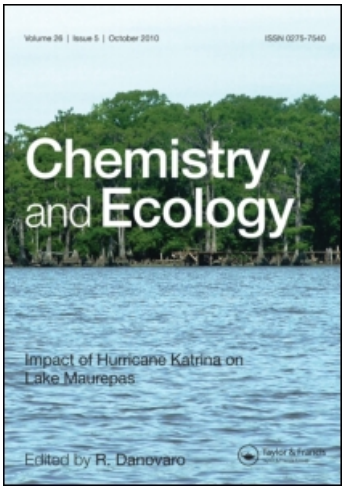

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P. Subramanian[a]; M. Prince Jeyaseelan[ab]; K. Krishnamurthy[a]
[a] Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai, Tamilnadu, India
[b] Research Associate in Fisheries, Tamil Nadu Rice Research Institute, Aduthurai

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The Nature of Biodegradation of Vegetation in Mangrove Ecosystem

P. SUBRAMANIAN, M. J. PRINCE JEYASEELAN† and K. KRISHNAMURTHY

Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608 502, Tamilnadu, India

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Experiments were carried out *in situ* and in the laboratory for 45 and 90 day periods respectively to study the nature and process of biodegradation of leaves/cladodes of 9 species of halophytes with special reference to mangrove vegetation. The leaching rate of chlorophylls *a*, *b*, bacteriochlorophylls *a*, *c*, *d*, phaeopigments, organic carbon and micronutrients such as Zinc, Copper, Iron and Manganese were studied at different intervals (10, 30, 90 days) and in varying salinity media (0.30, 16.60, 33.30‰S). The organisms involved in fragmentation, decomposition and biodeterioration have been listed. Total litter production in the wooded mangrove area was 7,457.07 tonnes/year (leaf litter alone 5,834.4 tonnes/year). The mangroves export substantial organic material to the neighbouring estuarine and sea waters and the values were estimated at 261 tonnes C/year and 1,566 tonnes C/year respectively. Only 783 tonnes C/year were utilised and retained for use within the mangrove ecosystem.

INTRODUCTION

The role of mangroves as nursery areas for the larvae and juveniles of many species of prawns, crabs, molluscs and for example fishes, is well known. Furthermore, the mangroves contribute nutrients, organic

† Present address: Research Associate in Fisheries, Tamil Nadu Rice Research Institute, Aduthurai 612 101.

matter and detritus to the adjoining coastal ecosystems, and thus support, the various pelagic and benthic communities of the waters of the continental shelf. The biodeterioration of mangrove-based litter such as withered twigs, leaves, flowers, stems, branches and roots results in continuous replenishment of organic detritus and nutrients to nearshore marine communities. The biodegradation of mangrove vegetation leads to the release of organic and humic substances which are partly dissolved in the surrounding water and as both particulate and dissolved forms transported to the sea, through estuaries and neritic inlets. Thus mangroves serves as a sanctuary and nutritional bank for the coastal aquatic ecosystems.

The present study assesses the contribution, made through the process of biodeterioration, of total litter and leaf litter of certain mangrove halophytes. It explores the comparative degradative properties of the leaves of different species and considers their utility in diet formulations for prawn culture. The present investigations were conducted using the mature green and old, yellowing fresh leaves/cladodes of halophytes.

DESCRIPTION OF THE STUDY AREA

The Pichavaram mangrove forests and aquatic ecosystem (11°26'N; 79°48'E) are located between the Vellar and Coleroon estuarine systems on the Bay of Bengal seaboard. These mangrove forests with their waters occupy an area of about 13 sq. km. The tides are semidiurnal and vary in amplitude from about 30 to 100 cm, reaching a maximum during the monsoon and postmonsoon (October and January) and a minimum during the summer season (March to May). The depth of the channels and various other waterways ranges from about 0.50 to 1.50 m and the waterspread area alone accounts for about 40% of total area. Most of the withered and yellowing mangrove leaves fall directly upon water as the channels are lined by this vegetation. Besides, the leaves falling on low lying areas come in contact with water during tidal immersion. Moreover, the wind (speed of 9 to 12 km/hr during April to July) also transports these fallen leaves and litter to the water. Some of the mangrove litter is deposited on higher land nearby but most of it comes into contact with the water system during high tide. The torrential rain of the monsoon season (annual rainfall 1,300 mm), with the bulk (75%) falling between October and December also assists in this transport.

There are about 30 species of halophytic vegetation in this mangrove ecosystem including about 20 species of mangrove flora, some 15 species of them belonging to the woody mangrove vegetation. These include (?) *Rhizophora stylosa*† Griff., *R. mucronata* Lamk., *R. apiculata* Bl., the natural hybrid *R. lamarckii*† Montr., *Avicennia marina* Vierh., *A. officinalis* L., *Aegiceros corniculatum* (L.) Bl., *Bruguiera cylindrica* (L.) Bl., *Ceriops decandra* (Griff.) Ding Hou, *Lumnitzera racemosa* (L.) Gaerin, *Sonneratia apetala* Buch-Ham and *Xylocarpus* sp.

MATERIALS AND METHODS

To study the relative degradation properties of foliage, nine species were selected (Table 1). They included two saltmarsh species (*Suaeda maritima* and *Arthrocnemum indicum*) possessing cladodes which are here considered as homologues of leaves). To compare the aspects of degradation of green leaves with that of naturally falling yellowing senescent leaves three species were chosen, viz., *Acanthus ilicifolius*, *Excoecaria agallocha* and *Suaeda maritima*. To compare organisms involved in *in situ* and laboratory degradation processes, the yellow leaves of *Rhizophora stylosa*, *Avicennia marina* and *Bruguiera cylindrica* were packed separately in Velon screen litter bags of nylon mesh (mesh size 1.20 mm) and immersed in water completely. The bags were immersed in the sub-surface water of the channel, and allowed to remain and decay there for 45 days. The channel chosen is one of the many natural and major waterways of this ecosystem. The green and yellowing leaves were plucked in fresh condition, immediately cleaned with tap water to remove dust and adhering salt particles and then repeatedly pressed between folds of blotting paper to remove moisture. Leaf thickness, initial weight of unit surface area, dry weight and ash weight were then measured. The initial weight was measured within 2 hours of collection (i.e. detachment from the plant). The weighed fresh leaves were dried to constant weight in a hot air-oven at 80°C for 48 hr. The ash weights of the leaves were found by igniting the dried leaves in a muffle furnace at 540°C for 6 hr. The organic carbon content was estimated following the method described by el Wakeel and Riley (1957). The calorific content of the fresh leaves was calculated from the organic carbon value following the method of Platt *et al.* (1969). The chlorophylls

† The species *R. stylosa* and *R. lamarckii* still await definite confirmation.

