not different from those which generally afflict the coastal zone in East Asia. Based on attempts to synthesize the issues confronting the development and management of the coastal zone in the region, the causal factors can be placed under three categories: **biophysical issues**; **sociocultural issues**; and **institutional issues** (Fortes & McManus, 1994). This categorization, however, is artificial as these issues are interconnected and interdependent. If they are separated in this book, it is only for convenience in presentation to facilitate ease in their understanding. They have been the focus of numerous conferences in many parts of the world so that only those aspects which directly relate to seagrass ecosystems will be emphasized.

Biophysical Issues - The biophysical issues confronting coastal zone management in East Asia include: degradation of coastal ecosystems and habitats; declining water quality and pollution; declining coastal fisheries; endangered marine species and coastal wildlife; coastal hazards including ocean storms and flooding; and global sea level rise.

Extensive sub- and intertidal filling in Singapore, cultivation for agriculture in Philippines, and mining in the Philippines, Thailand, and Malaysia have led to heavy siltation in estuarine areas causing burial, high water turbidity, and lower production of both seagrasses and their associated fauna (Fortes, 1989). The high sedimentation rate at the Segara Anakan-Cilacap lagoon in Indonesia, estimated to reduce the water body to only 40% of its present area by the year 2000 (Sujastani, 1984), could significantly decrease fishery catch in this highly productive area. The active mining firms in the Philippines produce at least 140,000 tons of mine tailings daily (EMB, 1990) which, if not properly contained, may find their way to river systems and eventually to the sea. Due to the degradation of the shallow coastal zones, small-scale, less equipped fishermen which comprise the majority of the region's coastal population are forced to fish in deeper waters -a more dangerous and costly option.

Human activities such as industrialization, development of recreational areas along the coasts, agricultural land uses, and dredge and fill operations are increasing in many parts of the world. Such activities have led to well documented declines of seagrass beds in both temperate and tropical areas (Maggi, 1973; Peres & Picard, 1975; Larkum, 1976).

On the other hand, natural perturbations such as cyclones, typhoons, tidal waves, volcanic activity, and the rapid encroachment of sand waves likewise constitute physical issues which can also be responsible for seagrass decline. However, they do not seem to be as widespread as man-induced changes (Patriquin, 1975; Zieman, 1976; Kirkman, 1978). Pests, diseases and population and community interactions similarly pose as stressors which have affected seagrass beds (Fortes, 1989).

Volcanic eruption and typhoons are remarkably debilitating. In Indonesia, the eruption of Krakatau in 1883 had completely destroyed the coastal vegetation along the southern coast of Sumatra and western Java. In the Philippines, the eruption of Mt. Pinatubo in June 1991 caused 23-69% decline in fish biomass along the ashfall deposit gradient in the nearby coastal environment of the province of Zambales, northwestern Philippines (Ochavillo et al., 1992). This could partly be the indirect effect of the eruption on the coral reefs, seagrass beds and mangrove fish habitats in the area.

Coastal development - In Botany Bay, Australia, decrease in the area of seagrass beds coincided with a period of industrial and residential development in the catchment during the period 1930-1987 (Larkum & West, 1990). The increased wave amplitude brought about by dredging eroded large tracks of seagrass beds, particularly during storm events. The loss has been attributed to a history of poor catchment management, uncontrolled effluent disposal and widespread dredging. Over the same period, Zostera capricorni was found to have undergone cyclical fluctuations in area throughout the bay, and had colonized many sites that were previously vegetated with Posidonia australis. Cambridge & McComb (1984) reported that from 1954 to 1978, the meadow area in Cockburn Sound was reduced from some 42-9 km^2, the loss coinciding with a period of industrial development on the shore and discharge of effluent rich in plant nutrient.

Pollution - Pollution from wastewater discharge and what appears to be a disease are diminishing seagrass populations in some estuaries along the coasts of East Asia. They result from intense development of coastal areas, thereby reducing water quality and success of seagrass growth. Any pollution resulting in reduced water clarity limits the production and survival of seagrass in coastal areas. Decreased water clarity reduces the amount of light reaching the bottom, shading the seagrass, and reducing its growth (Dennison, 1987). In the Philippines, only about 25% of industrial firms nationwide comply with water pollution control laws; at least 31 municipalities and ten cities discharge their sewage, industrial effluent, and domestic wastes into strategic river systems and coastal areas (EMB, 1990). With an increase in pollution, there is a concomitant decrease in seagrass biomass and reduction in species diversity. An inversion of algal dominance from the Floridiophycideae to the Chlorophyceae and Bangiophycideae has also been associated with pollution (Panayotidis, 1978).

In highly polluted waters, there is decrease in the amount of photopigments (Augier & Maudinas, 1979), hence, an attendant decline in photosynthetic rates. In these waters, Posidonia oceanica was found to accumulate the heavy metals chromium, cadmium, and nickel in their tissues, making the seagrass a potential indicator of heavy metal pollution (Giaccone et al., 1988). The root system is mainly responsible for mercury absorption whose concentration in the plant tissue seems to be correlated with its concentration in the sediments (Maserti & Ferrara, 1986). The consequences are physiological disorders of leaf tissues, with growth arrest and cellular necrosis (Cristiani et al., 1980). Detergents have been found to be lethal for seagrass tissues by altering its development. The basic compounds in detergents accumulate in sediments causing damage to the roots, rhizomes and leaves (Peres & Picard, 1975).

In the Philippines, in an initial attempt to investigate the rate of copper uptake by seagrasses in a bay polluted by copper mine tailings, Tabbu-Cruz (1989) found the concentration of the metal consistently twice greater in the smaller H. uninervis than in the bigger E. acoroides. This finding suggests an apparent correlation of the parameter with the morphology of the species. The concentrations of copper in the tissues of the plants were positively correlated with those in the sediment.

Pollution and the 'wasting disease' interact, causing seagrass to die-off rapidly (Short et al., 1991). The most observable effects of pollution stress appear to be a reduction in the population size and distribution of seagrass below naturally recoverable levels. Of the major pollution related effects, reduced available light resulting from eutrophication is by far the greatest threat to seagrass populations (see below). Areas outside Asia with identifiable seagrass declines resulting from pollution include Chesapeake Bay (Orth & Moore, 1983), Florida (Kenworthy et al., 1989), Cockburn Sound, Australia (Cambridge & McComb, 1984), and San Francisco Bay (Wyllie-Escheverria et al., 1989).

Suspended sediments - The two main factors contributing to water clarity reduction are suspended sediments and nutrient loading. Resulting primarily from upland runoff, boat traffic, wind mixing, and gleaning, suspended sediments shade the plants directly. Sand, silt and clay derived from deforestation (and swidden agriculture or 'kaingin' in the Philippines) wash into streams which carry the suspended materials into seagrass areas. Industrial, residential and commercial development which cause rapid rates of clearing and soil stripping in watersheds also contribute suspended sediments in the coastal waters. Differences in seagrass depth limit are largely attributable to difference in light attenuation underwater, although differences in seagrass growth strategy and architecture also appear to contribute to explain differences in their depth limit (Duarte, 1991).

Nutrient loading (eutrophication) - The major long-term threat to seagrass populations around the world is derived from coastal eutrophication. A particular problem in embayments with reduced tidal flushing, nutrient loading or eutrophication results from wastewaters which reach the coasts from industrial, commercial and domestic facilities, inadequate septic systems, boat discharge of human and fish wastes, and storm drain run-off carrying organic waste and fertilizers. Its direct impact is the enhancement of growth in many plant forms resulting in reduction of light (Orth & van Montfrans, 1984; Short et al., 1989). In seagrass-dominated coasts, the heavy nutrient load shades the plants by promoting planktonic and algal growth, creating a dramatic shift in community structure and resulting in declining health of the seagrass community which includes many commercially important species. The plants that compete with seagrasses for light include: phytoplankton (free-floating diatoms and dinoflagellates); macroalgae; and epiphytes (diatoms and algae attached to seagrass blades). Excessive nutrient loading can result in a shift to any of the three algal forms. For these reasons, seagrass health is an indicator of the overall health of bays and estuaries.

Ultimately the cause of nutrient loading along coasts is people, increased population density increases the problem. Nienhuis (1983) mentioned that the most plausible cause of mass decline of eelgrass in Lake Grevelingen in 1980 is associated with an increase in organic matter deposition on the bottom, following a change in nutrient loading of the lake, causing rapid deoxygenation and toxification of the sediments, and consequent dieback of plant rhizomes and roots. In order to solve the problem of eutrophication in coastal waters, nutrient loading should be reduced. In East Asia, however, this tends to be difficult largely because of the social and economic cost of actually eliminating or redirecting the discharge of human wastes away from the shallow coastal environment.

Physical disturbance - In many parts of coastal East Asia, blast fishing is a popular albeit extremely destructive fishing technique. In Cape Bolinao alone, six blasts per hour have been recorded (McManus, personal communication). The blasts when done in seagrass beds create blowouts or grass-free depressions within the beds. In blowout areas any one point will be recurrently eroded and reestablished at intervals of the order of 5-15 years (Patriquin, 1975). Such processes limit successional development of the grass beds (as evidenced by the absence of a well developed epifauna and flora characteristic of advanced stage of seral development), disrupt sedimentary structures, and may result in deposits much coarser than those characteristic of the sandy seagrass carpet. In coastal population or market centers, boat traffic causes scouring of the beds. This is brought about by the boats themselves or by the anchors and poles used to maneuver the boats at low tide. It also suspends sediments, contributing significantly to the increase of water turbidity and a decline in its quality.

Implications of climate change - Present sea temperatures in the East Asian seas are expected to increase by 1°C (Chou, 1994), the resulting enhanced evaporation and increased precipitation likewise expected to affect water salinity. With the increase in precipitation, more nutrients will be washed out to sea which can either have positive or negative effects for seagrass communities depending on the actual load. With erosion enhanced, current patterns in nearshore areas where seagrasses abound will be altered, with its adverse effects on the breeding and nursery functions of the ecosystems.

