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Seedling Emergence and Growth of Mangrove Avicennia marina (Forssk.) Vierh. Under Different Environmental Conditions in the United Arab Emirates

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SEEDLING EMERGENCE AND GROWTH OF MANGROVE *Avicennia marina* (Forssk.) Vierh. UNDER DIFFERENT ENVIRONMENTAL CONDITIONS IN THE UNITED ARAB EMIRATES

By

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ABSTRACT

Seedling emergence, survival and growth of gray mangrove *Avicennia marina* (Forssk.) Vierh. were studied in relation to different environmental factors through a series of experiments conducted at indoor low temperature, outdoor shaded and field areas at the Marine Resources Research Center, Umm Al Qaiwain. No emergence occurred when seeds were sowed in salinities equal to or higher than 60 ppt. Seedling survival rate decreased with increasing salinity at both indoor and outdoor experimental sites. Faster seedling growth rates were observed under outdoor shaded conditions than under indoor low temperatures. Results of field studies on a sloping beach indicated that the seedling survival was limited to a landward distance of about 5 meters from seawater line, whereas on a flat beach the survival of seedlings was observed up to about 19 meters from seawater line. Mangrove seedling survival growth rates decreased with distance from the seawater line in sloping and flat beaches due to the increase in salinity and depth of ground water. Higher chlorophyll content of the mangrove leaves were encountered in outdoor location than in indoor low temperature area. In the field, the leaf chlorophyll content of mangrove seedlings decreased in

the outward direction from the seawater line. Roots contained more moisture than stems or leaves. Moisture content of roots, stems, and leaves decreased with an increase in salinity of the seedling growing media in indoor areas and with increasing distance from seawater line in the field. In all analysed soil samples, more than 93% sand was found in the field study area; whereas sodium, potassium and calcium carbonate were the dominant chemical constituents of the sediment.

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CHAPTER I

INTRODUCTION

GENERAL

Mangroves are trees or bushes that usually grow between high spring tides and mean sea level. There are about 55 species of mangroves belonging to 21 genera and 13 families (Ghowail *et. al.* 1993) of which around 40 - 45 species occur in South East Asia (Clough, B.F. 1993). Chapman (1975) interpreted that mangroves, as a group, originated primarily in the Indo-pacific region. Mangroves occupy about 160,000 Km^2 world wide (Saenger *et. al.* 1983) and associated estuaries and coastal lagoons 83,000 Km^2 (Kapetsky 1985). The most common genera in the mangrove world are *Rhizophora* and *Avicennia* (Chapman. 1977). *A. marina* (Forssk.) Vierh. comes under class *Dicotyledons*, Sub class *Gamopetalae*, Series *Bicarpellatae* of order *Lamiales*, Family *Avicenniaceae*, Genus *Avicennia* and species *marina* (Pandian, M. 1990). The most luxuriant and diverse mangrove communities are found in the humid tropical and subtropical regions of the world. Mangroves are useful vegetation in a many ways as they protect the shores from sea erosion, provide good breeding and nursery grounds for fish and many crustaceans, used by tribals as housing materials, fire wood, charcoal and fodder for animals. Mangrove swamps are considered productive ecosystems in which the rate of primary productivity is high and trees contribute energy to detrital based marine food webs (Herald 1969, Odum and Herald 1972, Odum *et. al*. 1982, Twilley *et. al*. 1986). Mangroves also serving as a good areas for bees to produce honey. Healthy mangrove ecosystems appear to be more productive than sea grass, marsh and most other coastal systems (Odum, *et. al*. 1982). Golley *et. al*. (1962) reported the mangrove ecosystems produce a net primary production of 930 g m^{-2} yr^{-1} based on CO_2 exchange rates. Noakes (1955) estimated that wood production of an intensively managed Malayan mangrove forest was 39.7 metric ton ha^{-1} yr^{-1}. Teas (1979) suggested a wood production of 21 metric ton ha^{-1} yr^{-1} for a mature non managed red mangrove forest in South Florida, as he obtained his calculations from a litter/total biomass relationship. Litter fall is an important ecosystem process because it forms the energy basis for detritus-based food webs in mangrove swamps. According to Herald (1969), Odum *et. al*. (1975) also found that litter production from riverine red mangrove forests in South Florida was estimated to be 2.4 m^{-2} day^{-1} dry g of organic matter (or 8.8 metric tons ha^{-1} yr^{-1}). Odum *et. al*. (1975)

also found that 9% only of the original dry weight of the litter remained after four months in sea-water. Herald *et. al.* (1979), Lugo *et. al.* (1980) found that black mangrove (*Avicennia germinans*) leaves decompose more rapidly than red mangrove (*R. mangle*) leaves and apparently produce a higher percentage of dissolved organic matter.