TABLE I

The weight and proximate composition of fresh leaves/cladodes of halophytes collected from Pichavaram mangroves

Sl. No.	Species	Value per 100 sq. cm leaf area: Wet weight (gm)	Dry weight (gm)	Ash weight (%)	Moisture (%)	Chl. *a* (mg/gm)	Chl. *b* (mg/gm)
1.	*Ceriops decandra*	6.27	1.86	3.68	70.29	1.8087	0.1191
2.	*Avicennia officinalis*	4.24	1.08	4.02	74.49	1.8567	0.1247
3.	*Avicennia marina*	4.94	1.74	5.10	64.74	1.9022	0.1226
4.	*Rhizophora stylosa*	10.35	2.82	5.70	72.70	2.0953	0.1202
5.	*Suaeda maritima* L. Dum. (green)	13.88	1.99	5.64	85.69	1.1726	0.1202
6.	*Suaeda maritima* (yellow)	14.41	1.38	5.12	90.43	0.5351	0.1080
7.	*Arthrocnemum indicum* (Willd.) Moq.	9.73	1.53	6.56	84.24	1.2893	0.1185
8.	*Acanthus ilicifolius*[a] (green)	6.44	1.44	4.29	77.70	4.7050	0.1339
9.	*Acanthus ilicifolius* (yellow)	7.68	1.71	4.38	77.70	0.8416	0.1032
10.	*Derris heterophylla*[b]	1.45	0.57	4.23	60.60	7.4721	0.1667
11.	*Excoecaria agallocha* (green)	3.75	1.04	5.02	72.42	2.1895	0.1126
12.	*Excoecaria agallocha* (yellow)	5.45	0.87	4.39	34.50	0.6524	0.0965
13.	*Aegiceros corniculatum* L. Blanco	2.58	0.81	4,58	68.43		
14.	*Lumnitzera racemosa* Willd.	4.36	0.81	4.74	81.46		
15.	*Rhizophora apiculata* (green)	6.95	2.37	3.92	65.96		
16.	*Rhizophora apiculata* (yellow)	8.44	3.12	4.37	63.10		
17.	*Bruguiera cylindrica*	4.65	1.06	4.03	77.23		
18.	*Salicornia brachiata* Roxb.	10.61	1.23	4.73	88.45		

[a] The present name is *A. ebracteatus* Vahl.
[b] The present name is *D. trifoliata* Lour.

in fresh leaves and in the incubating water medium were estimated using standard procedures (described below).

Fresh leaves/cladodes of nine species (*vide* Table 1) were allowed in the laboratory (ambient room temperature 28 ± 2°C) to decompose in three naturally occurring water salinities. The waters were collected from the three adjacent aquatic biotopes:

1. Freshwater (from the upstream of the Vellar estuary) 0.30‰ salinity.
2. Mangrove vegetation-lined channel water (from Pichavaram mangroves 16.60‰ salinity.
3. Sea water (from Parangipettai beach) 30.30‰ salinity.

Glass jars (2.50 litre capacity) with lids were filled with 2 litres of water of the above three salinities. In each container 30 gm of fresh leaves were kept immersed and allowed to decay. Special care was taken to keep the leaves completely immersed in water. The experiments were conducted simulating as far as possible natural conditions. The leaves which were under incubation in water were gently stirred (daily for two or three minutes). The mouth of the container was 10 cm in diameter and was covered with a lid to avoid the deposition of air borne particles. The decrease in water level due to evaporation was occasionally made good by adding an adequate quantity of distilled water, thus ensuring strict adherence to original salinity value of the milieu.

Samples were taken on the 10, 30 and 90 day. The leaf samples taken for analysis included the decaying leaves as well as a known quantity of the water in which they were allowed to decay. These samples were kept in a hot air-oven at 80°C for 48 hr. and the dried leaves were powdered. The powdered samples were analysed for organic carbon and trace elements were estimated using flame atomic absorption spectrophotometry (AAS). The water samples of the experimental medium (of 3 varied salinities) were estimated for pigment concentration i.e. chlorophylls a, b, bacteriochlorophylls a, c, d, and total phaeopigments. The values are expressed in mg/m^3. For pigment analysis the standard procedures described by Steel and Baird (1968), Takhashi and Ichimura (1970) and Strickland and Parsons (1972) were used. A control series containing the waters collected from the same sources was maintained, but without the addition of foliage. The same salinity and temperature, values were maintained as in the experimental series.

To provide an estimate of the initial pigment concentration and

composition fresh green leaves were homogenised with 85% acetone, centrifuged and read in a spectrophotometer (UNICAM. SP 500) at different wavelengths.

RESULTS AND DISCUSSION

1. Certain physical characteristics of fresh green leaves

Among the halophytes (excluding those with cladodes), *Derris heterophylla* leaf was very thin and *Rhizophora stylosa* was very thick. The thickness of leaves is an important factor in their subsequent biodegradation. For a given weight (30 gm in this study), the thinner leaves have a greater surface area and thus expose a greater leaf area to the submerging medium, and therefore to bacterial, fungal and ciliate colonisation, which in turn, promotes rapid biodegradation. However, this susceptibility has certain inherent limitations. The moisture content of leaves/cladodes, the intracellular leaf space, the vascular system, softness or hardness of leaves/cladodes and the cuticle thickness of leaves are some of the intrinsic natural factors which influence the process of biodegradation among the various species of halophytes.

Derris heterophylla is a climber whose slender stem facilitates its climbing habit. The water content (in term of weight) of the thin leaves of *Derris heterophylla* was low (60.60%) when compared with other halophytes. Besides, per unit area of leaf *Derris heterophylla* has more chlorophyll content and less moisture value (*vide* Table 1). The cladodes of the following species showed higher water content, *Suaeda maritima* (90.43%), *Salicornia brachiata* (88.45%), and *Arthrocnemum indicum* (84.24%). Among the species analysed, the percentage ash content was maximum in *Arthrocnemum indicum* (6.56%) and minimum in *Ceriops decandra* (3.68%). In certain leaves of species such as *Acanthus ilicifolius*, *Derris heterophylla* and *Rhizophora stylosa* a lesser ash content was observed when compared to their counterparts occurring on the coast of Goa (West coast of India)—Bhosale *et al.* (1976).