A rise of sea level within the predicted range of 20 cm by 2025 is likely to be insignificant compared with man-induced influences on the coastal environment. Nevertheless, there would be substantial negative impacts on the seagrass community because it would be subjected to inundation, increased frequency and severity of storms and wave surge, increased rates of shoreline erosion, wetlands inundation and recession, modification of dynamic coastal physical properties, and damage to, or reduction of shoreline protective structures and facilities (Davidson & Kana, 1988).

<u>Sociocultural Isues</u> - The sociocultural issues in coastal zone management in East Asia include: poverty; degradation and loss of scenic values and cultural resources; loss of access to commonly held natural resources; public health issues; population growth; increasing social conflicts; and certain misconceptions that guide man's actions.

In East Asia, there are misconceptions that guide most people's interactions with their environment. They have an unclear perception of what the environment is in relation to themselves, the view being often anthropocentric, not sociocentric nor naturalistic. In addition, development is predicated largely upon environmental exploitation, not its protection, as the latter is not yet a perceived social need but an expensive and time-consuming activity. Environmental preservation and the pursuit of economic goals are considered in conflict with one another because they are based on two incompatible basic principles: the ecological principle of 'stability', as a precondition of the sustainability of ecological systems, and the economic principle of 'growth', as the inherent logic of economic systems (Simonis, 1989). The important point about these different viewpoints is that they will remain divergent so long as groups have different interests and different sources of information and knowledge (Adams, 1990).

Institutional Issues - The institutional issues include: low level of institutional capability for coastal area management; overlapping jurisdictions/ interagency conflict; lack of mechanism to limit free-access nature of fishery; lack of national policy on strategic development of the coastal zone; inadequate public support for management nitiatives; inadequate implementation of existing regulations; lack of an alternative paradigm of economic development that is also ecologically sustainable and politically acceptable.

Political interference and mismanagement is a 'normal' ingredient in any developmental effort in less developed countries. This results from misguided priorities arising from meager information base, lack of expertise, political favoritism and inefficient bureaucracy in the face of a dire lack of financial resources (Fortes, 1989). The much needed but least felt 'political will' to support the new movement of coastal environmental protection is locked in the traditional bureaucracy and political elite in the region. This determines the role seagrass resources management plays in more open decision-making procedures. Overall the seagrass ecosystems are continually being degraded at a rapid rate, raising serious doubt about their sustainability in the coming generation. Unfortunately, mitigative efforts being undertaken by the government and private sectors are insufficient, ineffective and largely socially unacceptable.

Consequences of Seagrass Loss

The results of the seagrass study under the ASEAN-Australia Living Coastal Resources Project (LCR), complemented by local initiatives, have shown that in the last ten years, a 20-60% decrease in the area of seagrass beds in ASEAN has occurred. While recolonization in some of these areas may be possible in 5-15 years, the immediate loss in economic benefits to coastal dwellers and in natural biodiversity the ecosystem supports may not be recoverable within the same period. Put simply, if the seagrass environment is not protected, the basic cycles (food, water and air) and alternative uses of the resources upon which a great majority of coastal inhabitants and their socioeconomic development are largely dependent would be placed in jeopardy. There are indeed few reasons for optimism in efforts to protect the region's seagrass resources. There are, however, enough reasons for all concerned to act -NOW!

Seagrasses often experience mass mortality and substantial reductions in the extension of their meadows which has far-reaching consequences in the ecosystem. The ecological functions associated with the ecosystem that may be lost due to habitat destruction or degradation include: shelter for ecologically and economically important species; food production or concentration; and critical nursery or spawning habitat. Many species or life stages of species have specific habitat requirements, and when available habitat is degraded or destroyed, the carrying capacity of the ecosystem for those stocks may be reduced (Jones, 1988). The epibenthic communities that colonize seagrass substrate also provide forage and can actively concentrate planktonic food resources and produce microhabitat suitable for any other food species, particularly crustaceans. The ecosystems also alter water circulation patterns and cause mixing. Turbulence can concentrate plankton and detritus, creating a source of food for both benthic and nektonic species. In East Asia, these ecological functions are seriously imperiled by stresses which put to serious doubt the recovery and biological sustainability of the habitat in this generation (Fortes, 1988b). In the Mediterranean, the regression of Posidonia oceanica beds caused a quantitative decline throughout the trophic chains and the physical transformation of some sedimentary substrata which resulted in alterations of biocoenosis composition and equilibrium (Bellan-Santini & Picard, 1984).

Seagrass Recovery Mechanisms

Forecasting seagrass colonization is important to predict ecosystem recovery. There is, however, a remarkable paucity of quantitative data on the rate of seagrass recovery which prevents the development of models to forecast this process. Although seagrasses can take up rapidly inorganic nutrients from the overlying water (Short et al., 1989), nutrient enrichments beyond their assimilative capacity can promote epiphytic algal growth adverse to their growth and production. In addition, the ability of seagrass to trap and bind suspended particulate matter is limited in silty environments. Under low to moderate nutrient loading conditions, seagrass can effectively filter large amounts of nitrogen and phosphorus from the water column (Short & Short, 1984). It is only when excessive amounts of nutrients have been added to the water that seagrass systems are unable to remove nitrogen and phosphorus from the water column sufficiently fast to outcompete nuisance algae. Macrophytes can also limit the epiphytic stands by excreting antibiotics or by keeping a high replacement rate of photosynthetic tissues (Sand-Jensen, 1977).

Seagrass recovery from physical disturbance and catastrophic decline involves the colonization by propagules and the overgrowth of bare substratum through rhizome expansion (Duarte & Sand-Jensen, 1990). Rhizome growth is supported by reallocation of photosynthetic products and must therefore be closely coupled to the development of leaf-bearing shoots. Furthermore, biotic communities associated with seagrasses often use their leaves as substratum or refuge, and their recovery relies, therefore, on the development of above-ground material. Thus knowledge of the coupling between rhizome growth and shoot development is important for forecasting the recovery of seagrasses and their associated biota.

In Calancan Bay, appearance and rapid expansion of beds of the pioneer genera Halophila and Halodule initiated the course of recolonization by seagrasses after devastation caused by the dumping of copper mine tailings since the mid-70's. Halodule uninervis colonized quickly on thin or thick sediments, but only to be outcompeted by Cymodocea serrulata five years after disturbance (Fortes, 1994b). C. serrulata was quick to colonize thicker sediments but was soon outcompeted by the green seaweeds Halimeda spp., Caulerpa spp. and Avrainvillea sp. With slight temporal and species variations, a similar pattern of seagrass colonization was documented by Birch & Birch (1984) after a devastation caused by cyclones in Cockle Bay, Queensland.

Maintenance of seagrass community over the colonized substratum requires that shoot senescence be balanced by shoot recruitment. This was demonstrated at the southeastern part of the causeway in Calancan Bay, where littoral mass of sediments was highly mobile, subject to the intensity of monsoonal water current.

Here, successful colonization by patches of H. uninervis was initially characterized by production of short shoots in annual cohorts, followed by the increase with time of mean shoot age, variability in shoot age structure, and length and number of standing leaves. Duarte & Sand-Jensen (1990) made parallel observations in the case of colonization by Cymodocea nodosa in similar highly mobile sediment conditions. In both cases, the patches were maintained by a balance between shoot recruitment and mortality rates, suggesting the importance of both parameters for growth maintenance in H. uninervis and C. nodosa patches and hence, for seagrass recovery.

In Calauag Bay, the seagrass beds exhibited a major shift in their growth-expansion potentials. From the east, recruitment rates were consistently higher than mortality rates (MSI/EPAI, 1993). On the other hand, from south to west, the rates were reversed. This trend is an indication of the status of the beds, where those at the eastern section were experiencing massive expansion while those at the west were experiencing a decline. This finding is consistent with the observation that the eastern part of the Bay is subjected to conditions comparatively more favorable for the growth of seagrasses. The western section, on the other hand, is highly subject to the impacts of natural elements, in addition to the disturbance wrought by both natural and man-induced stresses especially nearest the town of Calauag. Along the coasts from the northeast down and up to the northwest, the expansive potentials of the grass beds gradually decreased, implying the increasing influence of negative factors like the presence of mangroves in the east and southeast, the anthropogenic disturbance at the south and southwest, and the influence of waves and substrate at the northwest.

Solutions to the problems of seagrass loss along East Asian coasts are practically at hand. The task is to identify and rank the severity of these problems and investigate ways of dealing with and reducing these types of environmental impacts to the level where long-term success of seagrass communities is assured. Some recommendations for achieving healthy seagrass habitats and encouraging a recovery of their associated marine life and improving water quality over the long term include: improving waste water treatment; controlling surface run-off; regulating boat traffic; restoring seagrass beds; restricting fish, shellfish, seaweed harvest with the provision of alternative livelihood source, and enforcing pertinent regulations against unsustainable coastal practices as blast fishing, and the use of fine-mesh nets. The rapid biological recovery of Singapore River (Khin & Chou, 1990) and of an estuary in Connecticut (French et al., 1989) partly demonstrate that the potential for recovery of coastal ecosystems is great but only after significant reduction of nutrient loading and impacts of physical disturbances, coupled with the concerted effort and determination of the populace.

MANAGEMENT ASPECTS OF SEAGRASS ECOSYSTEMS

In Southeast Asia, 60% of its population (more than 200 million people) now live close to the shore (Chua, 1991). It is also projected that this population will double within the next 25 to 35 years with their increasing direct or indirect economic dependence on the coastal zone. It is thus inevitable that East Asia would face the problem of how to maintain and improve the integrity of its coastal resource base for sustainable use. The last two decades have seen a rapid increase in human development pressure on the shallow coastal resources of the region. This resulted largely from the increasing industrial and commercial development of the region's shorelines, coupled with the multifaceted demands of the population for food, transportation, waste disposal, living space, recreation and aesthetic pleasure. Unfortunately, most of these signs of man's dependence on coastal resources are not compatible, and in many cases, are mutually exclusive (Ferguson et al., 1980).

In many parts of the region, there is severe prevailing pressure on seagrass beds, mainly as sites for industrial development, avenues for transportation, for homesteads, and as dumping sites for wastes (Fortes, 1988b). These disturbances are exacerbated by mining of industrial minerals, drilling for and production of oil, massive deforestation and pollution. Yong (1989) and the Policy Workshop on Coastal Area Management held 25-27 October 1988 in Johore Bahru (Malaysia) emphasized the need for governments in the region to realize and take positive steps in addressing the following issues which are causing widespread alteration in coastal habitats of Southeast Asia: severe marine environmental degradation; heavy exploitation of coastal resources; lack of public appreciation of management efforts; lack of management capabilities; most people living in poverty; inadequate institutional support; and poor law enforcement.

