Prolonged inundation and ecological changes in an Avicennia mangrove: implications for conservation and management

Article *in* Hydrobiologia · June 1994

DOI: 10.1007/BF00005670

Hydrobiologia **285**: 237–247, 1994.
A. Sasekumar, N. Marshall & D. J. Macintosh (eds), Ecology and Conservation of Southeast Asian Marine and Freshwater Environments including Wetlands.

Prolonged inundation and ecological changes in an *Avicennia* mangrove: implications for conservation and management

Satish C. Choy[1] & Webber E. Booth
Universiti Brunei Darussalam, Gadong 3186, BSB, Brunei Darussalam, Borneo
[1] *Present addres: Australian School of Environmental Sciences, Griffith University, Nathan, Qld., Australia*

Key words: prolonged flooding, *Avicennia*, ecological changes, mangrove management

Abstract

The mangrove around Sungei Pemburongunan, just west of Tanjong Batu and Istana Darul Aman in the Brunei-Muara District, is unique in that it contains the only pure stand of *Avicennia marina* in Brunei Darussalam. In mid-October, 1990 the mouth of Sungei Pemburongunan was closed due to a natural build-up of a sandbar across it. The mangrove quickly became flooded and adverse effects on the flora and fauna were observed during the following weeks. In mid-December a channel was dug across the sand bar to reduce the flooding and normalise the ecology. Some of the dying *Avicennia* and *Lumnitzera* have since recovered but others such as *Acrostichum* and *Casuarina* have not. *Avicennia* showed some interesting responses to prolonged inundation. Many of the *Avicennia* that had flowered during the flood produced seedlings which are now well rooted and 40–80 cm in height. The survival of large numbers of these seedlings is attributed to the floor-related decrease in the number of grapsid and sesarmid crabs which predate on them. The crab and mollusc populations have largely recovered. Unlike periodic short-term flooding which does not seem to have any apparent adverse affect on the ecosystem, prolonged inundation can result in the loss of the *Avicennia* and its associated flora and fauna. Thus, fragile mangrove ecosystems such as this need to be monitored and managed closely.

This work demonstrates that contrary to conventional wisdom, human intervention and management can be beneficial to more fragile ecosystems, which could otherwise succumb to natural processes. Furthermore, it highlights the importance of the dynamic nature of the environment which should be considered in management and conservation programmes.

Introduction

The Meragang wetland (Fig. 1) around Sungei Pemburongunan, just west of Tanjong Batu and Istana Darul Aman in the Brunei-Muara district, is unique in that it contains the only pure stand of *Avicennia marina* (Forsk.) Vierh. in Brunei Darussalam. In other areas of the country, this species occurs as mixed stands with other mangroves, such as *Rhizophora*, *Sonneratia* and *Bruguiera*. The wetland is just west of the now disused Brooketon coalmine and covers an area of just over 50 ha. The 1:10000 Brunei map for the area (Sheet 55/95 NE) does not indicate the presence of any vegetation in the 'swamp', about 50% of which is actually covered by *Avicennia marina* and, to a lesser extent, by other plants such as *Casuarina*, *Acacia*, *Lumnitzera*, *Nypa*, *Excoecaria* and *Pandanus*. Only the southern and western fringes are devoid of any macrophytes. They are, however, covered by a dense layer of fine algae. There is evidence that these areas were, until