Among the halophytes, green leaves of *Aegiceros corniculatum* and *Bruguiera cylindrica* yielded high calorific values (Table 2). They may serve as good sources for readymade feed preparations. The organic carbon in *Avicennia officinalis*, *Derris heterophylla* and *Rhizophora stylosa* leaves of Pichavaram mangrove was less when compared with the values given by Bhosale *et al.* (1976) for the Goan mangroves. This might be due to the seasonal effect, because the leaves in the present

TABLE II

The micro-nutrients composition of fresh leaves of halophytes collected from Pichavaram mangroves

Sl. No.	Species	Leaf dry weight basis					Calorific value converted from carbon
		Iron (%)	Zinc (%)	Manganese (%)	Copper (%)	Organic carbon (%)	
1.	*Ceriops decandra*	0.0176	0.0020	0.0155	0.0018	29.67	4282.84
2.	*Avicennia officinalis*	0.0226	0.0024	0.0358	0.0014	33.47	4860.44
3.	*Avicennia marina*	0.0108	0.0022	0.0056	0.0014	34.50	5017.00
4.	*Rhizophora stylosa*	0.0113	0.0019	0.0289	0.0011	36.57	5331.64
5.	*Suaeda maritima* (green)	0.0185	0.0019	0.0030	0.0012	24.15	3443.80