Seagrass Ecosystems as Resources

Considering the benefits derived from the natural functions and resources of seagrass ecosystems, their management is justified. But in East Asia where most of the countries need to develop, living and non-living coastal resources remain an object to exploit, often on an unsustainable basis, in the long-term causing the loss of the habitats. As with their natural functions, the elimination functions of seagrass habitats strongly justify why they should be managed. These functions are given in Table 5.

From the data, two things are obvious: first, in these countries, the common and primary use of the coastal zone (seagrass areas) is associated with fish production, industrialization and urban development; second, information is yet inadequate in many important aspects. This set of data alone strongly justifies purposeful management of the region's coastal zone. Management of fishing practices in seagrass beds has resulted in sustained fishery harvest in Australia. Staples et al. (1985) found that postlarvae of Penaeus esculentus and P. semisulcatus, two of the three most important commercial species of prawn in the continent, settle exclusively in seagrass beds. The identification of these nursery grounds has led to the permanent ban on trawling in these areas of seagrasses. The total prawn industry of Australia earns the country's economy A$60 million annually (Coles, 1986).

Value of the Resources

A root cause of seagrass habitat loss stems from the failure of the present economic policies to value its components and the interactions among them. In most East Asian countries, conversion of seagrass beds to create seaweed farms, or to build access roads, fish ports, and other industrial facilities happen for two reasons: to meet the need for increased food production or hard currency, regardless of whether that production is sustainable or not; and because seagrass systems as the other natural systems are often undervalued.

Table 5. Elimination functions of seagrass habitats in coastal East Asia (modified from Fortes, 1989).

	Indo	Mala	Phil	Sing	Thai
Aquaculture					
fish	L3	L2	L3	X	L2
crabs	X	X	L1	X	L1
prawns	L2	X	L2	X	LW
Ricefields	X	X	X	X	X
Sugarcane	X	X	L1	X	X
Palm plantation	X	X	X	X	X
Other agriculture	X	X	X	X	X
Pasture	X	X	X	X	X
Solar salt	L1	X	L2	X	X
Industrial development	L2	L2	W3	W3	W3
Urban development	L2	W2	L3	W3	L3
Ports	X	X	W3	W3	L1
Airports	X	X	L1	L3	L1
Recreation	X	W	W3	W2	L3
Mining	X	L1	L3	X	L2
Waste disposal	X	W	W2	X	X
Flood run-off engineering	X	L1	L2	X	X
Boat traffic	L	X	W2	W2	L1

L, use is localized — 1, a minor use
W, use is widespread — 2, a moderate use
X, information inadequate — 3, a major use

Attempts to give monetary values to goods and services from seagrass beds have been made. The values were estimated based primarily on the fisheries the beds support. Thus, at Cairns, North Queensland, fisheries supported by seagrass beds produce about A$700,000 annually (Coles l986). More recently, Watson et al., (1993) estimated that the potential total annual yield from Cairns Harbor seagrasses for the three major commercial prawn species were 178 tons/year with a landed value of A$1.2 million/year. In Puget Sound, Washington, a 0.4 hectare of eelgrass bed was valued at US$12,325 annually. The value considered the amount of energy derived from the system as well as the nutrition it generated for oyster culture (Helfferich & McRoy, 1978), commercial and sport fisheries, as well as sport charters and waterfowl. Under conditions found in the East Asian region, revenues derived from seagrass fisheries alone could be substantial. If calculations are even only partially correct, and if applied to local seagrass resources, the economic value of seagrass beds would be considerably higher (Fortes, 1989).

Today we are stuck with the notion introduced by Giarini (1980) that in economic planning and decision making, it is an 'objective yardstick' to measure in monetary terms all factors that contribute to economic development. In the process, however, we should realize that we face the dilemma of pricing the priceless, of quantifying the unquantifiable, of creating common standards for things apparently unequatable (de Groot, 1992). Fonseca (personal communication) argued that trying to determine the monetary value of an obviously rich and biologically diverse resource as a seagrass ecosystem may be a waste of time, for this will only further delay its development. But until better instruments and methodologies are found, giving money values to ecosystem functions (where possible) may help convince decision makers and financiers of development projects of the importance of nature conservation and the true meaning of environmentally sustainable economic development. In the valuation process, however, ecologists should be involved more actively with the view that the whole exercise is purely for the purpose of management. This is because if they are not, others who are less informed of the true worth of the environment eventually will -and attach to it a much lower price. The low values attached to coastal resources are the principal reason for their continued destruction and degradation.

Available literature on seagrass valuation is extremely scarce. This is due to two factors: (1) many products and services of the ecosystem are not completely valued in current market prices; and (2) the production of some of these products and services occur beyond the seagrass ecosystem itself. Ideally, economic valuation of seagrasses should include both on- and off-site as well as marketed and non-marketed goods and services. However, the few valuation efforts concentrated mainly on estimating some on-site, marketed seagrass goods and services. The undervaluation of on-site seagrass uses arises partly from underestimation of products gathered for home consumption such as fishes, crustaceans and other invertebrates. Some environmental functions (e. g. some regulation functions) are of such a scale and nature that the contribution of a given component to such a function is practically impossible to quantify. This fact makes it difficult to give monetary value to these functions. Yet the cumulative contribution of individual components is essential for the maintenance of these functions, for example, the loss of genetic diversity or the changes in the chemical composition of the atmosphere are the result of the cumulative effect of many small-scale land use decisions (de Groot, 1992). Planners and decision makers should be aware of the existence of these 'unquantifiable' regulation functions. In addition, while it has been relatively easy to assign the monetary value of the damage to life and property catastrophes like typhoons and tsunamis cause along East Asian coasts, the value of the loss and disturbance of coastal landform, ecosystems, and their components have not been easy to acquire due primarily to incomplete awareness on the part of authorities and the poor state of knowledge on valuation techniques.

In order to achieve the objectives of seagrass resource valuation in East Asia, the following components should be valuated: (a) ecosystem products and services component; (b) fisheries and services component; and (c) economic valuation and optimization component. The first component aims to quantify the organic productivity and ecological role of the ecosystem as nursery and feeding grounds of economically important fish and invertebrates. The second component, similarly technical in approach, aims to investigate fisheries production and the services it provides. These two components shall be used as basis for the economic valuation and optimization component.

The motivation for seagrass resource valuation stems from three policy issues (PIDS, 1994): (1) the need to determine optimal use of a seagrass area, e. g. whether a site is best maintained as a seagrass bed or as a converted area, such as for seaweed culture, settlement, etc.; (2) the formulation of proper access and pricing schemes for various current uses that would eventually lead to the optimal pattern of use (e. g. mariculture license fees for government leased areas and the assignment of rights and responsibilities to various seagrass bed users; and (3) investment decisions on degraded seagrass areas specifically in the form of restoration effort. To address these issues, it is proposed that the following be estimated: (1) the direct cost of utilization, which are the usual payments to factors of production, except for the unpaid 'free gifts of nature'; (2) the user costs, which are pertinent to intertemporal relationships for those resources whose extraction bear on the availability of resources for the next generation; and (3) the environmental costs which arise from the relationships within the seagrass ecosystem itself. Various costs and benefits of alternative management options of seagrass areas shall thus be assessed through cost-benefit analysis based on sound economic principles for natural resource allocation.

Conversion from seagrass beds to other uses should occur only when the marginal net social benefits is greater than zero. Alternatively, a converted seagrass bed should be reconverted back to seagrass habitat if the present value of marginal net benefits (after accounting for costs such as restoration expenditures) is non-negative. Clearly, operationalizing these decisions implies deriving the shadow prices for the various goods and services that are produced in the current use schemes of seagrass areas. Thus the process of examining the operational aspects of the resource use location principles means simultaneous determination of the ecological pricing scheme for various seagrass ecosystems.

In terms of policy significance of resource valuation, once the net benefits are already estimated, then the value of degradation may be inferred from the differences in the profitability. The cost of depletion may be inferred from the cost of shifting from one seagrass bed use to another or from the value of foregone earnings. Implicitly, the trend of the past resource utilization must be analyzed so that resource use in the future can be projected.

Another potentially significant economic output of seagrass beds is its indirect contribution to fish production. Here, the value of seagrass beds as nursery and spawning sites needs to be scrutinized. In cases where the seagrass area is a source of fry of some species, loss of this source, previously costed at zero, implies obtaining the same product from an alternative source (such as a distant market) at a positive cost. In a similar case where certain fish species use the seagrass area at some early stage of its life cycle, valuation implies looking at the fish value when it is most dependent on such ecosystem. Using the value of mature fish, or at its harvest, tends to overestimate the seagrasses' contribution since other factors, such the other components of the foods chain, are important and fish are quite mobile.

Clearly, incorporating the offsite effects and environmental costs of various management options of seagrass ecosystems requires the application of various valuation methods. There is no one prescribed way of valuation. The choice depends on the data available that could reflect technological relationships within the ecosystem and between the seagrass ecosystem and other ecosystems, on the willingness and ability of users to respond to level-of-use surveys, questions on their 'willingness to pay' or 'willingness to accept compensation' queries (PIDS, 1994).

Management of Seagrass Resources

Quantitative data that justify management of East Asian seagrass systems are few. These focused mainly on numerical relationships of certain components, the observed effects of perturbations, patterns of use of their resources, and their potential to rehabilitate degraded coasts and help coastal economies. The high percentage of species overlap in the seagrass floras of the countries in the region and the comparable values obtained on their biomass and productivity imply the prevalence of equally similar patterns of local climate and coastal conditions (Fortes, 1992a,b). In addition, the similarity in the impacts to which the resources are subjected suggests similar patterns and strategies for regional protection and utilization of the resource. On the other hand, the high diversity and abundance of seagrass habitats and their resources in East Asia make them highly vulnerable and susceptible to both man-induced and natural perturbations (Fortes, 1991). While a growing awareness on the fundamental ecological and economic potential of seagrass ecosystems has very recently occurred, there are indications that natural recovery of a significant percentage of the habitats in the region is improbable within this generation.