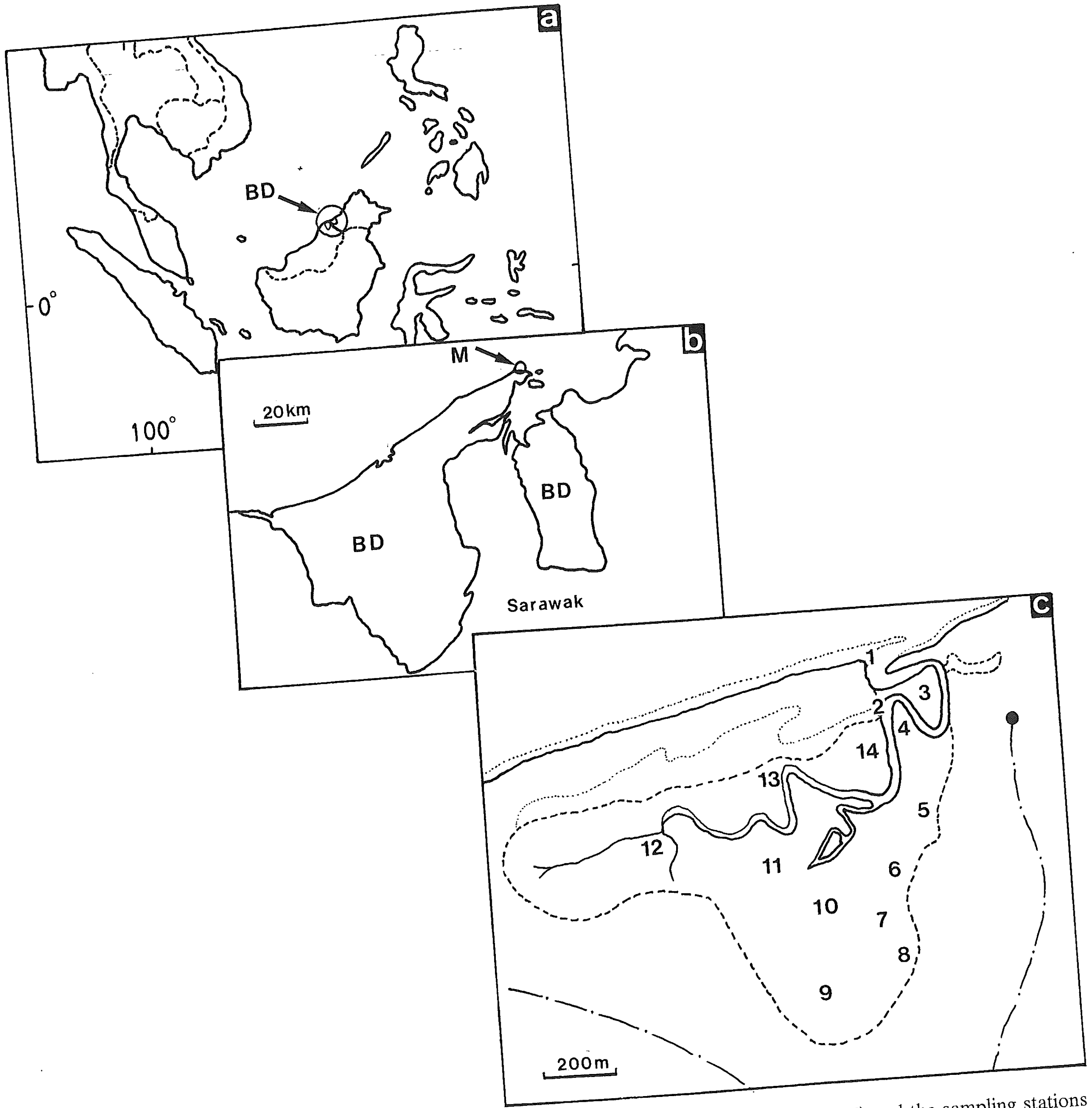


Fig. 1. Locality map of Brunei Darussalam (BD), the *Avicennia marina* wetland at Meragang (M) and the sampling stations (1–14) ----, wetland limits; ....., beach sand limits; —·—, road.

recently, covered by *Pandanus* sp., root stumps being still visible.

Apart from its ecological importance, the Meragang wetland is of social and aesthetic significance. Human activities observed in the area include fishing (using a variety of gear such as gillnets, crab nets, crab traps and tidal weirs), mollusc harvesting and recreation.

Ecological baseline studies were carried out during the early part of 1990. In mid-October of the same year the mangroves became flooded due to a natural build-up of a sandbar across the mouth of Sungei Pemburongunan, the stream flowing through the area. The whole wetland quickly became flooded; water level in the *Avicennia marina* grove and on the adjacent mudflats reached a height of about 0.5 m above MHWS. The area remained under flood for eight weeks, during which time increasing mortality of the mangrove flora and fauna was observed. On 16 December, a channel was manually dug to release the floodwater.

These events provided an unique opportunity for us to study the ecological responses of the mangrove flora and fauna to prolonged inundation and their subsequent recovery. The episode also forced us to reassess our views on certain approaches to mangrove conservation and management.

Materials and methods

Standard ecological methods were employed to survey the flora and fauna of the Meragang wetland. Using 1:10 000 maps and aerial photographs, field surveys were carried out to map the vegetation types. Based on this information, stratified random sampling was performed. Ten by ten metre plots were used to estimate the density of the mangrove plants at the different sampling stations (Fig. 1c). The same plots were revisited at different sampling times. Macroepifaunal (particularly crustaceans and molluscs) densities were estimated using five replicates of either 0.016 m^2, 0.25 m^2 or 2 m^2 quadrats within and between the permanent, demarcated vegetation plots. The smaller quadrats were used for high density, less mobile molluscs such as *Cerithidea* while the largest quadrat was for more widely dispersed or mobile organisms such as *Telescopium* and the crabs. The faunal quadrats samples were taken within the same general area at different sampling times. Fish fauna in the stream were recorded from catches made by fishermen. Four sets of surveys were carried out:

1. Prior to flooding (March-June, 1990)
2. During the flood (November-December, 1990)
3. Soon after the flood receded (January, 1991)
4. Nine months later (September, 1991)

Numerous visits to the site were also made between these periods. On these occasions and during the flood, however, only qualitative observations were recorded.

Results

The Meragang wetland has, as its dominant species, *Avicennia marina*. Other components of the flora include *Nypa fruticans* (Thunb.) Wurmb.,

Table 1. Plant density and the percentage mortality in the *Avicennia* wetland, after eight weeks of inundation. Hyphenated station numbers indicate sampling plots between the two designated stations.

Station no.	Species	Density (no. 100 m^{-2})	Percentage mortality
3	*Avicennia marina* (Forsk.)	25	0
	Excoecaria agallocha L.	1	0
	Acrostichum aureum L.	1	100
4	*A. marina*	17	0
4–5	*A. marina*	32	50
	Cassuarina equisitifolia L.	1	100
5	*A. marina*	33	73
	C. equisitifolia	7	100
	E. agallocha	3	0
	Lumnitzera racemosa Willd.	6	50
	Pandanus sp.	3	100
	Grass	?	75
	Rush	?	100
6	*A. marina*	15	0
7	*A. marina*	29	86
7–8	*A. marina*	74	31
8	*Nypa fruticans* (Thunb.)	3	0
9	*A. marina*	25	100
10	*A. marina*	17	59
	E. agallocha	2	50
	Grass	?	75
11–12	*A. marina*	50	0
11–14	*A. marina*	43	47
	E. agallocha	6	0
	Acrostichum speciosum	1	0
	Derris trifoliata Lour.	3	67
	C. equisitifolia	2	0
	Asplenium sp.	1	0
	Pandanus sp.	1	0
	Cymbidium sp.	1	0
	Leguminosae	1	0
13–14	*A. marina*	61	0