6.	*Suaeda maritima* (yellow)	0.0152	0.0018	0.0047	0.0011	17.94	2499.88
7.	*Arthrocnemum indicum*	0.1738	0.0046	0.0142	0.0025	18.98	2657.96
8.	*Acanthus ilicifolius* (green)	0.0440	0.0067	0.0131	0.0022	32.09	4650.68
9.	*Acanthus ilicifolius* (yellow)	0.0758	0.0052	0.0390	0.0022	45.20	6643.40
10.	*Derris heterophylla*	0.0511	0.0060	0.0080	0.0020	27.95	4021.40
11.	*Excoecaria agallocha* (green)	0.0512	0.0079	0.0203	0.0037	34.85	5070.20
12.	*Excoecaria agallocha* (yellow)	0.0272	0.0037	0.0300	0.0018	34.50	5017.00
13.	*Aegiceros corniculatum*	0.0171	0.0040	0.0130	0.0031	48.99	7219.48
14.	*Lumnitzera racemosa*	0.0437	0.0038	0.0200	0.0025	28.29	4073.08
15.	*Rhizophora apiculata* (green)	0.0280	0.0033	0.0685	0.0024	30.71	4440.92
16.	*Rhizophora apiculata* (yellow)	0.0186	0.0036	0.1085	0.0024	33.47	4860.44
17.	*Bruguiera cylindrica*	0.0288	0.0071	0.0788	0.0030	42.09	6170.68
18.	*Salicornia brachiata*	0.0339	0.0078	0.1088	0.0026	10.70	1399.40

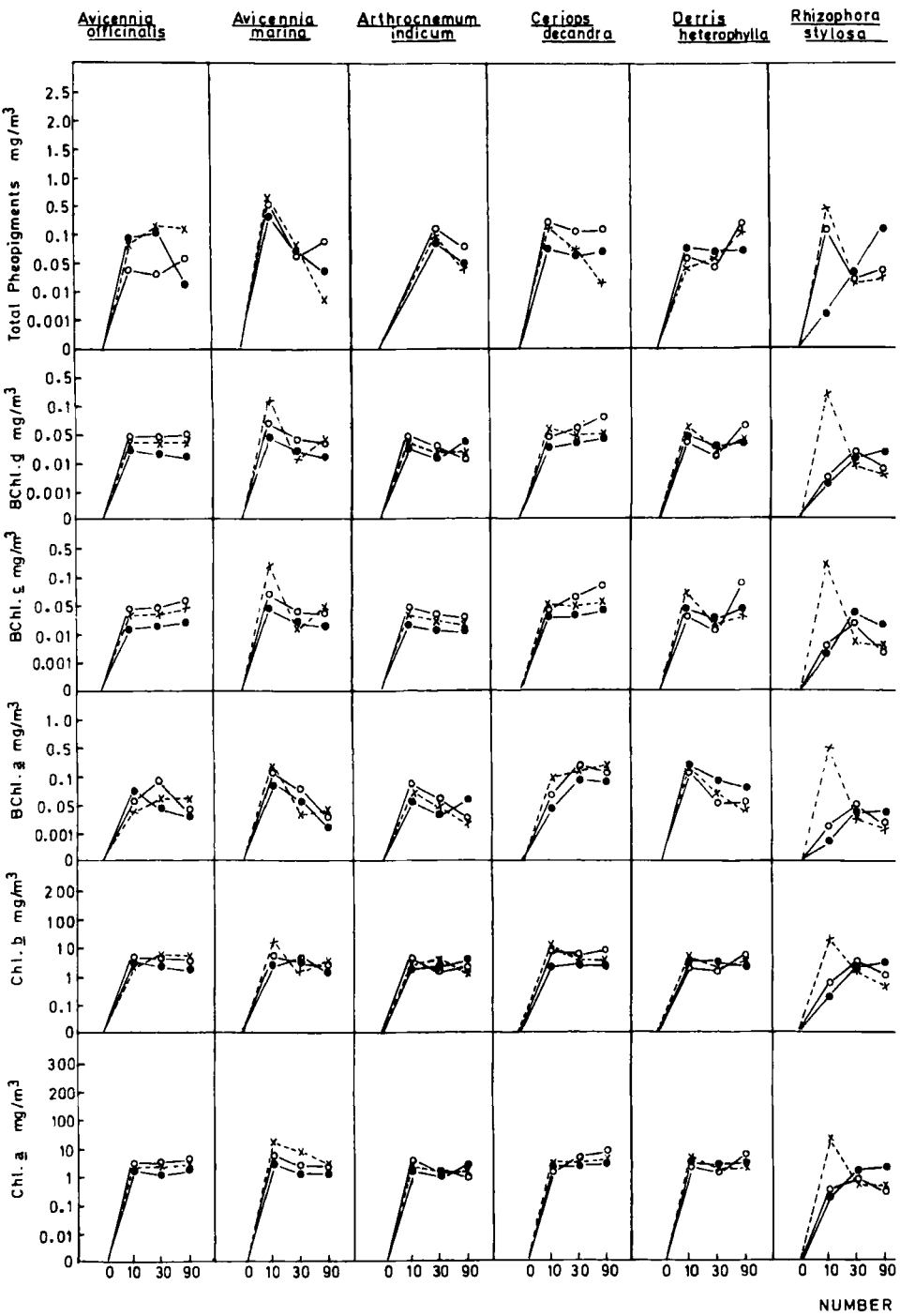
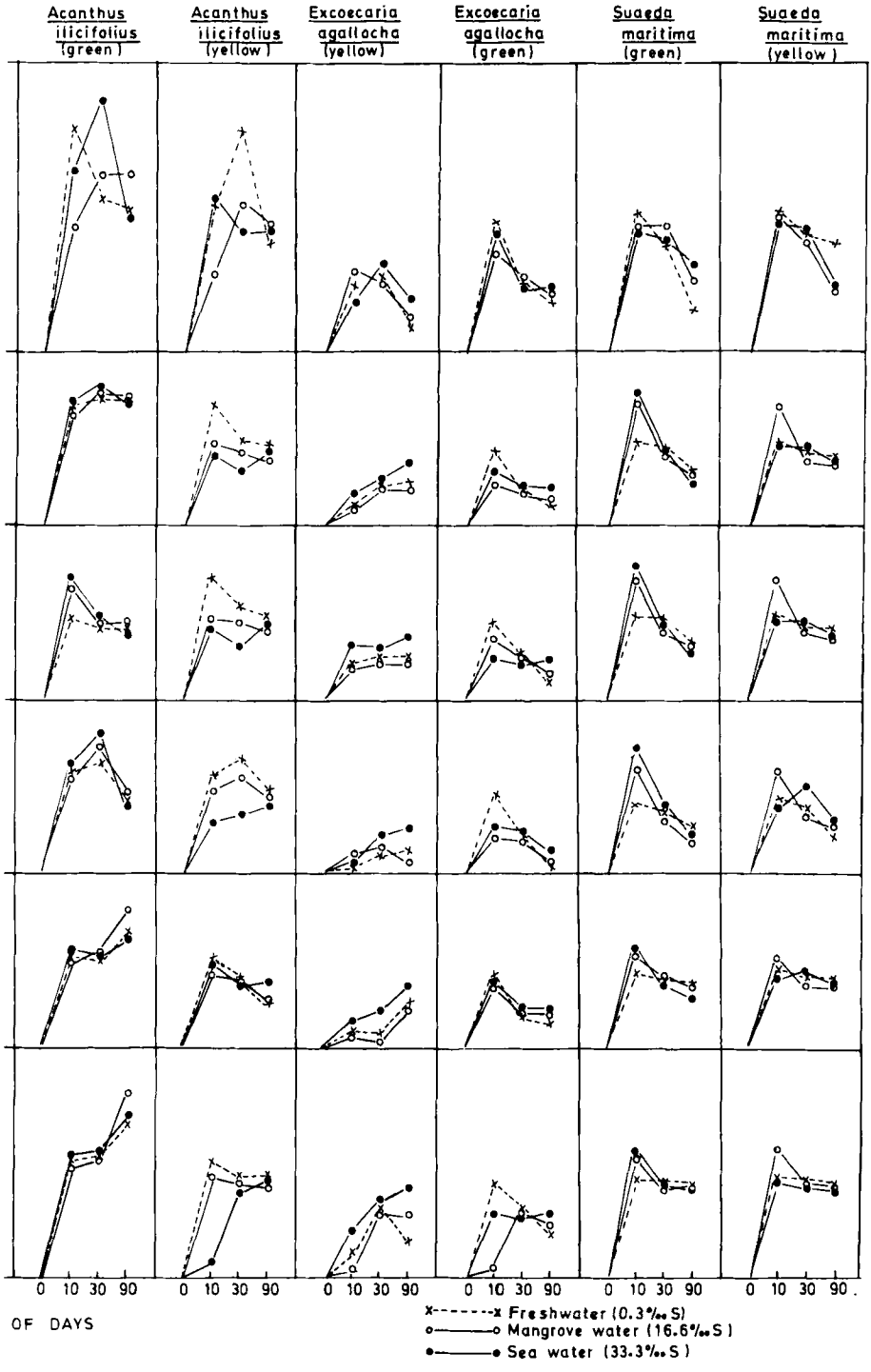