If one considers the fundamental functions of seagrass ecosystems and their potential role in coastal environmental and socioeconomic well-being of coastal populations, it becomes imperative to use the resource on a sustainable basis. Hence, integrated coastal zone management should be the goal. The strategies to attain this goal include: establishing national plans; fostering cooperation; implementation of policies for sustainable uses; expanding the resources; legislation and administration; and adherence to certain appropriate recommendations.

Establishing National Plans

Out of an awareness to protect and preserve biological diversity and to maintain ecological balance, national governments in the region are currently actively implementing means to conserve and integrate management of marine resources. However, the process of committing resources to address coastal zone issues has been slower than desirable, due to the higher priority given to terrestrial rather than marine concerns (Gomez, 1988). Consequently, enforcement of environmental policies are rendered ineffective. These facts have led to skepticism on the bureaucracy on the part of the people, with the subsequent erosion of public participation in information exchange among scientists, environmental planners and resource managers (Fortes, 1989).

Among the countries of East Asia, only the Philippines has formulated (but not implemented) a National Seagrass Management Program and proposed the creation of a Philippine National Seagrass Committee. The Program is envisioned to consist of five major components, namely: resource mapping and survey; research and development; information dissemination, education, training and publication; environmental management; and policy and legislation. More recently, seagrass transplantation and artificial seagrass systems are experimentally being used to rehabilitate some degraded coastal areas in the country. In Calancan Bay, a copper mining company was allowed to continue operations, with the submission of a rehabilitation plan which includes seagrass transplantation and artificial seagrass systems as a precondition. The relative success of the technique in the enhancement of local biodiversity and providing effective plant cover of an otherwise biologically desolate shallow zones has been a strong argument for their use in the rehabilitation of similar areas -a major goal of the Philippine Strategy for Sustainable Development. In addition, the techniques have become a part of the mitigation measures in the assessment of the environmental impacts of major industrial and energy projects near coastal areas. The comprehensive Coastal Environment Program (CEP) of the Department of Environment and Natural Resources (DENR) has incorporated a training component which focuses on the importance and use of seagrass systems in the sustainable use and protection of coastal areas. Pauly & Chua (1988) proposed, among others, the replanting of seagrasses as a necessary complement to any fishery management or pollution-control scheme in Southeast Asia.

In its effort to protect coastal environments, Indonesia has incorporated legal policies that pertain to the protection of seagrass resources. In Singapore, on the other hand, a realization of the critical role of seagrasses in the protection and maintenance of coral reef productivity in the island of Semakau helped convinced policy makers to protect the island (Chou, 1992). In Thailand, the government has granted the Phuket Marine Station a sizable amount of money primarily to protect its reef resources which includes seagrasses, while training courses in coastal zone management at the Prince of Songhkla University in Hat Yai, is regularly being conducted to address coastal environmental concerns. These steps are aimed at optimizing the use and conservation of seagrass systems. In all countries of East Asia, seagrass systems when present are now incorporated in plans to manage marine protected areas.

Fostering Cooperation

In response to the deterioration of the coastal areas and the need to manage their resources, countries of East Asia embarked on collaborative programs not only internally but with other countries in the spirit of cooperation and mutual benefit. These collaborations are too many to mention here, so that only those few which have direct implications to the management of seagrass habitats and resources will be considered. Hence, the countries in the region joined the ASEAN-Australia Economic Cooperation Programs which aimed at developing expertise in the region's marine science and establish closer linkages among the countries. Seagrass ecosystems in ASEAN were a focal point in the study. Similarly, a collaborative effort funded by the European Union (EU) that investigated the latitudinal variations in the phenology and survival mechanisms in seagrasses attempts to use the results in the assessment of coastal environmental impacts in the region. In November 1994, another EU-funded project was implemented to study the responses of coastal ecosystems (seagrass, coral reefs and mangroves) to deforestation-derived siltation.

In its fourth year at present, a graduate program (PhD and MSc) that focuses on the responses of local seagrasses to anthropogenic perturbations is being funded by the Dutch Government under the Cooperation in Environmental Ecotechnology for Developing Countries (CEEDC). Similarly, the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) has recently approved a graduate training program to investigate the functioning of Southeast Asian seagrass species under deteriorating light conditions. This project is being carried out as a part of the programme 'Structure and Function of Seagrass Ecosystems in Southeast Asia in the Framework of Coastal Zone Research and Management'. It is a multidisciplinary, international programme which is currently being set up to provide fundamental and strategic scientific information required for sustainable management schemes of Southeast Asian coastal zones. In a bold and significant move, the United Nations Environment Programme (UNEP), through its Regional Coordination Unit/East Asian Seas Action Plan, has recently embarked on a regional project in Asia-Pacific that aims to assess the effects of river discharges of sediment, nutrient and pollutants on seagrass beds, wetlands, and coral reefs. Countries in the East Asian Seas joined the ASEAN-US Cooperative Program on Marine Sciences: Coastal Resources Management Project (CRMP) in an effort to formulate integrated Coastal Resources Management plans. Included within each country pilot site are a variety of coastal resources commonly represented by seagrass beds, mangroves, coral reefs, small islands, inshore and offshore fisheries, coastal landform, minerals, etc. (Chua & Agulto, 1987).

Local experience in regional or international collaborative endeavors show that in many cases, funding agencies have compounded, instead of alleviating or solving, the problems of coastal zone management. This is due in large part to their concentration of resources to strengthening specific sectors disregarding externalities (Norse, 1993). Two positive advancements in this regard which partly rectify their contribution to the current situation are: fielding more qualified ecological economists and conservation biologists in traditional economics, engineering, and technology; and undertaking Integrated Coastal Zone Management (ICZM).

Implementation of Policies

An alternative to dealing with problems ad hoc, ICZM is aimed at the sustainable use of resources. This is through the implementation of a coherent set of management policies that cover most major habitats and use of various but coordinated approaches. For Southeast Asia, Table 6 shows the varied types of habitats included in marine protected area management, with the specific strategy adapted for each.

In the Pacific Northwest, natural scientists have investigated seagrass ecosystems since the mid-1960's. Their results, coupled with research from other regions, led to the formulation of seagrass management policies. These policies are being implemented to address human activity that might impact seagrasses (Wyllie-Echeverria et al., 1994).

Expanding the Resource

Unfortunately, most of the efforts towards environmental protection have focused not on ways to improve development actions and ecological resilience, but on curative or remedial actions. But considering the enormous constraints in resources and the limitation of time most countries in the region face, even these curative or remedial actions may be justifiably and significantly helpful in environmental protection. There is an urgent need for a concerted effort and pragmatic actions to mitigate the expected impacts from environmentally degrading developmental activities and consequently expand the resource. The impacts of the long-term recovery on the value that society places on seagrass beds (e. g. coastal stabilization, water column filtering, and fishery habitat) are completely unevaluated. Yet, given the rate of coastal development and loss of seagrass beds, attention must be given to some remedial measure. Hence, these experiences call for Habitat Rehabilitation and Restoration, applying the most benign, environmentally friendly,

Table 6. Major habitat types earmarked for protection in Southeast Asia. The management strategies are also included (After White, 1989)

Habitats protected	B	I	M	P	S	T
beaches				x	x	x
coral reefs	x		x	x	x	x
endangered wildlife	x					x
estuaries	x	x	x			x
islands	x		x	x	x	x
mangroves	x	x	x			x
seagrasses			x	x	x	
Type of management						
community-based			x	x		x
mooring buoys/signs	x		x	x	x	x
municipal park			x			
national park	x	x	x		x	x
zonation schemes	x	x	x	x		x

B, Brunei Darussalam; I, Indonesia; M, Malaysia;
P, Philippines; S, Singapore; T, Thailand;

technically sound, and cost-effective means in attaining its goal of replacing systems which had been destroyed or degraded and to provide for limited specific uses such as aesthetic or amenity purposes. When properly designed, restoration can expand the resource and contribute significantly to the replacement of lost or degraded ecosystem functions and can have a high degree of social acceptability.

One of the techniques currently used in mitigating coastal environmental impacts and expanding the areal extent of seagrass resources, at the same time restoring the biodiversity and productivity of degraded coasts, is the use of seagrass restoration 'technology'. This makes use of seagrass transplantation and artificial seagrass units. Usually a 'last option', it involves the alteration of the structure of the ecosystem by applying ecological principles to redirect natural self-organizing biological processes.

Seagrass Transplantation and Restoration - Over the past ten years methods and techniques for seagrass bed transplantation and restoration have been developed (Fonseca et al., 1982). Interest in restoration and the number of successful restoration projects especially on land and freshwater habitats are growing as more people understand its significance in maintaining the ecological balance and enhancing habitat value. In the case of seagrass beds, however, there have been no complete restoration successes (Kirkman, 1992). But studies have shown that within one year of transplantation, transplanted seagrass can effectively speed up the cleanup process and more quickly return the environment to a healthy productive ecosystem.

Few attempts were made to improve coastal conditions using seagrass transplantation in East Asia. In Thailand the only recorded study on seagrass transplantation was done by Sudara et al. (1992b). The results show that the seagrasses Halodule pinifolia and Enhalus acoroides had low growth rates when transplanted into different types of substrata. In Indonesia, the technique was tried in Pulau Pari, Seribu (Azkab, 1988c) using T. hemprichii.

An intensive study on the rehabilitation potential of seagrass transplantation in the region was undertaken in the Philippines. In Cape Bolinao, Fortes (1984) demonstrated the ability of seagrasses to colonize a biologically desolate area and improve plant biomass. In Calancan Bay, an area of about 0.01 km^2 around the mine tailings causeway has been transplanted with seagrasses. After five years, the study showed that there were no significant differences when the growth performance of naturally growing and transplanted materials of the same seagrass species was compared (Fortes, 1994b). The only observable (but statistically insignificant) difference was the slightly lower summer rates for the transplanted materials. In naturally growing E. acoroides, peak shoot growth rates (7.3-8.4 cm/d) occurred during the warm-wet months of September-October (Fig. 7a,c). Their subsidiary peaks (6.4-7.2 cm/d) occurred in summer (May), while their lowest rates (3.7-3.8 cm/d) were recorded during the cool-dry months of January-February. In the transplants, the mean peak (8 cm/d), secondary (5.7 cm/d) and lowest (2.8 cm/d) rates similarly occurred during the same periods as in the naturally growing materials of the species (Fig. 7b).