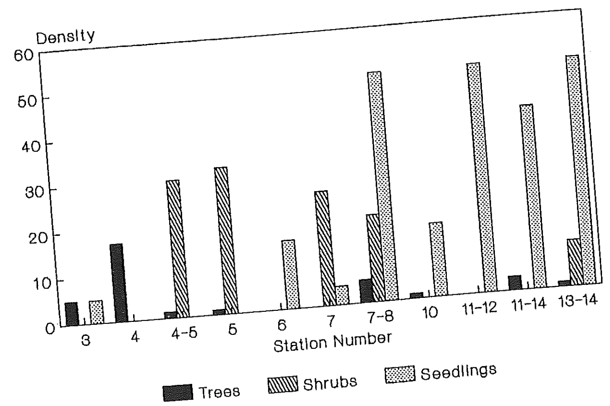
Excoecaria agallocha L., *Lumnitzera racemosa* Willd. and *Derris trifoliata* Lour. *Casuarina equisitifolia* L., *Acrostichum aureum* L. and *A. speciosum* L. occupy slightly raised sites within the wetland. Several species of rushes and grasses are also present on higher, firmer ground. Perched on old *Avicennia* stumps are the epiphytic orchid, *Cymbidium* sp. and the ferns, *Asplenium* sp. and *Drynaria* sp. A dense cover of micro- and meioalgae is present on the mud surfaces of the wetland.

Most plant species suffered some mortality during the prolonged inundation (Table 1). *Avicennia* suffered substantial losses of shrub-sized (1.5–5 m) plants (Fig. 2). There was total mortality at stations 7 and 9. Most tree-sized (>5 m in height) *Avicennia* survived although 50% of the low density plants at stations 4–5 and 7–8 died. The *Avicennia* seedlings shown in Fig. 2 actually appeared soon after the flood and have grown to a height of 40–80 cm in nine months.

Some *Avicennia* displayed necrosis of the bark and surface wood tissues (to a depth of about 1 cm) in the region of the stem that was submerged during flooding; yet they survived. Large diameter (0.5–1.5 cm) adventitious roots have, in many cases, begun to grow from just above the necrotic region. A large percentage of *Avicennia* pneumatophores died back either partially or completely as a result of the flooding. Side shoots have subsequently developed from the basal living portion of some of the original pneumatophores. Small numbers of new ones have also been produced. An additional response of *Avicennia* to the flooding has been the stimulation of flowering and fruiting by plants of all ages and sizes; some as small as 60 cm in height.

The relative abundance of molluscs prior to flooding, soon after the flood receded and 9 months later is given in Table 2. Densities and percentage survival of the more common species are given in Table 3 and Figs. 3–5. Densities of *Terebralia sulcata* (Born) and *Telescopium telescopium* (L.) increased significantly ($P<0.01$) during the flood. However, those which colonised the mudflats have since been reduced markedly in numbers. *Assiminea brevicula* (Pfeiffer) and *Theodoxus oualaensis* (Lesson) completely disappeared during the flood but since then, have reappeared in some places in large numbers. *Assiminea* shows preference for drier areas of the mudflat ($P<0.01$). *Telescopium*, *Terebralia* and *Theodoxus* have reappeared in the wet zone (mudflat streams) but have yet to fully recolonise the drier mudflat areas (cf. Figs. 3 & 4). *Cerithidea cingulata* (Gmelin) also suffered extensive mortality as a result of the flood. However, it has recolonised the area in greater than pre-flood densities, particularly in the wet zones (Fig. 5). The length of the dead shells were 17 ± 2 mm while those newly recruited in January were 2 ± 1 mm long.

Telescopium and *Terebralia* from within the area reproduced soon after the flood receded and ju-



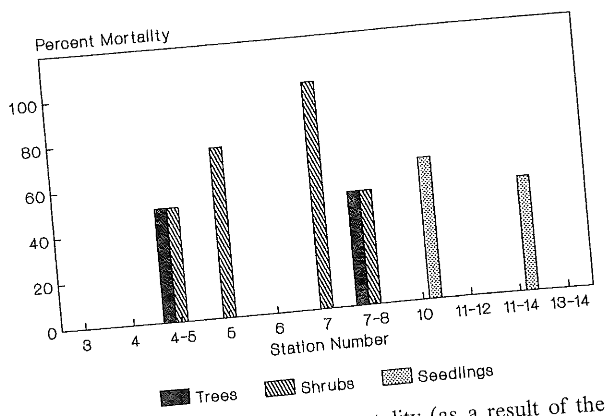


Fig. 2. Density and percentage mortality (as a result of the flood) of *Avicennia marina*. Trees, >5 m; shrubs, 1.5–5 m; seedlings, <1.5 m in height. Density of trees and shrubs, no.100m^{-2}; density of seedlings, no.m^{-2}. Plots between designated stations are hyphenated.

Table 2. Mollusc abundance in the *Avicennia* wetland during different periods. 1, prior to flooding; 2, just after flooding had receded; 3, nine months later; + rare; ++ occasional; +++ common; ++++ abundant.

	Relative abundance		
	1	2	3
Gastropoda			
Assiminea brevicula (Pfeiffer)	+++	+	++++
Cassidula mustelina Deshayes	++	+	+
C. pilosa Gassus	+	+	+
Cerithidea cingulata (Gmelin)	++++	+	++++
C. obtusa Lamarck	+++	+	++
Chicoreus capunicus (Lamarck)	++	+	+
Ellobium aurisjudae L.	++	+	+
E. aurismidae L.	+	+	+
Littoraria carinifera (Menke)	++	++	+
L. scabra (L.)	++	++	+++
Nassarius olivaceus Brug.	++	+	+
Nerita planospira Anton	++	+	+
N. balteata Reeve	++	+	+
Telescopium telescopium (L.)	+++	+++	+++
Terebralia sulcata (Born)	+++	+	+++
Thais tissoti (Petit)	++	+	+
Theodoxus oualauiensis (Lesson)	++	+	+++
Heminoea sp.	++	+	+
Onchidium sp.	++	++	+++
Bivalvia			
Anadara granosa Iredale	+	+	+
Barbatoa sp/	+	+	+
Enigmonia enigmatica (Iredale)	+	+	+
Gafrarium tumidum (Röding)	++	+	+
Geloina coaxons	+++	++	++
Glauconome sp.	++	+	+
Isognomon amonoides (Reeves)	++	++	++
Saccostrea echinata (Q & G)	+++	+	++
Solen sp.	++	++	++

