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IMPROVING THE AQUATIC ENVIRONMENT OF SEMI-ENCLOSED AREAS THROUGH BIOLOGICAL APPLICATIONS

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ABSTRACT

Southeast Asia has the world's richest marine biodiversity. Population growth and economic development pressures continue to degrade the coastal and marine environment. While awareness and management programmes are being promoted, attention should at the same time be given to the rehabilitation of degraded coastal systems. The increasing popularity of marine leisure activities throughout the region is evident from the growing number of marinas. Sheltered waters within the marina promote loading of nutrients and pollutants and a general decline of water quality. The marine leisure community is an important stakeholder in coastal use and can participate actively in coastal environmental maintenance. Marinas can improve the environmental quality of their enclosures through biological interventions. This approach involves enhancing growth of biological organisms selected to perform specific ecological roles. Macro-algae can be used to remove excessive nutrients, filter-feeding organisms to remove suspended sediment, and burrowing organisms to re-condition the seafloor. This paper discusses preliminary investigations into the use of potential species to improve water quality in a Singapore marina.

INTRODUCTION

Coastal development has increased extensively throughout Southeast Asia in the last three decades (although temporarily arrested by the 1998 economic crisis). Human-engineered construction in coastal areas interferes with coastal physical processes, leading to deterioration of water quality within created enclosures(1). Apart from harmful components such as heavy metals, tributyl tin, petroleum hydrocarbons and untreated sewage, which accumulate in these waters, excessive build-up of nutrients pose a major problem. Within these enclosed or semi-enclosed systems, nutrient-driven algal blooms can affect the aesthetic qualities of the waters, causing fish kills and general deterioration of the system.

The abundance of natural habitats such as coral reefs, and the tropical climate make Southeast Asia an attractive destination for marine recreation and leisure. This is evident from the fast-developing network of modern coastal marinas and yacht clubs across the region. Marinas and yacht clubs require sheltered conditions, commonly achieved through engineering where solid seawalls are constructed to produce the desired effect. The enclosed or semi-enclosed (depending on engineering design) body of water is deprived of adequate natural flushing. This interference with natural coastal processes often leads to deterioration of water quality within the marina.

Environmental quality changes influence the community structure of marine life by favouring the more tolerant species. Populations of these species may, however, be depressed by the lack of habitat availability. At the same time, the presence of other species that could grow in such waters may be restricted by the availability of specific niches. Whichever the case, there are species that can perform effective "cleansing" roles. For example, macro-algae can be used as biological filters for the uptake of excessive nutrients within semi-enclosed systems. Their presence needs to be enhanced as a biological solution to improving the environmental quality of semi-enclosed waters. There is currently little information on the improvement of water quality in semi-enclosed marine systems using macro species bio-manipulation.

Investigations have recently been initiated, focusing on the use of plant and animal species to improve water quality in semi-enclosed marine systems by capitalising on their ecological roles and by exploring whether their abundance is restricted by availability of appropriate ecological niches. The project, in collaboration with a local marina, Raffles Marina, includes a detailed survey of marine species present within its semi-enclosed system and aims to establish whether their populations can be enhanced (if restricted by niche availability). Species that are efficient in "fixing" nutrients and other pollutants can then be identified and techniques developed to facilitate their growth within the marina will. Experiments were conducted to assess the effectiveness of the green mussel, *Perna viridis*, as a pollution management agent.

Raffles Marina's concern for marine environmental conservation is evident from the design of its berthing facility. The protective outer seawall is not a solid wall and does permit restricted movement of tidal currents. This ensures that the waters within can support some marine life. Although the design of the outer seawall permits flow of seawater through it, water movement is nevertheless restricted. While creating a sheltered environment for the berths, it also becomes a trap for nutrients, sediment and other pollutants. Any sheltered body of water will favour accumulation of these inputs, which are not swept away or diluted by full tidal flushing. Past monitoring of water quality parameters indicated elevated nutrient levels within the marina compared to the surrounding sea. Since storm drains did not flow directly into the marina, the obvious source of nutrients is from the flushing of boat toilets while berthed.

Water quality can be improved by enhancing growth of biological species that perform specific "environmental cleansing" roles. For example, filter-feeding species are effective in removing suspended sediment from the water column. They can help to improve water clarity, and if harvested and removed regularly, can lower sediment load of the enclosed waters. Similarly, macro-algae are effective nutrient scrubbers and can lower nutrient levels. What is required is a menu of different species that can "fix" certain pollutants.