In C. serrulata, however, a slight temporal variation in growth performance between naturally growing and transplanted materials occurred. While peak and lowest growth rates under both conditions were observed during similar periods as in E. acoroides), subsidiary peaks were not pronounced, except in naturally growing plants where these were recorded in April (Fig. 8a,c). In the transplants, growth response was unimodal with peaks (1.5 cm/d) occurring in August-September with the lowest rates (0.8 and 0.9 cm/d) occurring in January-February (Fig. 8b). The pattern of growth of the shoots in both E. acoroides and C. serrulata is highly positively correlated with the pattern of water temperature recorded for the area during the period (R^2 = 0.851-0.914, $p<0.0001$, n=16).

In 1989 and with slight variations in species growth rates, the transplanted sprigs of C. serrulata and Halodule uninervis and plugs of E. acoroides showed remarkable growth in all four directions to cover 98% of the gaps (bare patches) on the substratum. In the following year, the plants coalesced to attain the original biomass and productivity levels and no portions of the substratum were left bare. There was on average an annual bed expansion of 32%. The results indicate that even on copper mine tailings, the seagrasses could grow fast and probably regain their lost ecological functions. One of the latter was shown by the general increase with time of the number of fish associated with the structures (from 2-17 in 1989 to 22-34 in 1990). The number of fish caught in the transplanted areas represents 33.3% of the total number of fish species recorded from the same western portion of the causeway.

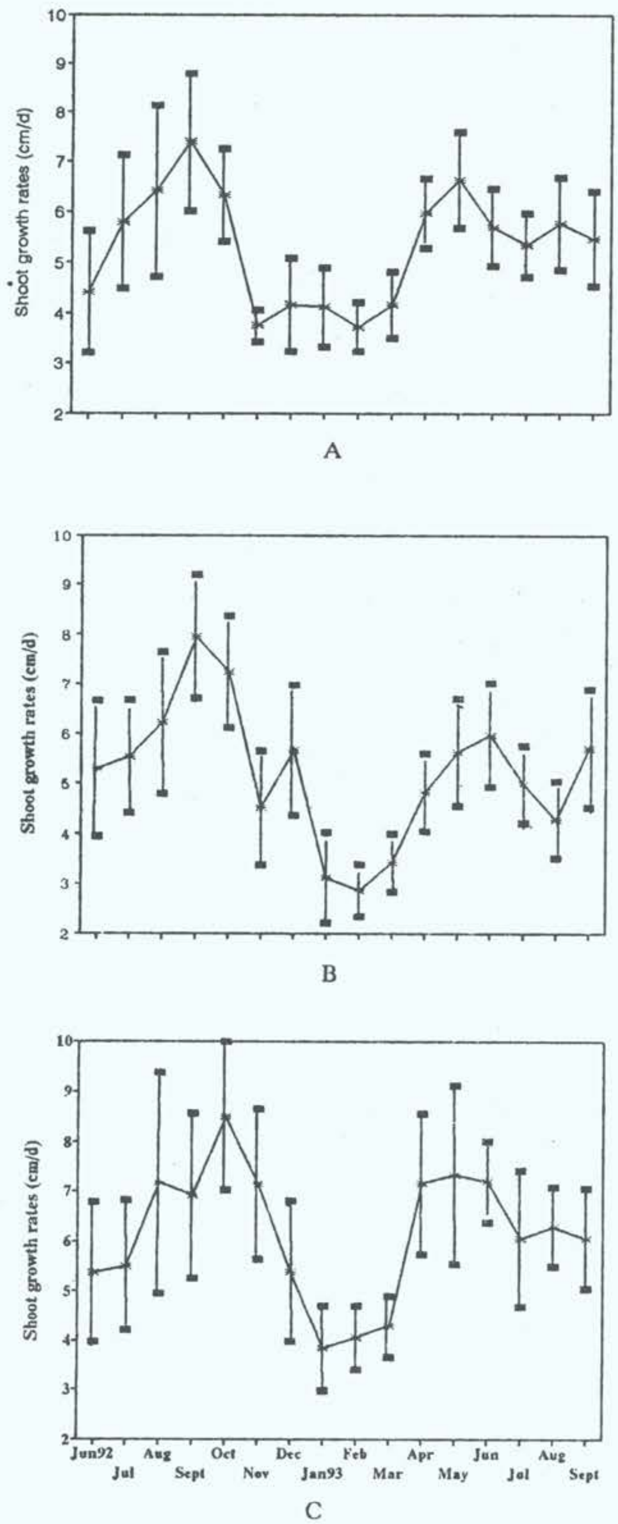


Fig. 7. Shoot growth rates of <u>Enhalus</u> <u>acoroides</u> in Calancan Bay, Philippines. A, from a natural bed at Station 1; B, transplanted bed at Station 2; C, natural bed at Station 3. Error bars are also shown; n=10-16.

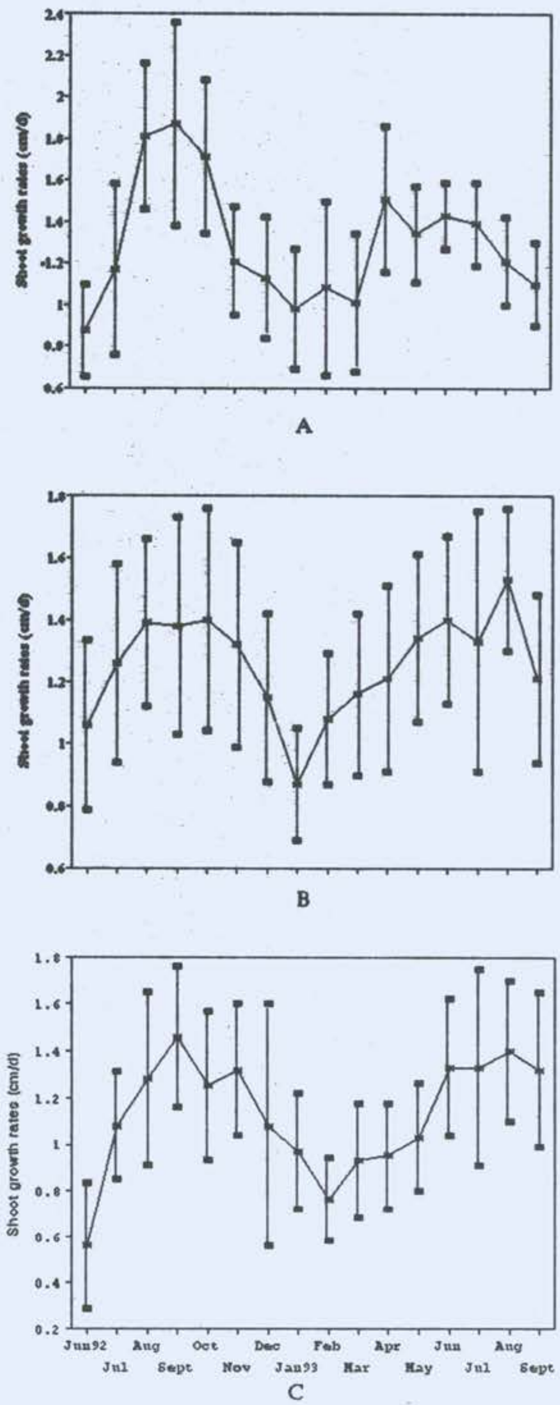


Fig. 8. Shoot growth rates of <u>Cymodocea</u> <u>serrulata</u> in Calancan Bay, Philippines. A, from a natural bed at Station 1; B, transplanted bed at Station 2; C, natural bed at Station 3. Error bars are also shown; n=10-16.

Many attempts have been made to establish seagrass populations by planting vegetatiye shoots or seeds, but most have met only limited success because of improper selection of site and transplant materials (Harrison, 1991). Careful selection of the transplant site is of paramount importance; if the conditions of sediment stability, light and nutrients are not favorable, the plants will not grow; if the conditions are favorable, then transplanting may speed the natural and slow process of colonization. Unfortunately, until seagrasses are better understood, it will not be possible to define the precise conditions that favor particular seagrass species.

The plants to be transplanted must be chosen carefully because local populations may have limited abilities to adapt to variations in the environment. There is also the need for more standardization in the measurement of 'success' in the transplanting procedure.

Artificial Seagrasses - With limited success, attempts have been made to use artificial seagrass units (ASU) to investigate and monitor the recruitment patterns, change in the diversity of fish communities, and study their potential to improve biomass production in degraded coastal areas in East Asia. Hence, in Singapore, Lee & Low (1991) demonstrated that the technique could effectively enhance fish and shrimp fauna within three months of its implantation in Singapore River. The structures were found to be good niches for stocked seabass (Lates calcarifer). In the Philippines, the technique was used to improve the biodiversity and productivity of a biologically desolate area in Cape Bolinao (Fortes, 1984) and mitigate the impacts of mine tailings in Calancan Bay (Fortes, 1994b). At the cape, the number of fishes so far identified within the ASU's (Fig. 9) significantly exceeded that found in natural seagrass beds in the area (Salita-Espinosa & Fortes, 1992). 62% of the species are new to the specific study station, with only 15.4% similarity or species overlap with the fish fauna of an adjacent seagrass bed. These results suggest active fish recruitment by the units, implicating the potential of ASU's as effective fish recruiting devices, useful as a supplement to improve and rehabilitate otherwise desolate areas.

In Calancan Bay the 1,000 m^2 area 'planted' with artificial seagrasses has shown that the technique works in at least attracting a significant percentage of the natural fish fauna in the bay. They have demonstrated relative success in resisting decay and fouling despite the massive colonization by plant epibionts of the overhanging structures. The number of fish species found at the areas with the artificial seagrasses comprised 46.2% of the fauna recorded at the nearby seagrass bed and 86% of that found in the transplanted seagrass areas.