Table 3. Mollusc density (x ± S.E., no. m^{-2}) and mortality (% dead, in brackets) in the *Avicennia* wetland. 1, preflooding; 2, a few days after the flood receded; 3, nine months later. Dry, moist mudflat zone; wet, mudflat stream and pool zones. At each station, densities of species between episodes 1 & 2 and 2 & 3 are significantly different ($P<0.01$).

Stat. no.	Species	1	2	3
6 (dry)	*Cerithidea cingulata*	344 ± 50 (8)	390 ± 48 (10)	1920 ± 300 (60)
	Terebralia sulcata	2 ± 1 (0)	13 ± 2 (0)	1.25 ± 0.2 (75)
	Telescopius telescopius	1 ± 1 (0)	5 ± 1 (50)	0.5 ± 0.1 (100)
	Assiminea brevicula	11 ± 4 (0)	0	96 ± 5 (0)
	Theodoxus oalauensis	13 ± 2 (0)	0	0
	Littoraria spp.	5 ± 3 (0)	2 (0)	12 ± 2 (0)
	Geloina coaxons	2 ± 1 (100)	8 ± 2 (100)	2 ± 1 (100)
6 (wet)	*C. cingulata*	731 ± 100 (5)	56 ± 10 (93)	3156 ± 95 (6)
	T. sulcata	6 ± 2 (5)	28 ± 7 (15)	192 ± 24 (5)
	T. telescopium	3 ± 1 (5)	16 ± 2 (0)	64 ± 15 (0)
	A. brevicula	0	0	0
	T. oalauensis	12 ± 4 (0)	0	96 ± 7 (0)
9	*C. cingulata*	324 ± 54 (5)	46 ± 10 (98)	1500 ± 100 (40)
	T. sulcata	4 ± 2 (0)	15 ± 3 (10)	16 ± 3 (20)
	T. telescopium	3 ± 1 (0)	7 ± 2 (10)	10 ± 3 (10)
10–11	*C. cingulata*	1011 ± 135 (5)	350 ± 55 (95)	1280 ± 150 (0)
	T. sulcata	2 ± 1 (0)	12 ± 3 (5)	2 ± 1 (30)
	T. telescopium	6 ± 2 (5)	9 ± 3 (5)	5 ± 2 (6)
14	*C. cinqulata*	480 ± 87 (10)	410 ± 78 (100)	380 ± 65 (90)
	T. sulcata	1 ± 1 (0)	3 ± 2 (10)	1 ± 1 (0)
	T. telescopium	1 ± 1 (0)	3 ± 2 (0)	1 ± 1 (0)

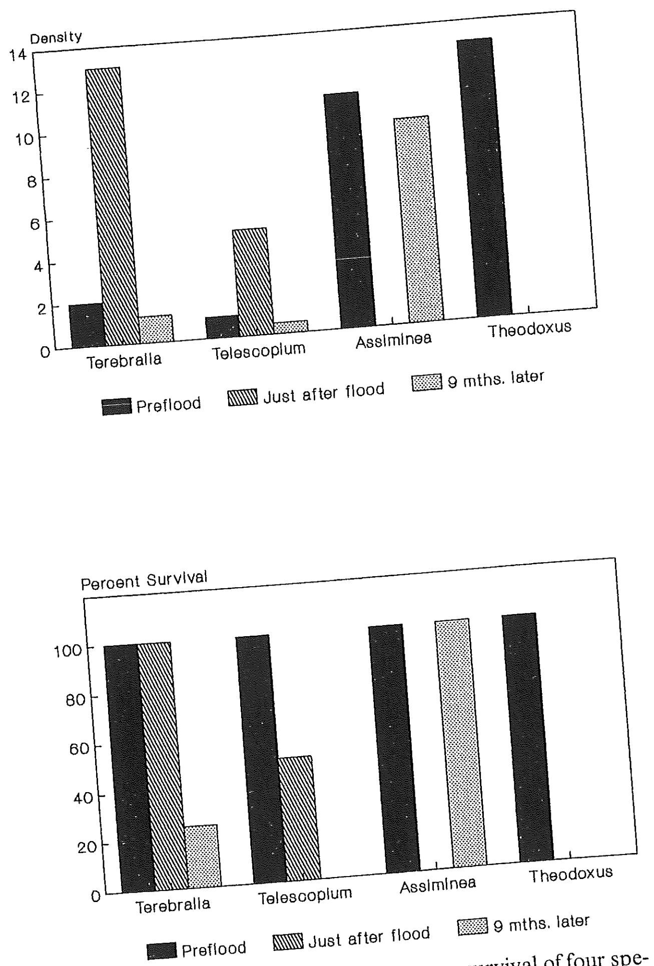


Fig. 3. Density (no.m^{-2}) and percentage survival of four species of molluscs in the dry mudflat areas of the mangrove.