FIGURE 1 Pigment concentrations of the experimental incubating medium of varying salinities at varying intervals of time.



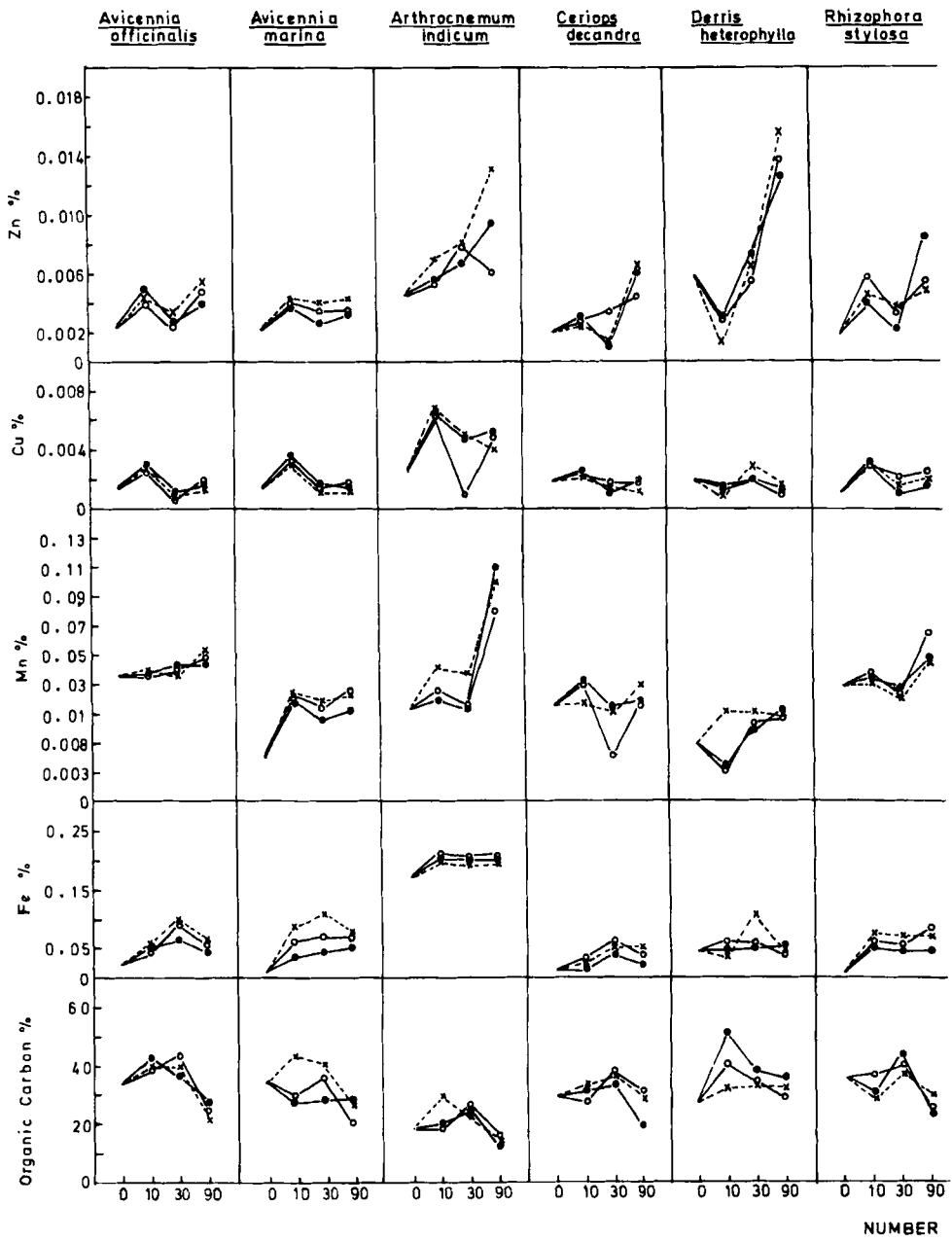
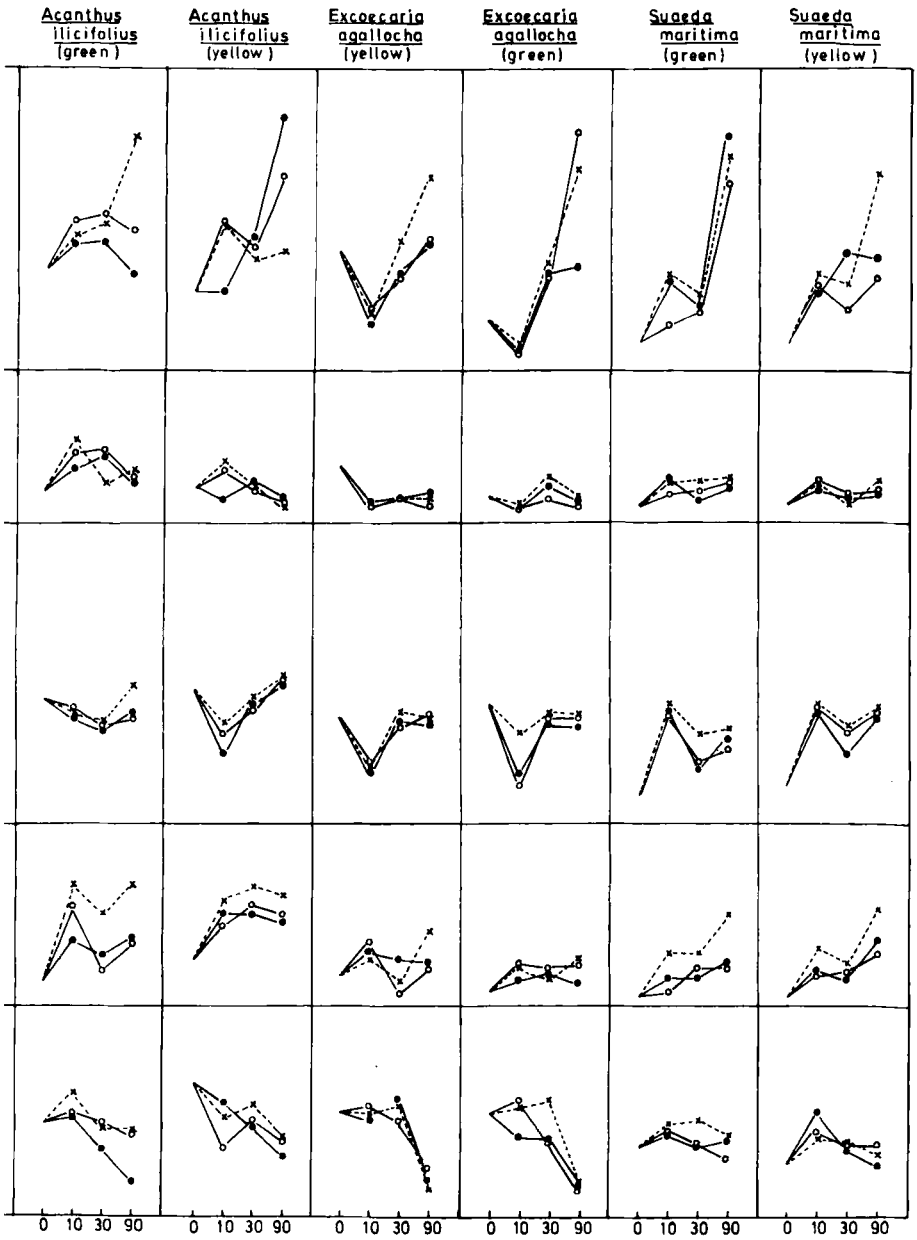


FIGURE 2 The percentage of organic carbon and heavy metal concentrations of the leaves decaying in varying salinities and at varying intervals of time.



study were collected during December (north-east monsoon period on south-east coast of India). Of the trace elements analysed in green and yellow leaves of fresh and degrading condition iron and manganese showed a higher percentage than zinc and copper (*vide* Table 2, Fig. 2). When freshwater was used as the experimental incubating medium, certain vegetation like *Excoecaria agallocha* and *Suaeda maritima* yielded higher values of iron in the 90 day studies (Fig. 2). This might be due to the ability of the medium and material (freshwater and leaf) to attract certain bacterial flora and microfauna, and thus pave the way for increased biomass and induce changes in elemental composition. The very structure of chlorophyll, once decomposition sets in, would facilitate the liberation of binding elements like iron and magnesium to the water. The favourable pH would act as a catalyst for the entire procession of events. Microbes accumulate elements either by consuming leaves or by adsorbing them from the incubating medium, or at favourable pH by both methods. With the long term incubation, the manganese percentage increased in *Arthrocnemum indicum* and *Excoecaria agallocha.*

2. Degradation of leaves in the laboratory

(i) *Release of organic materials:* The organic carbon level of fresh leaves increased during biodegradation. Microbial (fungal and bacterial) colonization and the development of assemblages of ciliates and other organisms were responsible for this increase. During the process, the leaves attained peak organic carbon value after 10 days; the value then declined (Fig. 2). An initial increase in the carbon and nitrogen content of decaying leaves was observed by Godshalk and Wetzel (1978). The rate and magnitude of this increase varied in different species. For the purpose of discussion the 90 day duration of the experimental studies on biodeterioration will be considered in 3 periods as arranged below:

(i) Short-term period (0–10 days)
(ii) Middle-period (11–30 days)
(iii) Long-term period (31–90 days)

The leaves of *Avicennia marina, Acanthus ilicifolius* (green), *Arthrocnemum indicum, Derris heterophylla, Excoecaria agallocha* and *Suaeda maritima* (yellow) attain maximum organic carbon values within the short-term period, after which it started to decline. This could be

due to heterotrophic bacteria utilising the organic carbon source. *Avicennia officinalis*, *Ceriops decandra*, *Excoecaria agallocha* (green), *Rhizophora stylosa* and *Suaeda maritima* (green) attained maximum organic carbon content in the middle-period of the experimental span of time.