If these species can perform such roles, why are they not present in an environment where the high availability of nutrients and/or pollutants obviously favours their growth? There are many reasons why these species do not appear naturally in the marina. One of these could be the lack of proper settlement space. Macroalgae for example need some structure to hold on to and also require abundant sunlight. To promote growth of macroalgae, such habitat opportunities have to be made available. The challenge is to provide these settlement spaces within the confines of the marina without them interfering with boat movements and other marina operations.

Biological solutions are environmentally most acceptable (notwithstanding alien species introductions, and genetically-modified interventions, both of which require greater and more careful prior planning and investigation). The results, particularly the protocols and techniques for promoting active growth of desired species, will be useful for application to any coastal water body that is similarly semi-enclosed. With the improvement of water quality, marinas can serve as special habitats to a diversity of marine life. It can eventually use its waters to support species for the aquarium trade and also participate in the culture of threatened species for seeding and ranching purposes.

MATERIALS AND METHOD

A survey of marine biodiversity was first carried out to provide an indication of which species are naturally available, and where and how they were distributed within the semi-enclosed marina. This survey will establish whether present populations in the marina are restricted by the lack of niche availability and provide a list of naturally-occurring candidate species that can be exploited for their environmental cleansing abilities. The survey covered species attached to fixed structures such as the seawall and pilings, floating structures such as pontoons and floats, the water column, and the sea floor. Specimens from the fixed and floating structures were easily collected by hand. Nekton was sampled using nets while the benthic community was sampled using an Eckman grab.

Experiments were carried out with filter-feeding green mussels (*Perna viridis*). Mussel spats grown on ropes were introduced to an experimental berth. They were brought in from a farm close to the causeway in the Johore Strait where salinity is lower than at the marina. These mussels grow naturally on the outer seawall but are not abundant. In all, 80 ropes of mussels were used, 10 of which contained 3-month old mussels while the remaining 70 contained mussels that were over a year old. Each rope was 2m in length. Mussel samples were collected fortnightly, sealed in containers and transported in ice to the laboratory. The tissues were extracted, dried, weighed and acid digested prior to heavy metal analysis by a Perkin Elmer AA600 graphite furnace atomic adsorption spectrophotometer. Water samples were collected for nutrient analysis and physical data such as salinity and dissolved oxygen measured in situ.

RESULTS

A general survey of marine life within the marina completed in 2000 year showed a healthy diversity of 72 pelagic species and 63 benthic species. In addition, the epibiotic community attached to the seawalls, pontoons and pilings was diverse. The pelagic species were dominated by fish (63 species) and included 3 species of jellyfish, 3 of crabs and 1 each of a swimming polychaete, a squid and a sea-snake

(Table 1). Sixteen of the 63 fish species were bottom dwellers (such as the catfishes *Plotosus lineatus* and *Arius venosus*) while 8 were those that generally inhabit reefs (such as *Chelmon rostratus* and *Platax teira*). The fish community included species from a variety of trophic levels and niche specialisations. Of interest is the presence of the seahorse, *Hippocampus kuda*, puffers, archer fish and food fishes.

Table 1. List of pelagic species sampled within Raffles Marina (B=bottom dwellers, C= reef-associated).