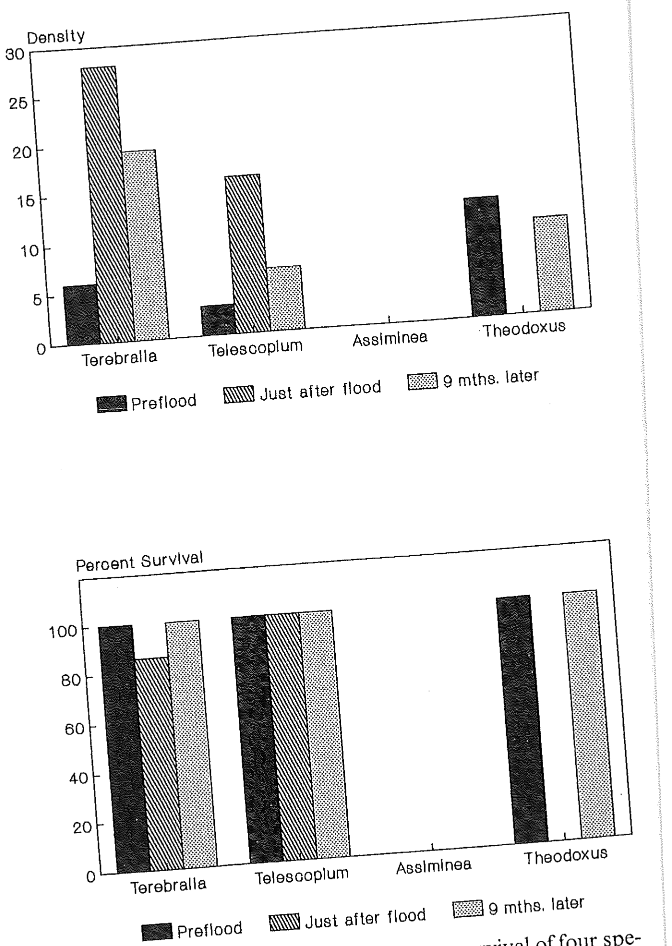


Fig. 4. Density (no.m^{-2}) and percentage survival of four species of molluscs in the wet mudflat areas of the mangrove.

veniles from that single cohort have grown to 23 ± 4 mm and 18 ± 4 mm, respectively in nine months. *Assiminea*, *Theodoxus* and *Cerithedia* seemed to have been recruited from outside. In nine months, *Assiminea* grew to 3 ± 2 mm and began breeding in July. *Theodoxus* grew to 5 ± 2 mm in the same period while *Cerithedia* has had two waves of recruitment, the first just after the flood receded and the second in May-June. These have grown to 11 ± 2 mm and 6.7 ± 1.4 mm in nine and five months, respectively. Post-flood *Cerithedia* and *Theodoxus* have yet to breed in the Meragang wetland.

The other very abundant and conspicuous invertebrate group in the *Avicennia* wetland is the crustacea (Table 4). Most of the more common species, which had virtually disappeared during the flood have since reappeared (Fig. 6). During the flooding, mudlobsters *Thalassina anomala* (Herbst) were commonly seen out of their flooded burrows during the daytime and, along with sesarmid crabs, climbing trees. Newly moulted specimens were often observed being killed and eaten by crabs such as *Scylla serrata* (Forskål) and *Thalamita* spp. Areas where the mangroves had died as a result of the flood and, previously occupied by small sesarmid crabs (such as *Chiromantes*, *Parasesarma* and *Clistocoeloma*), have been colonised by the larger *Metaplax* (Fig. 6, stn. 6). *Uca annulipes* (Latrielle) and many of the sesarmid crabs reproduced during May-June; the former have grown to 5–8 mm in carapace width in four months.

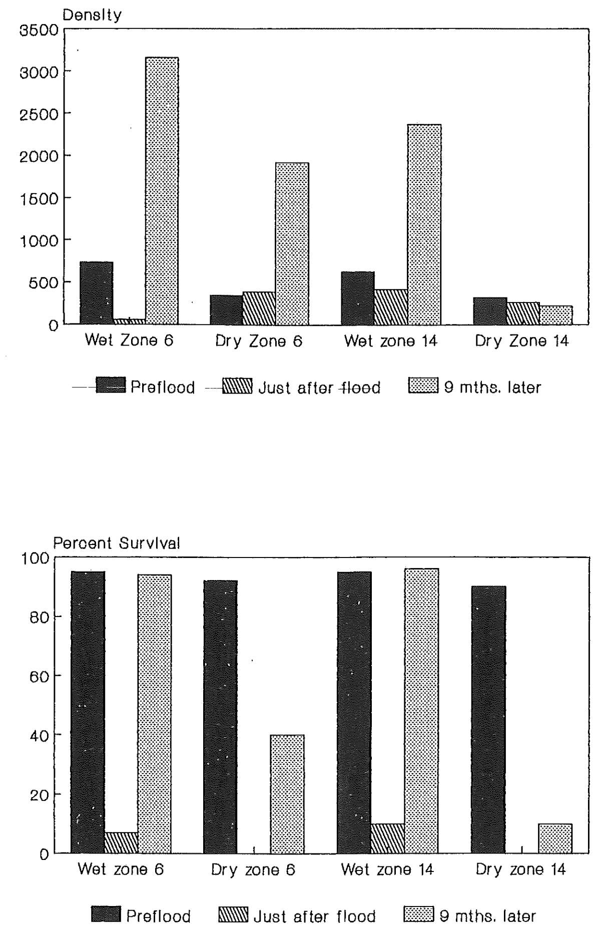


Fig. 5. Density (no.m^{-2}) and percentage survival of *Cerithidea cingulata* in the wet and dry zones of sampling stations 6 and 14.