The organic carbon content of green and yellow leaves decreased during the later stages of decomposition (long-term period: *vide* Fig. 2). A similar trend was observed in withered *Rhizophora mucronata* leaves at Goa (Sumitra Vijayaragavan *et al.* 1980). The increased organic carbon content reflects an increase in protein content which could serve as a source of protein if used as an ingredient for formulated prawn diet. During the period of the experiment, the rate of increase in organic carbon content in the various species varied with salinity.

The following inferences and conclusions flowing from the present investigation *inter alia* would be useful in the preparation of efficient feed from the green and senescent yellow leaves: (1) Species such as *Ceriops decandra*, *Avicennia officinalis*, *Derris heterophylla*, *Excoecaria agallocha* (yellow) when kept soaked in mangrove channel water yielded higher organic carbon content, whereas *Rhizophora stylosa*, *Suaeda maritima* (green), *Arthrocnemum indicum* and *Acanthus ilicifolius* (green) when incubated in freshwater, gave higher values of organic carbon; and *Suaeda maritima* (yellow) and *Excoecaria agallocha* (green) showed a higher concentration of organic carbon using sea water as a soaking medium. (2) Among the species of halophytes investigated, higher percentages of iron and copper were found in *Arthrocnemum indicum*; and zinc and manganese were found to be high in the *Acanthus ilicifolius* leaves. The decomposing leaves of *Suaeda maritima* and *Derris heterophylla* showed an increase in zinc concentration between 5 and 10 fold over a 90 day period.

The various changes occurring in leaves during the degradation process have been observed and listed by Odum *et al.* (1979) as follows:

(a) Loss of soluble compounds resulting in loss of dry weight, rapid loss of sugars, starches and organic acids.
(b) Microbial colonisation and increase in attached bacteria and fungi.
(c) Mechanical fragmentation.

Similarly, in the present study the loss of chlorophylls from the leaves and their release to the milieu was noticed. Certain elements like Zn, Mn, Fe, Cu were retained within the leaves as evidenced by their

TABLE III

The organisms involved in the *in situ* decomposition process of mangrove litter

Organisms	Vegetation		
	R. stylosa	*A. marina*	*B. cylindrica*
Bacteria	*Bacillus*	*Bacillus*	*Bacillus*
	Micrococcus	*Micrococcus*	*Micrococcus*
	Vibrio	*Pseudomonas*	*Vibrio*
	Alcaligenase	*Alcaligenase*	*Alcaligenase*
	Enterobacteriaceae	*Enterobacteriaceae*	*Pseudomonas*
Fungi	*Actinomysid* sp.	*Auresbasidium* sp.	*Actinomysid* sp.
	Sterile mycelium	*Absidia* sp.	*Auresbasidium* sp.
	Penicillium sp.	*Curuvularia* sp.	*Sterile mycelium*
		Fusarium sp.	
		Phoma sp.	
Nematodes	*Linhomoeus* sp.	*Adoncholaimus* sp.	*Adoncholaimus* sp.
	Adoncholaimus sp.	*Desmodora* sp.	*Linhomoeus* sp.
	Theristus sp.		
	Sphaerolaimus sp.		
	Desmodora sp.		
Amphipods	*Maera othonides*	*Grandidierella gravipes*	*Grandidierella* sp.
	Grandidierella gilesi		*Maera othonides*
	Corophium madrasensis	*Corophium triaenonyx*	*Corophium madrasensis*
	Eriopisella chilkensis	*Gammaropsis esturinus*	*Paracalliope indica*
	Gammaropsis esturinus	*Paracalliope indica*	
Isopods	*Cirrolina* sp.	*Cirrolina* sp.	*Cirrolina* sp.
			Synidotea sp.
Tanaeids	*Tanais philetareus*	—	—
Polychaetes	*Spionidae* sp.	*Spionidae* sp.	*Spionidae* sp.
	Tylonereis sp.		*Tylonereis* sp.
Molluscs	—	*Laternula* sp.	*Laternula* sp.
		Musculus sp.	*Musculus* sp.

percentage increases (Fig. 2). Further, in certain cases (*Excoecaria agallocha* and *Derris heterophylla*) the loss in percentage of Zn and Mn during the initial stage (10 days) could be due to the microbial colonisation and increase in colonies of attached bacteria and fungi.

It is interesting to note that Odum *et al.* (*op. cit*) observed from their experiments that only 9% of original leaf remained in the litter bags placed in sea water, 39% in brackish water and 54% in freshwater after 4 months. They also observed that after a year, those leaves placed under dry conditions retained 35% of their original weight. The mesh size (2–4 mm) of the litter bags restricted the entry of large detritus consumers. In our litter breakdown study conducted in the mangrove channel, we used Velon screen bag nets (1.20 mm mesh size). These bags would permit entry of young amphipods, isopods, tenaids and

nematodes (Table 3), but prohibited large sized detritus consumers. They mechanically comminute the decaying leaves, and between 10 and 20% of original leaf remained after a period of 45 days.

(ii) *Release of chlorophyll from the leaves:* In the present study, the leached out pigment values from the leaves kept in different experimental waters of varying salinity exhibited identical patterns. However, a higher range of variation was observed with species such as *Avicennia marina*, *Ceriops decandra*, *Excoecaria agallocha*, *Acanthus ilicifolius* and *Rhizophora stylosa*. In general, chlorophyll *b* values were higher than chlorophyll *a* in many of the samples analysed. In *Suaeda maritima*, the rate of release of chlorophylls from its cladodes to the medium was quickest in the short-term period followed by a gradual decrease with time. Moreover, chlorophyll release into the aquatic experimental medium was very high when using sea water as the medium. Chlorophyll release into the water progressively decreased from higher to lower salinities (Fig. 1). It is of interest to note that the chlorophyll values were extremely high in the freshwater experimental series of *Rhizophora stylosa* during the short-term period, but not so in the intermediate and higher saline waters or in later stages (30 and 90 days). The higher wax, lignin and tannin content of *Rhizophora stylosa* leaves might be responsible for this variation. The poor chlorophyll leaching in *Excoecaria agallocha* might be due to the presence of latex in their leaves. The bacteriochlorophylls *a*, *c*, *d* were higher during the initial stages (10 days) in most of the leaves in all salinity media. Among the analysed halophytes, the capacity for pigment leaching was greater when kept in a freshwater medium (0.30‰ S) for *Avicennia marina*, *Derris heterophylla*, *Rhizophora stylosa*, *Acanthus ilicifolius* (yellow) and *Excoecaria agallocha* (green). When using the mangrove channel water of 16.60‰ S. the pigment leaching capability was high in *Arthrocnemum indicum*, *Ceriops decandra* and *Suaeda maritima* (yellow). In the case of *Acanthus ilicifolius* (green), *Excoecaria agallocha* (yellow) and *Suaeda maritima* (green) the propensity for leaching was high when kept in sea water of salinity (30.30‰.