Class	Order/Family	Status	Species
Scyphozoa	Rhizostomeae		*Phyllorhiza sp.*
			Rhizostome sp.1
			Rhizostome sp.2
Polychaeta	Amphinomidae		*Chloeia flava*
Cephalopoda	Loliginidae		*Sepioteuthis sp.*
Crustacea	Dorippidae		*Neodorippe callida*
	Portunidae		*Portunus pelagicus*
			Thalamita sp.
Osteichthyes	Clupeidae		*Sardinella sp.*
	Ariidae	B	*Arius venosus*
	Plotosidae	B	*Plotosus lineatus*
	Antennariidae	B	*Lophiocharon trisignatus*
	Atherinidae		*Hypoatherina valenciennei*
	Belonidae		*Strongylura strongylura*
	Hemiramphidae		*Zenarchopterus buffonis*
	Centriscidae		*Aeoliscus strigatus*
	Syngnathidae	B	*Hippocampus kuda*
		B	*Hippichthys cyanospilos*
		B	*Hippichthys penicillus*
	Scorpaenidae	B	*Synanceja horrida*
	Platycephalidae	B	*Cymbacephalus nematophthalmus*
	Ambassidae		*Ambassis kopsii*
			Ambassis vachelli
	Centropomidae		*Lates calcarifer*
	Serranidae		*Cephalopholis boenak*
			Diploprion bifasciatum
		B	*Epinephelus coioides*
	Pseudochromidae	BC	*Congrogadus subducens*
	Terapontidae		*Pelates sexlineatus*
			Terapon theraps
	Apogonidae		*Apogon amboinensis*
			Apogon hyalosoma
			Apogon margaritophorus
			Sphaeramia orbicularis
	Haemulidae	C	*Plectorhincus chaetodonoides*
	Lutjanidae		*Lutjanus johnii*
	Nemiptheridae		*Nemipterus peronii*
		C	*Scolopsis vosmeri*
	Scatophagidae		*Scatophagus argus*
	Ephippidae		*Platax teira*
	Monodactylidae		*Monodactylus argenteus*
	Silliganidae	B	*Sillago sihama*
	Lobotidae		*Lobotes surinamensis*
	Pomacanthidae	C	*Pomacanthus annularis*
	Chaetodontidae	C	*Chelmon rostratus*
		C	*Coradion chrysozonus*
	Chaetodontidae		*Parachaetodon ocellatus*
	Carangidae		*Caranx ignobilis*

			Caranx sp.
	Cichlidae		*Etroplus suratensis*

Continuation

Osteichthyes	Pomacentridae	C	*Abudefduf bengalensis*
		C	*Pomacentrus tripunctatus*
	Labridae	C	*Choerodon anchorago*
			unidentified genus and species
	Mugilidae		unidentified genus and species
	Blenniidae	B	*Omobranchus ferox*
		B	*Omobranchus zebra*
	Gobiidae	B	*Butis butis*
		B	*Butis koilomatodon*
	Siganidae		*Siganus canaliculatus*
			Siganus guttatus
	Toxotidae		*Toxotes jaculatrix*
	Monacanthidae		*Acreichthys tomentosum*
			Anacanthus barbatus
			Chaetodermis penicilligerus
			Monocanthus chinensis
			Paramonacanthus choirocephalus
	Ostraciidae		*Rhynchostracion nasus*
	Tetraodontidae		*Arothron reticularis*
			Tetraodon nigroviridis
	Diodontidae		*Diodon liturosus*
Reptilia	Acrochordidae		*Acrochordus granulatus*

The benthic community (Fig. 1) was dominated by polychaetes, represented by 51 species (Table 2), most abundant of which were *Polydora* sp., *Drilonereis filum* and *Sthenolepis japonica*. Most abundant polychaete families were Spionidae, Cirratulidae and Orbiniidae.

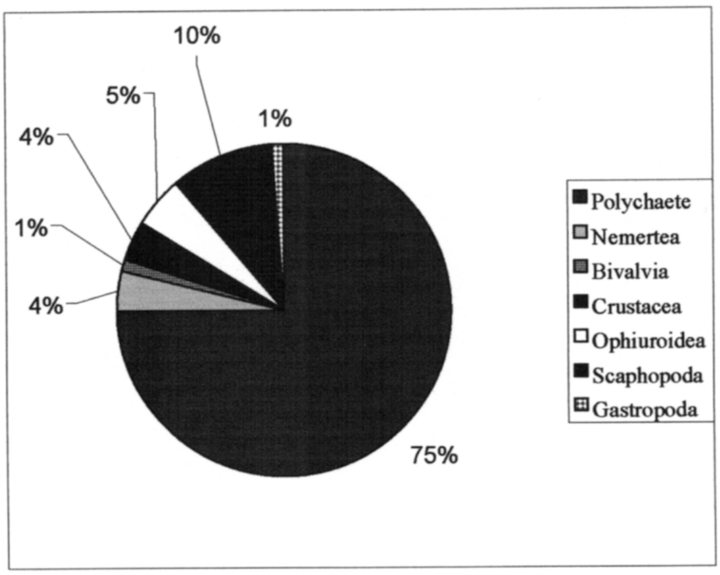


Fig. 1. Benthic community composition within Raffles Marina

Table 2. List of benthic polychaete species from Raffles Marina.