Thirty two species of fish (Table 5) have been recorded from the stream which meanders through the *Avicennia* mangrove. Our observations indicate that many of the larger species such as the Lethrinids, Carangids, Lutjanids, Serranids and Mugilids are visitors and come in during high tides to feed. Others, such as the Sphyraenids, Lutjanids, Siganids, Theraponids and some Leiognathids, use the area as a nursery. The more permanent ichthyofauna include the Gobids, Toxotids, Scatophagids, Periophthalmids, Centropomids, Ariids, Plotosids, Theraponids and some Leiognathids. Most of the large species are

Table 4. Relative abundance of crustaceans in the *Avicennia* wetland. 1, before flooding; 2, just after the flood receded; 3, nine months later, +, rare, + +, occasional; + + +, common; + + + +, abundant. Taxonomic authorities can be found in Sasekumar (1974) and Lovett (1981).

	Relative abundance		
	1	2	3
Cirripedia			
Chthamalus malayensis	+ + +	+	+ +
Balanus sp.	+ + +	+	+ +
Isopoda			
Limnoria sp.	+ + + +	+	+ + +
Sphaeroma sp.	+ + + +	+	+ + +
Decapoda			
Penaeidae			
Metapenaeus brevicornis	+ +	+ +	+ +
M. ensis	+ +	+ +	+ +
Parapenaeopsis hardwickii	+	+	+
P. hungerfordi	+	+	+
Penaeus merguiensis	+ +	+ +	+ +
P. indicus	+ +	+ +	+ +
P. monodon	+ + +	+ + +	+ +
P. semisulcatus	+ +	+	+
Sergestidae			
Acetes indicus	+	+	+
A. erythreaus	+	+	+
A. sibogae	+	+	+
Palaemonidae			
Palaemon spp.	+ +	+	+
Alpheidae			
Alpheus sp.	+	+	+
Anathus sp.	+	+	+
Synalpheus spp.	+ +	+ +	+
Portunidae			
Charybdis spp.	+ +	+ + +	+
Portunus pelagicus	+ +	+ + +	+
P. sanguienolentus	+ +	+ +	+
Scylla serrata	+ + +	+ + +	+ + +
Thalamita spp.	+ + +	+ + +	+ +
Grapsidae			
Chiromantes eumolpe	+ + + +	+	+ + +
C. indiarum	+ + +	+	+ +
Clistocoeloma merguiensis	+ + + +	+	+ + +
Metaplax elegans	+ +	+	+ + +
M. tredecim	+ +	+	+ + +
Metapograpsus frontalis	+ +	+ +	+ +
Parasesarma plicatum	+ + + +	+	+ + +
P. rutilimanum	+ + + +	+	+ +
Sarmatium spp.	+ + + +	+	+ + +
Leipocton sordidulum	+ + + +	+	+ + +
Nanosesarma andersonii	+ + +	+	+ +

Table 4. (Continued)

	Relative abundance		
	1	2	3
Ocypodidae			
Uca annulipes	++++	+	++++
U. rosea	+++	+	+++
U. triangularis	+++	+	+++
Macrophthalmus crinitus	+++	+	++
Xanthidae			
Heteropanope glabra	++++	+	+++
Coenobitidae			
Coenobita sp.	+++	+++	++
Paguridae			
Clibanarius spp.	++	+	+++
Thalassinidae			
Thalassina anomala	+++	+++	++

regularly caught by the fishermen. During the flood there was increased fishing activity and initially the fish size was maintained but as the flooding persisted the number of larger fish caught declined. The species composition, however, remained similar throughout. No fish kills were observed during the flood. Soon after the flood receded, gobies and mudskippers which appeared to have increased in abundance began to breed. Juveniles grew to 13 ± 3 mm and 18 ± 3 mm in standard length, respectively in six months.

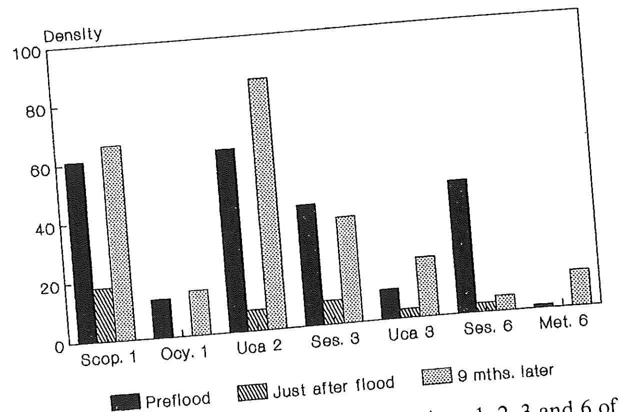


Fig. 6. Density (no.m^{-2}) of crabs at stations 1, 2, 3 and 6 of the mangrove. Scop., *Scopimera bitympana*; Ocy., *Ocypode cordimana*; Uca, *Uca* spp.; Ses., sesarmids; Met., *Metaplax* spp.

Table 5. Fish collected from the *Avicennia* wetland stream. Taxonomic authorities can be found in Matsuda, *et al.* (1984).

Family	Scientific name	Local name
Rhinobatidae	*Rhynchobatus* sp.	pari
Ariidae	*Arius* spp.	gagok, utek
Belonidae	*Hemiramphus* sp.	
	Tylosurus sp.	
Carangidae	*Caranx* spp.	bamasa, menokok
Centropomidae	*Chanda* spp.	
Toxotidae	*Toxotes jaculator*	
Gobidae	*Hemigobius* sp.	
	Pseudogobius spp.	
	Brachygobius doriae	
Lactariidae	*Lactaria* sp.	kelapa-kelapa
Leiognathidae	*Gazza minuta*	bilis pilajau
	Leiognathus bindus	bilis
	L. equulus	pulup-pulut
	L. splendens	bilis
	Secutor insidator	bilis
Lethrinidae	*Lethrinus lentjan*	anduping
Lutjanidae	*Lutjanus* spp.	ketambak
	L. argentimaculatus	merah
Mugilidae	*Mugil* sp.	balanak
	Valamugil sp.	balanak
	Liza sp.	kembura
Periophthalmidae	*Periophthalmus* sp.	
	Boleophthalmus sp.	
Platacidae	*Platax* sp.	bunda
	Plotosus sp.	badukang
Scatophagidae	*Scatophagus argus*	kitang
Serranidae	*Epinephalus* spp.	kerapu
Siganidae	*Siganus* spp.	belais
Sphyraenidae	*Sphyraena* sp.	linkoh
Tetraodontidae	*Tetrodon* sp.	piasau-piasau
Theraponidae	*Therapon jarbua*	kirang-kirang