In the case of *Suaeda maritima*, the dissociation of chlorophyll from the cladodes was rapid during the degradation process. High chlorophyll values were observed in the water on 10th day and the values gradually declined towards the 90th day. Microorganisms could easily invade and start comminution of the cladodes because of the presence of water storage soft parachymatic tissue. *Suaeda* spp. are among the pioneers

in colonisation of new mangrove lands; hence the ability for fairly rapid degradation of this vegetation would promote fertility, paving the way for further colonisation by various other types of vegetation.

3. Biota of degrading leaves

The breakdown of decaying plant materials to particulate organic matter and to fine detritus is a complex process of ecological energetics. In the natural environment (litter bag experiment), initial decomposition was undertaking by innumerable microorganisms such as bacteria, yeast, fungi and ciliates, these were followed by higher organisms such as tanaids, amphipods, isopods, decapod larvae, nematodes and polychaete worms continuing until decomposition is complete and the energy transferred to higher trophic levels.

In these experiments the bacterial populations were higher at the 15 day than at the 25th (Table 4) when there was invasion by higher trophic organisms. During the 45th day sampling, the nematode population was dominant in *Bruguiera cylindrica* detritus. In the case of *Avicennia marina* high population of amphipod, isopod and tanaids were noticed, but the nematode population was poor. In the case of *Rhizophora stylosa* the tube-dwelling polychaete population was abundant whereas the amphipod, isopod and tanaid populations were scanty. Furthermore, the presence of remnants of crustacean appendages among all detrital samples reveals the frequent visits of other higher carnivores. The above observations would reveal the participation by successively higher trophic organisms in detrital food utilisation. The organisms involved in the comminution of mangrove litter from the *in situ* experiments are listed in Table 3.

In the laboratory microcosm study it was found that besides bacteria and fungi, ciliates played an important role in the biodegradation of

TABLE IV

Bacterial population of the *in situ* litter bag experiment

Samples	Bacterial population (CFU) × 10^6		
	0 day	15 day	25 day
Water	0.41	0.46	0.54
Avicennia marina	0.20	10.92	9.62
Bruguiera cylindrica	0.32	6.68	5.32
(?) *Rhizophora stylosa*	0.25	52.24	2.18

leaves. In some instances, larvae of insects (probably of two species) would penetrate the decaying cladodes/leaves of *Suaeda maritima*, *Arthrocnemum indicum*, *Acanthus ilicifolius* and *Ceriops decandra*. It was interesting to observe that in such leaves harbouring a good population of larvae, ciliates were poorly represented suggesting the possible predation of ciliates by insect larvae. Moreover, the storage paranchymatic tissues (meant for water storage in cladodes) of *Suaeda maritima* and *Arthrocnemum indicum* were used to house these larvae during the process of degradation. These larvae, after a brief period, encysted and became dispersed in the water. The cysts would float for sometime before adhering to the walls above the water surface of the container. Predation of ciliates by the larvae delayed the degradation process.

4. Biota-related chlorophyll increase:

The freshwater experimental medium containing *Avicennia marina* and *Rhizophora stylosa* showed higher values of chlorophylls *a*, *b* and bacteriochlorophyll *a*, *c*, *d* than the channel water from mangroves and the sea water media. A similar trend was also observed with yellow and senescent leaves of *Acanthus ilicifolius* and *Excoecaria agallocha* (Fig. 1). An interesting green pigmented protozoan was observed in the freshwater experimental medium of *Avicennia marina*. These organisms were noticed only in the series of freshwater experiments on *Avicennia marina*. The biomass of these organisms was very high during initial stages (10–20 days). It gradually decreased as the days wore on. The organisms encountered in the present study seem to be green *Paramesium* sp.

5. Comparison of fully grown green and senescent yellow leaf biodegradation process:

For a known weight, fresh green leaf covered greater area than yellow leaf of the same species (Table 1). This may be due to the synthesis of lignin materials in the older leaves. Generally, the yellow leaves showed more manganese content than green leaves (Fig. 2). The pigment content of yellow leaves was very poor when compared to the green leaves. This was evident in *Acanthus ilicifolius*, *Excoecaria agallocha* and *Suaeda maritima* leaves/cladodes.

The reason for the decrease of chlorophyll during the process of

degradation could be attributed to the following possible factors working separately or jointly.

(i) Ciliates primarily consume the chloroplast/plastid material.
(ii) Chloroplast will gradually fade away in the absence of active photosynthesis.
(iii) Larvae of certain insects also feed on the chlorophylls.

Hence the fall in value of chlorophylls. In the *in situ* series conducted in the mangrove channel, the leaves were completely decomposed in 45 days because of the cumulative and intensive comminution at later stages by amphipods, isopods, decapod larvae, polychaetes, etc. The occurrence of insect larvae was replaced in the field by nematodes such as *Linhomoeus* sp., *Adoncholaimus* sp., *Theristus* sp., *Desmodora* sp., etc. which also normally occur in the Pichavaram natural mangrove environment (Sultan Ali, *per comm*). The probable reason for the absence of nematodes in the laboratory experiments could be due to the lack of a soil substratum. The ecological-niche simulated in the laboratory conducted in shade without soil became slightly anaerobic and was probably unsuitable for the establishment of other organisms. Moreover, in nature bacteria would achieve fragmentation of the leaves more rapidly by virtue of their ability to produce coenzymes, which respond to a wide variety of organic substrates (Brock, 1970).

6. Importance of mangrove leaf litter production

The mangrove complex ecosystem is bathed by neritic water, backwater, estuarine water and freshwater. The admixed waters are rich in dissolved oxygen, humic substances, nutrients, nanophytoplankton, plankton, shellfish and fish. About 200 species of fish, 50 species of prawns, 30 species of crabs and 20 species of molluscs use the mangrove ecosystem either as larvae or juveniles or subadults or adults in one way or other. The pH of water is always on the alkaline side (7.0–8.5), most often the soil is also rich in organic carbon and nutrients (Sundararaj and Krishnamurthy, 1974; Krishnamurthy and Prince Jeyaseelan, 1981; Subramanian, 1983).