Order	Suborder	Family	Species
Orbiniida		Orbiniidae	*Haploscoloplos kerguelensis* *Scoloplos armiger* *Scoloplos (Leodamas) gracilis* *Scoloplos (Leodamas) sp.*
		Paraonidae	*Aedicira sp.* *Aricidea sp.* *Aricidea longobranchiata*
Spionida	Spioniformia	Spionidae	*Aonides oxycephala* *Aguilaspio sexoculata* *Paraprionospio pinnata* *Polydora sp.* *Prionospio malmgreni* *Pseudopolydora kempi* *Pseudopolydora sp.*
		Magelonidae	*Magelona cincta*
	Cirratuliformia	Cirratulidae	*Cirratulus filiformis* *Cirriformia tentaculata* *Tharyx marioni* *Timarete sp.*
Capitellida		Capitellidae	*Capitella capitata* *Heteromastus filiformis* *Mediomastus californiensis* *Notomastus latericeus*
Phyllodocida	Aphroditiformia	Polynoidae	*Polynoidae sp.* *Lepidonotus sp.*
		Sigalionidae	*Sthenolepis japonica*
		Chrysopetalidae	*Paleanotus debilis*
	Nereidiformia	Hesionidae	*Ophiodromus angustifrons*
		Pilargiidae	*Otopsis sp.* *Pilargis sp.*
		Syllidae	*Typosyllis sp.*
	Glyceriformia	Glyceridae	*Glycera natalensis* *Glycera rouxi* *Glycera sp.* *Glycera tesselata*
		Goniadidae	*Glycinde kameruniana*
		Lacydoniidae	*Paralacydonia paradoxa*
		Nephtyidae	*Aglaophamus dibranchis* *Aglaophamus lyrochaeta* *Nephtys sp.*
Amphinomida		Amphinomidae	*Linopherus hirsuta*
Eunicida		Eunicidae	*Eunice antennata* *Eunice indica*
		Lumbrineridae	*Lumbrineris nagae* *Lumbrineris sp.*
		Arabellidae	*Drilonereis filum*
		Lysaretidae	*Oenone fulgida*
Oweniida		Oweniidae	*Myriochele sp.*
Terebellida			*Isolda pulchella*
		Terebellidae	*Amaeana sp.*

Sabellida		Sabellidae	*Laonome sp.*

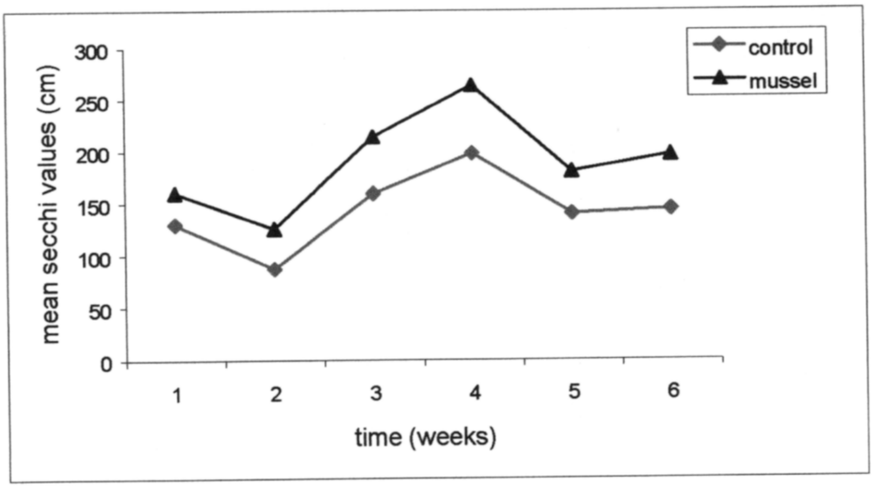
The epibiota on the seawalls and pilings was dominated by crustacea (barnacles) and gastropoda (limpets), which form about 99% of the community. Crabs included *Myomenippe hardwicki* (which was most common), *Lauridromia indica*, *Selatium brockii*, *Metopograpsus* sp. and *Schizophrys aspera*. The gastropod families Neritidae and Littorinidae were well represented. Other fauna included gorgonians and ascidians. The epibiotic community of the pontoons showed a greater diversity of 10 phyla from 2 kingdoms (Table 3). Common were the calcareous tube polychaetes, sponges, ascidians and stinging hydroids. Less common were soft corals (5 species), zooanthids, seafans and seawhips.