Discussion

Although there is substantial literature on human-induced stresses to mangroves, very little is available on the effects of natural disturbances (Lugo & Snedaker, 1974; Johns, 1986). What there is of the latter mainly deals with either periodic or large scale factors such as cyclones, tidal waves droughts, lightning strikes, etc. (Jimenez *et al.* 1985; Johns, 1986). These studies deal mainly with immediate effects and the recovery dynamics of the mangrove ecosystem have been largely ignored. Our study can therefore be discussed in the light of this deficiency.

The eight-week flooding of the Meragang wetland adversely affected populations of some of the resident plant and animal species. Evidence based on the degree of disturbance and mortality of the dominant species suggest that longer inundation could have resulted in the destruction of the entire *Avicennia marina* ecosystem. Although there have been some previous closures, none of them lasted for more than a fortnight. The opening of the mouth of the stream to allow the drainage of the floodwater and restore the original tidal patterns of marine and fluvial water exchange has, after a period of about nine months, allowed the wetland to return close to the original community structure. However, there have been some changes in population densities and patterns of species distribution.

As yet unexplained is why one size class of *A. marina* only displayed mass mortality. Few large trees died and seedlings were, at the time of the flood, present in insufficient numbers to be considered. Almost all pneumatophores of large and shrub-sized trees that were submerged died back from their tips as a result of the flooding. If, as reported in most treatises on mangroves, the pneumatophores have an important vent role for respiratory gases (Chapman, 1976; Stewart & Popp, 1987), then both size classes should have died. The fact that the larger trees and some of the shrubs survived means that *A. marina* plants can, for long periods survive without pneumatophores. This brings into question the essential respiratory role of these structures (Tomlinson, 1986). Manipulative investigations need to be undertaken to determine the minimal pneumatopore requirement for each size class of these mangroves.

During the flood the salinity did not vary greatly from the normal situation (10–14 gl^{-1}) and therefore the plants should not have been subjected to extreme levels of osmotic stress.

The majority of the shrub deaths were of trees on ground away from the central creek. The large trees were either close to the creek or on raised islands associated with *Thalassina* mounds. The differences in position or substrate may therefore have either directly or indirectly had an influence on the difference in survival between the two size classes. A feature noted soon after the flood release was the development of dense mats of black fungal hyphae on the dead shrubs. There is a possibility that fungal infection may have played a role in the mass mortality, a hypothesis that fits in well with blanket deaths in some areas where root to root contact may have allowed the fungus to spread in the physiologically weakened plants during the flood. However, we have no direct evidence that such a pathogen was in fact involved. The fungus observed could have been a saprophyte that invaded the plants after they had died.

Unlike the other plants in the flooded area, *Avicennia marina* displayed adaptations which assisted its survival and re-establishment.

In spite of the ring barking and necrosis of the outer wood of some *Avicennia*, the deeper inner wood with its multiple cambia (Zamski, 1979) has been able to maintain sufficient conductance to allow the damaged plant to survive. Many have produced adventitious roots from just above the necrosed zone. These have grown rapidly towards the soil forming *Rhizophora*-like prop roots. These new roots assist in supporting the damaged plants and supplement the conductive role of the rest of the root system.

The ability of the pneumatophores to form lateral shoots below their flood-damaged tips is another adaptation for recovery. Many *Avicennia* are currently operating on 10–50% of their original pneumatophores and most of these are in the form of recently produced lateral shoots.

There has been an increase in the incidence of flowering and fruiting and so large numbers of propagules have become available for reseeding the affected wetland. The result has been the appearance of high densities of *Avicennia* seedlings of the same age class in extensive areas of the wetland where, prior to the flood, they were uncommon. Their survival, just after the flood receded, has been attributed to the timely temporary decrease in the number of sesarmid and grapsid crabs which normally predate on the newly fallen propagules (G. Maxwell, pers. comm.). Although crab populations have recovered, these seedlings are now well established and beyond being susceptible to crab damage. However, very few new seedlings have since appeared. Thus, the result has been establishment of a single age class of seedlings. Such age discontinuities (often despite continuous seedling production) in mangroves are not uncommon and may be explained in terms of changing patterns of predation pressure (Osborne & Smith, 1991; Robertson, 1991).

The disappearance of many species of the mudflat fauna as a result of the flood may be attributed to a single, or more likely, a combination of factors. These include the inability to carry out sufficient gaseous exchange, problems in ionic regulation, toxic chemicals, lack of food and predation. The high mortality of *Cerithidea cingulata* may be due to the first factor. Although *C. cingulata* has the ability to carry out aquatic as well as aerial respiration, it seems better adapted for the latter (Rao *et al.*, 1986). Prolonged submergence could have resulted in respiratory distress. *Terebralia* and *Telescopium* are normally found in the wetter areas of the mangroves. They seem well adapted for prolonged submergence as well as aerial exposure, provided the conditions are moist. They survived the flood. However, when the flood receded many of them were caught out in exposed areas which quickly became dry. These died of desiccation. Most of the other molluscs may have suffered high predation from fish and swimming crabs which moved onto the mudflats during the flood.