The density of trees in the mangrove forests varies on the different islets and parts. The smaller vegetation, comprising younger trees and plants of less than 10 cm girth at breast height (gbh) varied from 970 to 3,000 trees/ha, (mean 2,110 potential trees/ha). The density of larger trees (more than 10 cm gbh) varied from 80 to 450 trees/ha with an

TABLE V

Estimates of mangrove leaf litter production

Locality	Type of mangrove	Production (t/ha/year)	Source
A. *Mangrove forests*			
Florida†	*Rhizophora*	7.30	Heald (1971)
	Avicennia	4.85	Lugo & Snedaker (1974)
Puerto Rico†	*Rhizophora*	3.65	Golley *et al.* (1962)
Mgeni estuary,†	*Avicennia*	9.67	Steinke (1980)
South Africa	*Bruguiera*	9.71	
Chantaburi,†	*Ceriops, Lumnitzera,*	6.26	Aksornkonae & Khemnark (1980)
Thailand	*Rhizophora*	7.52–8.31	
	Avicennia, Bruguiera, Xylocarpus		
Phuket, Thailand†	*Rhizophora*	6.70	Christensen (1978)
Matang, Malaysia†	*Rhizophora*	6.60–10.30	Ong. *et al.* (1979)
Sydney region†	*Avicennia*	4.58	Goulter & Allaway (1980)
Pichavaram, India	*Rhizophora* spp.	11.62	Present study
	Avicennia spp.	3.35	"
Panama	*Rhizophora*	7.10	Golley, *et al.* (1968)
B. *For comparison with other forests:*			
Panama	Moist tropical forest	8.80	Recalculated from the total litter data of Golley *et al.* (1975) to leaf litter based on our results.
Pasoh, Malaysia	Lowland Dipterocarp forest	8.30	Bullock (1973)

† *Source:* Macintosh, D. J., 1982. Fisheries and aquaculture significance of mangrove swamps with special reference to the Indo-West Pacific region. In: Recent advances in aquaculture, (eds) James F. Muir and Ronald J. Roberts, Croom Helm, London pp. 3–86.

average of 320 trees/ha. In various areas of the ecosystem, the leaf litter (mainly contributed by species belonging to *Rhizophora* and *Avicennia*) production varied from 0.90 to 3.10 gm/m^2/day, with an average of 1.65 gm/m^2/day (602.25 gm/m^2/yr) on dry weight basis (courtesy: Mr. M. Muniyandi). A comparison of litter production of some mangroves of the world is given in Table 5. The litter production of Pichavaram mangroves compares favourably with these estimates. In this context it is of interest to note that the estimates of marsh grass production as reported in literature varies from 500 to 2,800 gm/m^2/yr (dry weight basis). The seston content in the Pichavaram mangrove water was often as high as 0.97 gm/l in certain parts.

The total litter fall from its exclusive wooded parts (of about 780 ha), even for this small area accounts for an impressive 7,457.07 tonne/yr. A reference to Table 2 will show that the organic carbon of leaf litter on a dry weight basis of the various halophytes ranged from 10.70% (*Salicornia brachiata*) to 48.99% (*Aegiceros corniculatum*). The woody species such as *Rhizophora*, *Avicennia*, *Excoecaria*, *Bruguiera*, etc., contain in their leaf litter about 35% carbon. Lakshmanan and Rajeswari (1983) have found that the organic carbon content of *Rhizophora apiculata* and *Rhizophora lamarckii* collected from here were higher in young and mature leaves, (34.70% and 41.70% respectively) than the shoot within the bud scales and in medium sized leaves (26.40% and 31.60%). In *Rhizophora stylosa*, it was higher in young and medium sized leaves (34.20% on average), than in the shoot within the bud scale and in mature leaves (varying from 31.90% to 33.80%, Laksmanan and Rajeswari, 1983). These values broadly agree with the present findings on green and yellowing leaves of *Rhizophora stylosa*. The maximum leaf litter was accounted for by 3 species belonging to *Rhizophora* and 2 species of *Avicennia* and their organic carbon values were also high.

The total production of leaf litter (that had fallen and remained) within the wooded area was 7.48 tonne/ha/yr. The region enjoys semi-diurnal tides and there are 3 major estuarine mouths and neritic inlets connecting the ecosystem with the sea. They maintain contact with the sea and with the spring semidiurnal tidal influence extending to a distance of about 15 km, and maximum spring tidal amplitude of 1.50 m, the marine element is predominant in the ecosystem. However, a considerable freshwater flow, through the drainage of irrigation channels and the Coleroon distributory of the Cauvery river delta, is also responsible for keeping the ecosystem in a healthy, dynamic and fertile state. The adjoining backwater also connects this to the Vellar estuary besides its connection to the sea.

The admixed waters are rich in dissolved oxygen and nutrients and highly productive in terms of primary, secondary and tertiary production. Based on salinity values observed over the past two decades in the mangrove ecosystem complex, it may be inferred that 30% of the enclosed waters could be labelled as mangrove resident water, 10% of backwater-estuarine origin and 60% of the Bay of Bengal origin. In other words the admixture of waters consists of a composition predominantly of the marine element, followed by the fluviatile—backwater and estuarine element complex in the proportion of 60:30:10.

The total litter production (twigs, leaf, flower, etc.) for the wooded areas of these mangrove would be, as already stated, 7,457.07 tonnes/yr, of this the leaf litter amounts to some 6,000 (to be exact 5,834.4 tonnes/yr) and in terms of organic carbon (based on Table 2) taking it as 35% on an average on dry weight basis, the total litter dry weight contribution equals to 2,610 tonnes C/yr (for leaf litter alone 2,100 tonnes C/yr). (For the entire 13 km^2 mangrove ecosystem comprising land, water and forests—the maximum would be 12,428.45 tonnes/yr for total litter and 9,724.22 tonnes/yr for leaf litter alone, assuming for the moment that all the waterspread and land areas were covered with litter derived from this forest). Determined on the degree of marine penetration, even a conservative estimate would reveal that some 60% of this mangrove litter produce of 1,566 tonnes C/yr would be exported to the Bay of Bengal to enrich an equivalent of 8,000 ha of sea surface falling within its immediate (10 fathom line) vicinity. The annual mean value of productivity of the sea water was observed as 0.265 gm C/m^2/day (Krishnamurthy *et al.*, 1979). Some 261 tonnes C/yr would be the contribution made by the mangrove ecosystem to the Vellar estuary (for a stretch of 40 ha from its Vellar mouth to a point opposite Biological Station—a distance of one km) and some 783 tonnes C/yr would get deposited within the ecosystem for use by its varied visitors and denizens and to enrich by sedimentation upon the banks and bottom and for building new lands. With accelerated denudation of the forest canopy, we lose not only the land stability and sediment building properties of the mangroves, but also the all round substantial enrichment made by the 'mangal' (Macnae, 1968) to all the adjoining coastal ecosystem.

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