Table 3. Epibiota of the floating pontoons in Raffles Marina.

Kingdom	Phylum/Division	Class/Order	Family
Plantae	Chlorophyta	Siphonales	Caulerpaceae
			Codiaceae
Animale	Porifera		
	Cnidaria	Hydrozoa	Hydroids
			Soft Corals
		Gorgonacea	
		Zoanthidea	Zoantidae
	Platyhelminthes	Turbellaria	
	Nemertea		
	Annelida	Polychaeta	Nereidae
	Mollusca	Gastropoda	Littorinidae
			Others
		Bivalvia	Mytilidae
			Ostreidae
	Crustacea	Amphipoda	
		Decapoda	Camptandriidae
			Grapsidae
			Majidae
	Echinodermata	Holothuroidea	
		Echinoidea	
		Ophiuroidea	
	Chordata	Ascidiacea	

Water transparency, determined by Secchi readings, improved significantly (ANOVA, $p<0.05$) within the mussel experimental berth compared to locations beyond it (Fig 2). The levels of ammonia, nitrite, nitrate and phosphate did not show significant differences between the waters within and beyond the mussel berth. Evident is the accumulation of heavy metals within the young mussels in the short span of time of their introduction. Copper and nickel content rose after the second week of mussel introduction. Copper level increased from 33.65 to 58.76ppm while nickel increased from 2.54 to 5.96 within a month of introduction.

Figure 2.Transparency of water within and beyond mussel berth.



DISCUSSION

Literature on the improvement of semi-enclosed marine waters by physical, chemical and biological means is not extensive. These interventions can be used singly [(2)] or in combination [(3)]. Biological remediation has a potential in reforming impacted environments [(4,5)] and more investigations are needed.

A study of heavy metal levels in marine sediments of Singapore indicated varying levels of copper, zinc, lead and cadmium [(6)]. These levels were influenced by sediment particle-size and types of human activity. An earlier but brief investigation showed that heavy metal and nutrient loads within the marina were twice the concentration of the surrounding waters.

Untreated sewage discharged from the boats berthed in marinas has a profound effect on the biological communities [(7,8)]. Current investigations of another marina, Punggol Marina, showed high eutrophication (high primary productivity and Chlorophyll a) correlated with higher measures of nutrients (nitrate, nitrite, ammonia) and Total Petroleum Hydrocarbons [(8)]. Similar monitoring studies reporting the effect of pollutants on the biota established in marinas have been reported [(9,10)]. They all indicate a need to find biological solutions to improving water quality so that its environmental capacity and integrity can be enhanced.

Knowledge of sewage treatment has been applied effectively, employing physical, chemical and biological means for environmental remediation. Bioremediation or biomanipulation is a favoured approach as physical and chemical means of remediation in a marina may trigger other undesirable changes. Unregulated inputs of nutrients cause eutrophication. Aquatic micro- and macrophytes use up nutrients effectively and create conducive conditions for bacterial decomposition of organic matter [(11)]. Their ability to bioaccumulate contaminants like heavy metals is known. Use of aquatic weeds for remediation (phytoremediation) is a more recently evolved branch of bioremediation. Aquatic macrophytes have been widely used in remediation of freshwater ecosystems quality [(12)]. Seaweeds have been used in biological nutrient removal systems to improve coastal water [13]. Under conducive conditions like excess nutrients and light, algal blooms are known to establish in closed or semi-enclosed systems.

It is an established fact that like artificial reefs, coastal marinas provide extensive and sustainable substrata to a variety of flora and fauna [1]. They can be manipulated to serve environmental cleansing functions and help to improve the environmental capacity of the enclosed waters. The species diversity at Raffles Marina presents a wealth of target organisms that can be exploited to remediate the waters. Experiments with the mussels showed potential applications with heavy metal uptake and water clarity improvement. Further investigations with other species will identify those that are effective in lowering pollution load. Growth of these target species needs to be encouraged as substratum availability may not be present. The introduced mussels on ropes, for example, grew rapidly, while the naturally occurring ones were not abundant and confined to the outer seawall. Once identified, management protocols for the candidate species need to be developed for the frequency of their introduction and removal, including techniques to reduce human effort.

Marine habitat biomanipulation is a promising and developing discipline with immense scope for application. Environmentalists prefer management interventions, which are biological as they are ecological compatible. Most work has been on freshwater systems and only few have been on marine systems.

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