Grapsid (Grapsinae and Sesarminae) and Ocypodid crabs, which virtually disappeared as a result of the flood, have recovered in number. *Metaplax* spp. have colonised recently killed *Avicennia* areas which were previously inhabited by other sesarmids. It seems that these sesarmids prefer covered areas while *Metaplax* spp. show preference for more exposed ones. Changes in substrate quality and competition may have also contributed to this segregation. No fish kills were reported in the area during the flood. The flood water remained saline and oxygenated throughout the period (10–14 gl^{-1} and 50–70% saturated, respectively) and therefore tolerable to the fish. Most fish, molluscs and crustaceans in the flooded area would have been eventually fished out had the stream mouth not been opened as regular supply of young from the sea is required to maintain species diversity and abundance. Since the mouth opened and the flood receded, many juveniles of a variety of organisms including fish, molluscs and crustaceans have been observed within the mangrove channels and on the mudflats. Some of these were produced within the area while others have been recruited from the sea.

The ecological functions and significance of mangrove ecosystems have been stressed on numerous occasions and is one of the highlighting features of the ASEAN-ICLARM-US Coastal Resources Management Project (see Chua *et al.*, 1987). The mangroves of Brunei Darussalam are still well preserved but it is inevitable that some areas will be lost to development of agriculture, aquaculture, industry and housing. The impact of such losses can be minimized by planned development and rational management. The proposed National Mangrove Management Plan is a major step towards this.

Most management strategies, however, consider only large tracts of mangroves and very often small groves can disappear unnoticed. The relatively small *Avicennia marina* wetland around Sungei Pemburongunan may succumb if it is not managed specifically. Its closeness to the city and its easy accessibility makes it very vulnerable. It could be easily made a target for conversion into other uses such as aquaculture pondification and real estate development. Its survival is therefore under threat.

The first reaction regarding the conservation of a small mangrove ecosystem such as this would be to declare it as a preserve. However, total preservation often leads to irregular monitoring and non-management. Such an approach may not work as the mangroves here could die a natural death, a result of the dynamic processes of ecosystems. The build-up of the sandbar across the mouth of the stream is a manifestation of this. Paradoxically, we feel that in this particular case only human intervention can help the mangrove survive. It needs to be monitored and managed

closely. This can be effectively done if the area is utilized in a non-destructive way.

A recommendation that the area be developed into a recreational cum educational facility was made to the Department of Town and Country Planning, Ministry of Development and an encouraging response was received (Director of Town & Country Planning, in litt.). Background information and details of our recommendation are given in Choy & Booth (1991). The benefits of such a development will be that, besides creating greater public awareness of the natural heritage, the *Avicennia* mangrove and its associated flora and fauna at Meragang will be conserved through closer monitoring and appropriate management.

References

Chapman, V. J., 1976. Mangrove vegetation. J. Cram, Germany, 447 pp.

Choy, S. C. & W. E. Booth, 1991. Ecology of the 'Api Api' (*Avicennia marina*) wetland around Sungai Pemburongunan, Meragang with proposals for its utilization, conservation and management. Document prepared for the Department of Town and Country Planning, Ministry of Development, Brunei Darussalam, 25 pp.

Chua, T. E., L. M. Chou & M. S. M. Sadorra, 1987. The coastal profile of Brunei Darussalam: resource assessment and management issues. ICLARM Techn. Rept. 18, Fisheries Dept., Brunei Darussalam & ICLARM, Philippines, 193 pp.

Jimenez, J. A., A. E. Lugo & G. Cintron, 1985. Tree mortality in mangrove forests. Biotropica 17: 177–185.

Johns, R. J., 1986. Natural disturbances in mangrove ecosystems. In S. Cragg & N. Polunin (ed.), Report of the workshop on mangrove ecosystems dynamics. UNESCO/UNDP, New Delhi: 37–44.

Lovett, D. L., 1981. A guide to the shrimps, prawns, lobsters and crabs of Malaysia and Singapore. Universiti Pertanian Malaysia, Serdang, 156 pp.

Lugo, A. E. & S. C. Snedaker, 1974. The ecology of mangroves. Annu. Rev. Ecol. Syst. 5: 39–64.

Matsuda, H., K. Amaoko, C. Arasa, T. Uyeno & T. Yoshino, 1984. The fishes of the Japanese Archipelago. Tokai University Press, 437 pp.

Osborne, K. & T. J. Smith III, 1990. Differential predation on mangrove propagules in open and closed canopy forest habitats. Vegetatio 89: 1–6.

Rao, D. G. V. P., V. P. Rao, K. S. R. P. Rao, V. U. Devi & S. K. Patnaik, 1986. Studies on the respiration of cerithiids. In M. F. Thompson, R. Sarojini & R. Nagabhushanam (eds), Indian Ocean: Biology of Benthic Marine Organisms. A. A. Balkema, Rotterdam: 85–95.

Robertson, A. I., 1991. Plant-animal interactions and the structure and function of mangrove forest ecosystems. Aust. J. Ecol. 16: 433–443.

Sasekumar, A., Distribution of macrofauna on a Malayan mangrove shore. J. anim. Ecol. 43: 51–69.

Stewart, G. R. & M. Popp, 1987. The ecophysiology of mangroves. In R. M. M. Crawford (ed.), Plant life in aquatic and amphibious habitats. Blackwell Scientific, Palo Alto, CA: 333–345.

Tomlinson, P. B., 1986. The botany of mangroves. Cambridge University Press, Cambridge, 413 pp.

Zamski, E., 1979. The mode of secondary growth and the three dimensional structure of the phloem in *Avicennia*. Botanical Gazette 140: 67–76.