In a related study, alterations in the size and density of artificial macrophytes have shown varying degrees of response from the colonizing biota. Amphipods did not differentiate among bottle brushes with different surface area to volume ratios (Russo, 1987) and fish larvae settled indiscriminately on any surface (Bell et al., 1987). On the other hand, some invertebrates discriminated among natural macrophytes of different shapes (Nicotri, 1980; Edgar, 1983). Many species colonize artificial substrata before any periphyton is available, signifying a primary response to shape rather than food (Hall & Bell, 1988). In addition the results show that both epiphyte cover and macrophyte shape were important but responses were highly species-specific (Schneider & Mann, 1991b). Predation by a small fish, Fundulus, and the crab, Neopanope, on a variety of invertebrates was not significantly affected by the presence or absence of artificial macrophytes. It was

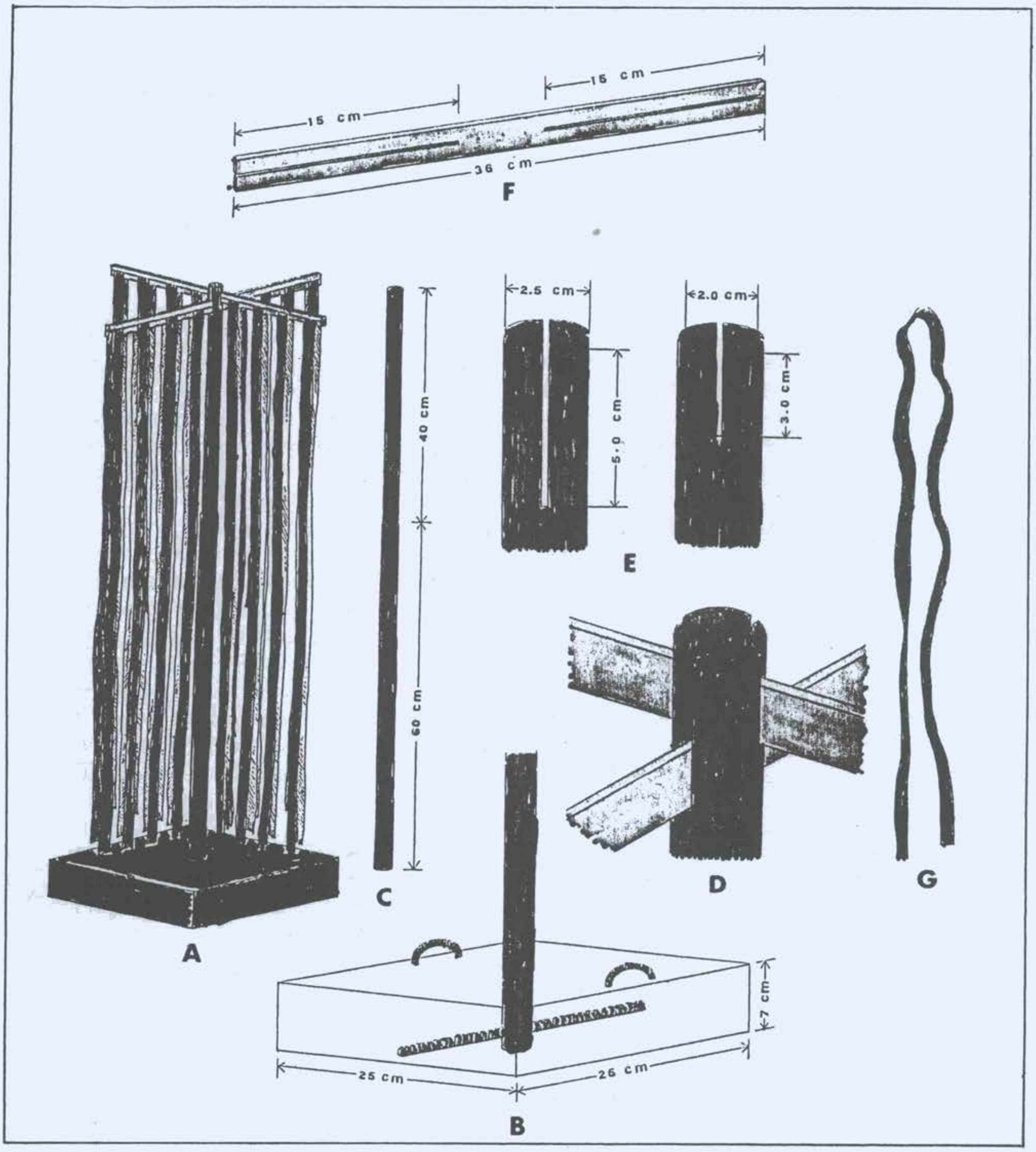


Fig. 9. An artificial seagrass unit (ASU, Type ENH, A) and its parts: B, cement base; C, PVC pipe, two sizes; D, top of PVC pipe showing slits and hangers; E, pipe slits; F, plastic hanger; G, plastic mantle strip.

therefore concluded that while epiphyte cover is an important factor for some species, the influence of shape does not operate primarily through differential predation mortality.

Legislation and Administration

In the region, White (1989) mentioned country-specific policies and conservation plans aimed towards this goal. Hence, Brunei is developing plans for management of its offshore and inshore fisheries, water quality in Brunei Bay, oil spill contingency, mangrove and coastal forest, coral reefs, coastal beach erosion, and red tide occurrences; Indonesia chose the Cilacap-Segara Anakan Lagoon on the south coast of Java, an extensive lagoon which serves as a nursery area for an offshore shrimp fishery, as the pilot area; Malaysia chose most of the coastlines of the states of Johore and its offshore islands where extensive mangrove-estuarine habitats, coastal agricultural lowlands, beaches, small coral reef islands, and sites being developed as port and industrial areas abound. The goal of the plan is management of mangrove habitat, water quality maintenance, aquaculture, coastal erosion control, inshore fisheries, sand mining, and tourism; the Philippines selected the whole of Lingayen Gulf in the northwestern part of the country where coral reefs and offshore fisheries, seagrass beds, small islands, beaches, rivers, estuarine systems useful for aquaculture abound; Singapore's primary concern is ocean space for shipping, small islands, coral reefs, remnants of coastal forests, the Singapore River and coastal land for ports, industry, recreation, and housing. In the midst of these programs, however, there is a dismal lack of management policies and conservation programs that utilize substantial scientific knowledge on coastal ecosystems in the East Asian region.

One legislation that has a great potential use in management of coastal resources is the Environmental Impact Assessment (EIA). In recent years, it has evolved from a mere regulatory mechanism of government to become a useful management tool. In undertaking the EIA required in major developmental activities, however, its adoption as a planning tool is influenced largely by pressure from the funding agencies. This pressure is manifested in at least two ways: review of environmental impact reports to ensure that projects receiving development assistance do not cause undesirable environmental effects; and support, by way of funds and technical assistance, for environmental protection policies and environmental enhancement programs in recipient countries. In addition, it is the responsibility of funding agencies to ensure that the environmental and sociocultural imperatives are not compromised in the process.

Recommendations

Some recommendations may be made for the sustained use and development of the seagrass habitats and their resources. These include the following: database development; development of national plans; creating awareness and research promotion, sustainable management; conservation of biodiveristy; and education and training.

Database development is a well recognized need in as far as coastal zone management in East Asia is concerned. A regional study under the ASEAN-Australia Economic Cooperation Program (Marine Science) Living Coastal Resources Project (Phase 1) was implemented with three objectives. One of these objectives was to provide a database for coastal and continental shelf ecosystems (with emphasis on mangroves, coral reefs and soft bottom communities including seagrasses). The results of the project is now the largest database of such nature in the world. For it to be useful, however, it has to be translated into a language that is easily understandable by the direct beneficiaries of the resources.

Development of national plans includes incorporation of a holistic approach in planning for both scientific research and for environmentally related decisions. In a number of local initiatives addressing management of the coastal zone, the contracting parties now agree to take all necessary measures for the protection of coastal resource with the recognition of seagrass ecosystems as an essential component of the marine environment. However, in most instances, guidelines which are too general to be useful have been the focus of discussion.

For the purpose of this book, and modified from the resolutions agreed upon at the First and Second Southeast Asian Seagrass Resources Research and Management Workshops (SEAGREMS I and II), the following action-oriented measures to protect seagrass habitats in the region are recommended. Adapted in part from a similar plan in the Mediterranean, these are based on the rationale that a sustainable environment is achievable only through utilizing ecosystem management principles that recognize the interdependency of humans and their environment:

1. With effective enforcement measures, ban bottom trawling and other fishing methods with negative effects on seagrass meadows in shallow coastal areas where these meadows abound;

2. Prohibit discharges of urban and industrial effluent to the sea and rivers and sea dumping of dredged material and all kinds of industrial wastes;

3. Ban coastal construction (marinas, docks, breakwaters) on or close to seagrass beds or reconstruction of beaches with the artificial relocation of sand;

4. Promote experimental transplants and restoration in coastal areas where water and sediment quality have been improved;

5. Develop public education programs on the conservation and management of coastal marine environment and in particular of seagrass meadows;

6. In case of emergency, identify environmentally high-risk coastal areas and develop adequate intervention plans to preserve seagrass meadows;

7. Establish coastal and marine protected areas wherever meadows of particular scientific or natural interest or areas recognized as important to seagrass conservation are found;

8. In areas where information are lacking, develop both basic and impact research on seagrass meadows;

9. Develop a database on seagrass to collect and make readily available information regarding geographical distribution, bathymetric distribution, meadow structure and morphology, community structure, status, and environmental use; and

10. Develop monitoring activities of seagrass meadows through the establishment of permanent transects to follow the development and behavior of seagrass beds.

In the Mediterranean, the beds of P. oceanica are generally recognized to be vital to the sea's ecosystems. Hence, to control trawling and other activities having adverse effects on the beds and other phanerogam meadows is a common policy. The study of P. oceanica system in the area is considered a priority listed in the European Economic Commission draft directive on species and habitats.

In creating awareness and research promotion, there should be an effective public awareness campaign on the ecology of seagrasses and other coastal resources and research focusing on their frailties and strengths in the face of a rapidly deteriorating marine environment. To complement the campaign are programs so that 'awareness' becomes 'understanding'. Thereafter, the qualities and economic value of coastal systems should be institutionalized through the formulation and implementation of national seagrass management programs. The target audience of such campaigns should be the government officials, coastal developers (housing, estates), road engineers and transport planners, aquaculture pond developers, agriculture developers, shellfish/fish harvesters, tourism promoters, urban sanitation officials, the mining industry, port and harbor authorities, international development funding or implementing organizations, educators, and legislators. The most compelling and challenging objective of any legislative agenda is the institutionalization of ecological knowledge so that this can be useful in addressing environmental concerns. This is possible through its incorporation in management practices, translation into legislative measures, and infusion in sociocultural norms.

Conservation of biodiversity - As a new scientific discipline, conservation biology or the science of conserving biological diversity, started in the 1980's as an offshoot of the environmental upheaval that swept the immediately preceding decade. Since then, it has become a powerful tool in making and influencing decisions in political, socioeconomic, scientific, or technological circles. This is because directly or indirectly, people benefit from marine foods and ecological services from the sea. This is one compelling reason why everyone should share responsibility for the conservation of the coastal and marine biodiversity. In countries of East Asia the unconditional conservation of seagrass systems remains as the best option to ensure their sustained productivity (Fonseca, 1987; Fortes, 1989). However, this western-inspired scheme is grossly unsuitable and unacceptable in developing countries at least at the present stage of their development since a greater percentage of their population is largely dependent upon such resources. Nevertheless, seagrass ecosystem conservation should be a goal and must be built into the decision-making process if only to sustain coastal self-sufficiency. This difficult task is best achieved when the citizens are well informed so that they can participate in the process, can raise questions about possible choices, and legally ensure compliance with laws and regulations (Norse, 1993).

Education and training - As guiding principles in the formulation of a program of education and training on coastal resources management, the following may be useful. They form the basis of and unify the classroom and field activities prescribed in regular school curricula. As much as possible, experiential ('do-to-learn') education should replace the 'read-to-learn' approach:

1. Human beings are part of ecosystems, and they shape and are shaped by the natural systems;

2. The sustainability of ecological and social systems are mutually pendent so that a shared vision of desired human and environmental conditions should be developed;

3. It is through an ecological approach that the biological diversity, ecological function, and defining characteristics of natural ecosystems are recovered and maintained;

4. It is desirable to integrate the best science available into the decision-making process, while continuing scientific research to reduce uncertainties;

5. The best approach to coastal zone management is that which acknowledges that ecosystems and institutions are characteristically heterogeneous in time and space and which integrates sustained economic and community activity into the management of ecosystems;

6. In the implementation of ecosystem management principles, coordination between government and non-government sectors should be encouraged.

The incomplete understanding of the region's seagrasses makes the resources only marginally useful when compared to the other resources that abound along its coasts. Since seagrass acts as a filter of estuarine waters, stabilizes sediments, and provides habitats for numerous marine organisms, its condition must be a concern to those seeking to protect or restore the health of tidal waters, estuaries, and seas.

APPLIED RESEARCH NEEDS

Lessons have been learned from studies of degraded seagrass ecosystems undertaken only when their deterioration is well advanced. For one, this makes assessment of the pristine condition difficult and any prediction derived from it grossly inappropriate or unreliable. In East Asia, there is an urgent need to undertake and sustain research activities focused on topics which are relevant, pragmatic, and easily understood in the administrative circles. Among others, these topics include: inventory and stock assessment; mapping and classification; community and ecosystem dynamics; socioeconomic studies; and evaluation of seagrass-related management policies and programs.

Inventory and Stock Assessment

Few studies have been made to make an inventory and assess the biological stocks in East Asian seagrass beds. The most extensive study so far conducted is in the Philippines where the habitats have been the subject of inventorial surveys and assessments in connection with environmental impact assessments in coastal industrial (power plants, tourism, petrochemical, oil explorations) development, resource and ecological assessments of degraded fishing grounds and coastal zone management initiatives. As in other Southeast Asian countries, the studies have been conducted as part of coastal environmental profiles (e. g. Brunei Darussalam, Chou et al., (1987) and as a major activity of the ASEAN-Australia Living Coastal Resources (LCR) project. In these countries, seagrasses have also been incorporated as components for protection in marine protected areas.

Mapping and Classification

Management practices are ineffective without a knowledge of where the seagrass beds exist. The major difficulty in estimating seagrass area is that most of the beds are not visible from the air. Turbid waters make it difficult to distinguish the beds in satellite and aerial images. Mapping of seagrass areas for coastal management purposes, however, has been undertaken with some success in certain parts of the Philippines. Mainly through the LCR project and in coordination with the National Mapping and Resources Information Authority of the Department of Environment and Natural Resources (NAMRIA-DENR), and using data from digitizer analysis of landsat imageries and low altitude photography, Fortes (1989) and Fortes & Bina (1992) estimated the area of seagrass beds at seven study sites in the country (Table 7). From the data complemented by ground truth surveys, they were able to classify the status of the beds according to the degree of perturbation.

Table 7. The seven sites in the Philippines where seagrass beds have been mapped using remote sensing technology. The status of the beds are also given.

	Area (km^2)	Status
Cape Bolinao	25.00	38%, good; 49%,fair; 13%, poor
Calauag Bay	7.70	33%, fair-good; 67%,poor
Pagbilao Bay	1.89	100%, poor
Puerto Galera	1.14	70%, good; 30%, poor
Ulugan Bay	2.97	17%, good; 51%,fair; 32%, poor
Banacon Island	7.81	73%, good; 27%, fair
Calancan Bay	0.07	29%, good; 71%, poor

Although the actual area of seagrass beds estimated at these seven sites represents only a small percentage of the total area where seagrasses are found, it represents the initial scientific estimate of seagrass coverage in the Philippines. Hence, it is more useful when compared to the five million hectares of the beds in the country estimated without any scientific basis (Thorhaug, 1987). Rectifying the most recent (1990) landsat image from NAMRIA and supplemented by ground truth surveys, analysis show that the seagrass beds of Cape Bolinao may be delineated according to shoot density. Hence, the seagrass beds comprise a total of 25 km^2 of reef area. 10% of this total area comprises beds with 1200-1400 shoots/m^2; 14% comprises beds with density of 900-1100 shoots/m^2; 5% comprises beds with 700-800 shoots/m^2; 27% comprises 200-400 shoots/m^2; and 44% comprises beds with <200 shoots/m^2.

In Calauag Bay, the seagrass habitats can be delineated into five density categories. Digital analysis of landsat images, supported by actual ground truth surveys, indicate that a total of 5 km^2 of seagrass beds exist in the bay: about 2.2 km^2 comprising seagrasses with densities of 1,300 - 2,580 shoots/m^2; and about 2.8 km^2 of sparse beds comprising seagrass densities of <50 - 800 shoots/m^2. Most of the altered seagrass habitats belong to the sparse category. Highest mixed plant densities (1,479 - 2,580 shoots/m^2) were found in mixed and lush growths of four-five species, or composed almost solely of the wide-leafed H. uninervis growing densely on sandy-muddy substrate and at a favorable depth just below the mean low low water of spring tides.

Since seagrasses are closely associated with coral reefs and extensive meadows are often found between the reefs and the coastal fringes that support mangroves, the total area of seagrass habitats in the country could approximate those of the other two ecosystems. In addition, the identification of the centers of distribution of seagrasses in Cape Bolinao and in the other study sites would indicate the greater probability that these areas are nurseries for juveniles of some economically important species of vertebrates and invertebrates. For practical purposes, the data would facilitate the classification of seagrass beds for coastal zoning and conservation purposes.

For selective protection and use, the seagrass beds of East Asia may be classified into categories on the basis of the degree and nature of alteration to which they are subjected and on their general community response to specific habitat conditions. In the Philippines, based on the above criteria, Fortes (1990) classified the seagrass areas into: **pristine**, **disturbed**, **altered,** and **emergent**. Pristine seagrass meadows are those with high or low diversity of species, bordering land masses far removed from human habitations, disturbed only by the normal intensity of natural elements. These meadows form climax assemblages in shallow waters, usually dominated by E. acoroides, T. hemprichii and C. rotundata. This type of habitat should be preserved and protected from any form of alteration, to be made available only for scientific and educational purposes.

Disturbed seagrass are meadows of high or low diversity beds occupying bays and coves, adjacent human habitation. These are the constant objects of man's activities and impacted by domestic and industrial effluent. These meadows may yield the highest biomass, protein levels and production rates and should be the subject of effective mitigation measures.

Altered seagrass meadows are low species diversity areas, permanently and completely changed or converted to other coastal uses like salinas, fish or shrimp ponds, and waste dumps. They have the potentials to be converted back into seagrass areas through hydrographic engineering, massive transplantation and rehabilitation. This type of seagrass habitat should be the subject of proper multiple use programs.

In the emergent category, seagrass community diversity is low, controlled in large part by extreme physico-chemical conditions. Ruppia maritima and Halophila beccarii, which form extensive growths in almost freshwater or in brackishwater habitats, belong to this category. In some parts, freshwater and terrestrial macrophytes and herbs may co-exist with the seagrasses.

Based on the above classification of seagrass meadows and the results of the survey, the seagrass beds in Calauag Bay belong to the disturbed and altered categories. Comprising a total area of 2.2 km^2, the disturbed seagrass habitats are found mostly in the upper part of its eastern and southeastern sides associated with the effects of the conversion of the mangrove areas into fishponds, cutting of the trees for domestic uses, or unsound fishing practices like haphazard placement of fish enclosures. About 0.4 km^2 of the beds, located at the upper part of the eastern rim (Pulong Pasig), with a seagrass cover of 70-80%, and density of ca 900-1,400 shoots/m^2 is being considered as a sanctuary (MSI/EPAI, 1993).

Community and Ecosystem Dynamics

In recent years, fields of marine science have undergone a revolution in approach, with greater emphasis being placed on dynamic processes rather than static description. This is a necessary complement to the structural parameter approaches. Hence, energy fluxes, community metabolism, and ecosystem dynamics are currently in focus to answer questions which are environmental in nature and which are incompletely elucidated using solely structural parameters.

In East Asia attempts to understand the integrated ecological function of coastal components including seagrasses are virtually non-existent. To date, the work of Alino et al., (1993) presents an initial estimate of ecotrophic efficiencies for 24 subcomponents (including seagrass) of a reef flat in Cape Bolinao. Quantified and analyzed using ECOPATH II, the parameter estimates also help indicate areas in the system worthy of further investigation. Components of related works on seagrass dynamics include those of Chong & Sasekumar (1981), Salita-Espinosa (1991), Klumpp et al. (1992; 1993), Erftemeijer et al. (1993a), and Jarre (1993).

At the community level, temporal and spatial changes in seagrass community metabolism, and heterotrophic-autotrophic shifts, should be the focus of future efforts. Extensive observational data on stress factors both naturally- and man-induced should be gathered and their effects on the community parameters (above) established. A seagrass community does not disappear or develop according to a stable pattern, because each population consists of individuals with specific reproductive periods and life spans. How these responses of the communities affect the patterns of their use by the inhabitants should be studied. Energy exchanges between target components, food circuits, successional development, and restoration could be implemented. A long-term activity, this ecosystem-level approach is the ultimate measure of ecosystem resilience. It is also at this level where preventive, not merely curative, measures to halt environmental damage could be initiated.

Socioeconomic Studies

The socioeconomics of seagrass utilization in East Asia is relatively unstudied. In Thailand, however, and working with people from 17 villages in Trang Province, the Yadfon Association has documented the extensive degradation of seagrass beds, mangrove forests and coral reefs largely brought about by the use of inappropriate fishing gear (Pisit, 1995). Primarily through self-help programs, it was successful in improving the condition of the marine life at the same time maintaining the traditional way of life of the coastal inhabitants, proving that local fisherfolk are capable of managing their resources in a sustainable manner.

In connection with a fishery management project in Calauag Bay, 38% of the respondents in an interview catch fish from seagrass beds (MSI/EPAI, 1993). They consider seagrasses mainly as food source and habitat for fish. However, many of them still consider coral reefs as the primary location of the fish they are catching. The destructive fishing practices prevalent in seagrass beds in the bay are dynamite fishing, use of cyanide, and pollution especially from Calauag town.

There is a prevailing perception that the major institutional problems confronting any management initiative of the seagrass resources (or other marine resources in the bay) in the region are: lack of government will; meager budget; diverted priorities; inadequate staff size; unresponsive basic school curricula; insufficient staff training; meager logistics support; ineffective enforcement structure; lack of legislative reform; corruption; worsening peace and order situation; too much red tape; lack of general environmental awareness and education; lack of integrated and hierarchical planning; and poor transport system and communications. Considerable reorganization in the environmental and agricultural sector is another important institutional issue. This is why there has been so much planning and so little implementation.

One of the pragmatic means by which seagrass ecosystem (as the other coastal ecosystems of the tropical world) could be protected is for government to enact, or reformulate existing, laws that accurately reflect social mores and norms. Once this is done, their implementation occurs without undue difficulty. But as it is at present, most laws related to resource use are at odds with social values, so that their legitimacy are questioned and resisted. It is therefore necessary to place the advent of tropical coastal zone management into sociopolitical perspective so as to appreciate the likelihood of acceptance or rejection by groups concerned. This is an effective way of interfacing the technical and social information for use in the management strategy.

Evaluation of Management Policies and Programs

In East Asia trained research personnel in seagrass science as well the financial resources to sustain the needed activities are likely to be limiting in the years to come. This scenario makes it imperative that research and development efforts on seagrasses have significant positive environmental and economic implications. Among others, they should input into environmental evaluations that focus on management policies and programs or options to minimize, if not prevent, environmental problems, at the same time acquire data that would influence policy decisions. This calls for a concerted effort on the part of all sectors of the government and especially the users.

Evaluation policies that directly relate to seagrasses in East Asia are non-existent. However, with the seagrass-related programs currently in force in most members countries, their evaluation is expected in the next few years to come. In 1993, as a result of an evaluation of management policies relating to seagrasses, the Seagrass Science Policy Seminar, School of Marine Affairs, University of Washington, identified the key issues for seagrass management in the Pacific Northwest. These are: (1) the potential for non-point source impacts on the quantity and quality of habitat suitable for persistence of seagrass; (2) the need for resource inventories documenting seagrass distributions and characterizing populations; (3) the need for restoration of seagrass systems destroyed by coastal zone development; (4) enhanced coordination of regulatory and management activities; (5) ethnobotanical information and its relevance to policy decisions (6) comparative studies with seagrass systems and policy agendas and activities in other regions of the US; and (7) the need for linking management research with basic ecological research. Concerns pertaining to the evaluation of programs on seagrass resources management are thus closely similar in both the Pacific Northwest and East Asia.

ACTION PLAN FOR RESEARCH AND DEVELOPMENT

Currently, research and development efforts on East Asian seagrasses suffer from a lack of purposeful objectives and long-term goals for meeting the challenge of sustainable use. Only by taking a vigorous proactive conservation stance on modification to the habitat and one that is actively supported by the highest offices of government will there be any hope of slowing, stopping and reversing the trend of seagrass habitat loss. Hence, the goals of seagrass research and development in East Asia should be considered within an environmental and resource use framework. These objectives and the actions that specifically address them include (After Fortes, 1994a, adapted from Holligan & de Boois, 1993):

OBJECTIVE 1: To determine the role seagrass ecosystem plays in the maintenance of the integrity of the coastal zone and the monetary value of its resources

<u>Action 1</u>: Undertake a time series analysis to monitor the status and rate of expansion or area reduction of seagrass beds of East Asia.

<u>Action 2</u>: Assess the impacts of habitat changes on the associated fisheries and dynamics of the ecosystem.

<u>Action 3</u>: Define, implement and evaluate functional restoration of critical sites using transplant optimization techniques including the maintenance of genetic diversity of restored seagrass beds and investigation of habitat resiliency.

<u>Action 4</u>: Apply applicable techniques to valuate both direct (e. g. fisheries) and indirect (e. g. organic matter, ecological functions as nurseries and spawning grounds, erosion control) goods and services from seagrass beds, including potential ses if these benefits are compromised by adverse impacts.

OBJECTIVE 2: To determine the response of the ecosystem to environmental forcing factors.

<u>Action 1</u>: Undertake intensive process studies and dose-response experiments focused on pollution, sedimentation and fluxes in temperature salinity.

<u>Action 2</u>: Simulation experiments and prognostic modeling for predictive management of target components over a wide range of space and time scales (e. g. seagrass-dependent fish and prawn fisheries; endangered sea cows, sea turtles)

OBJECTIVE 3: To determine how land use patterns and human activities affect the morphodynamics of seagrass ecosystem

<u>Action 1</u>: Undertake socioeconomic data analysis of the associated impacts identified.

<u>Action 2</u>: Help develop a consistent national policy on coastal resources (seagrass) management.

OBJECTIVE 4: To intensify interhabitat connectivity studies (coral reef-seagrass bed-mangroves).

<u>Action 1</u>: Investigate physical processes linking the ecosystems.

<u>Action 2</u>: Investigate the nutrient fluxes between the ecosystems

<u>Action 3</u>: Investigate animal migration patterns among the ecosystems

<u>Action 4</u>: Assess the effects of human impacts as a link between these habitats

OBJECTIVE 5: To establish indices useful in developing scientific and socioeconomic bases for the integrated management of the coastal resources.

<u>Action 1</u>: Incorporate seagrass beds in marine protected areas

OBJECTIVE 6: To translate the understanding under the aegis of a Seagrass Information Network for East Asia (SINEA).

<u>Action 1</u>: Introduce information technology

<u>Action 2</u>: Systematize data acquisition and handling

<u>Action 3</u>: Undertake massive information campaign atall levels of society.

CONCLUSION

Resource management perspectives of seagrass systems in East Asia draw significance from the predictive value of the ecological and environmental outcome of activities so far undertaken in member countries. Current distribution patterns of the seagrasses, values of seagrass biomass, turnover rates, production, and recruitment and mortality rates are directly useful in planned and existing efforts in rehabilitation, restoration and coastal zone planning. Similar and related parameters have also been initiated for the fauna associated with the beds. Hence, some information are now available on the seagrasses with the desirable structural and dynamic features, on areas in the region suitable for transplantation, or areas suitable for multiple use, faunal species with resource and conservation potential, and those whose importance is yet to be elucidated for prospective planning. With the distribution and extent of the seagrass habitats in some of the areas known, the nature and relative abundance of the other resources associated with the beds (i. e., fishes, crustaceans) could similarly be predicted within a reasonable limit of error.

Paradoxically, the major cause of environmental problems in Southeast Asia is not the result of development, but the lack of it. For the region, development of the coastal zone is inevitable, primarily to address the growing need of its coastal populations for food, shelter, and to provide positive benefit to some interested parties. Such economic dependence, however, has caused environmental degradation, overuse of resources, and multiple-resource use conflicts which, while constraining development, are warning symptoms of unsustainable economic developments that require immediate corrective management measures (Fortes, 1988b; 1989). Indeed, there is a need for an integrated coastal zone management for the purpose of conserving the region's renewable resources. However, the underlying theme of this endeavor should be environmentally sustainable economic development. This has grown out of the perception that natural processes which support life on earth are being threatened by human activities, as well as from acceptance of an environmental ethic which limits human use of natural resources. Considerable attention is, therefore, given to long-term or inter-generational ecological criteria. The World Conservation Strategy, drawn up by the International Union for the Conservation of Nature and Natural Resources (IUCN 1980) contends that sustainable economic development is desirable. But it can only be achieved via conservation of biological resources and essential ecological processes, the preservation of genetic diversity, and sustainable use of species and ecosystems.

Local management practices that deal directly with seagrass resources are few. Nevertheless they have shown that with proper implementation, the scheme objectively equated with production in the context of the rural setting where the resource is rooted, improvement in yield and quality of the environment is significantly sustained. More importantly, a marked change in attitude has occurred, reflecting in part, a greater awareness of the vital function and intrinsic values of the seagrass ecosystem. Truly, this is a period of great opportunity for the region to contribute to global efforts in sustaining and improving management of shallow water resources. Indeed the '80s were a 'decade of seagrasses' in the East Asian region; the '90s are a testing one for the whole of coastal Asia.

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