According to Collette (1983) many species of fishes move into mangroves at a particular stage in their life history - usually as juveniles, and the success of fisheries in many tropical regions may be closely tied to the health of mangrove swamps which serve as important nursery grounds for many species such as Snappers (Lutjanidae), jacks (Carangidae) and mullets (Mugilidae). Snedaker (1978) estimated that more than 90% of marine species in some regions are found in mangrove swamps during one or more periods of their life cycles. Much of the productivity of mangrove swamps is based on organic detritus of mangrove origin (Odum and Herald 1972, 1975) rather than on phytoplankton or sea grasses. Collette (1983) after surveying the fish communities in 14 mangrove swamps in northern Australia, Papua New Guinea and Irian Java reported the presence of over 200 species from 58 families. According to his data, the 12 families most commonly observed in the mangrove swamps studied were Hemiramphidae, Gobidae, Apogonidae, Tetradontidae, Blennidae, Lutjanidae, Ophichthidae, Eleotridae, Pomacentridae, Ambassidae and Siganidae. He has also calculated that many fishes of economic importance spend part of their life cycles in mangrove swamps.

In Arabian Gulf area, quite recently the mangroves seem to have attracted the attention of agriculturists, marine scientists and coastal development authorities. The common species of mangrove found along the coasts of the United Arab Emirates (U.A.E.) is *A. marina* which is also known as gray mangrove. According to Halwagy *et. al.* (1972) and Zahran (1974), *A. marina* may be the only mangrove species present in the Arabian Gulf area. This species generally grow about up to seven meter in height (Rabanal *et. al.* 1978). Prominent mangrove colonies exhibiting healthy luxuriant growth are present along the shores, nearshore islands and lagoons of Abu Dhabi, Umm Al Qaiwain, Khor Kalba and Ras Al Khaimah whereas only scanty growth of this species is observed in Ajman and certain parts of Dubai. Concerning the survey conducted by the United Nations Development Program (UNDP), the United Arab Emirates has got about 3000 ha of mangroves (Rabanal *et. al.* 1978).

Mangrove afforestation program is one of the projects initiated by the Ministry of Agriculture and

Fisheries of the Government of U.A.E. for the protection of the coast line and development of fisheries and fishery resources of the country. Since large scale variations are observed in Oceanographic and climatological conditions of the U.A.E, the present work is aimed to investigate seedling emergence and changes in the growth parameters of *A. marina* as influenced by the temperature, salinity and the distance from the sea shore line. Such study is significant as no previous work has been done on the effects of environmental conditions on the survival and growth of *A. marina* in the U.A.E.

The seed emergence and seedling growth studies were conducted at indoor low temperature and outdoor shaded conditions through four experiments (Experiments 1 to 4). These experiments were aimed at investigation of the effects of salinity and temperature on the emergence and growth of *A. marina* under two different environmental conditions. Simultaneously, studies were also made in the field which were comprised two experiments (Exp. No.5 and 6) on a sloping beach and one experiment (Experiment No.7) on almost a flat beach near the drain area of fish culture ponds in the Marine Resources Research Centre, Umm Al Qaiwain. These field experiments were intended to study the effect of environmental aspects such as distance from seawater line, ground water salinity and depth of water table on the seedling growth and survival.

The experiments are summarized in Table 1 whereas Fig. 1 is the index map showing the area of the field studies at Umm Al Qaiwain.

CLIMATIC CONDITIONS

The climatic conditions along the United Arab Emirates coastal zone is arid and characterized by high temperature, scanty precipitation, high relative humidity rates, high potential rates of evaporation, and low moderate wind speed. The mean maxima and mean minima values of air temperature, relative humidity and annual rainfall for Umm Al Qaiwain are shown in Table 2. Hot weather (mean maximum air temperature > 35°C) prevailed from June to September. Relative humidity is usually high (mean maximum relative humidity > 85%) for most of the year. Wind data for Umm Al Qaiwain station indicated a mean wind speed of 7.5 Km/hr during 1991 (Climate data, Ministry of Agriculture and Fisheries 1993). The prevailing low energy wind encourages the development of dew and fog in arid coastal environment such as that of UAE. Dew is an effective element in such arid conditions to wash out the salts accumulating on mangrove leaves and also to feed the soils of mangrove with some fresh water at night, especially during hot dry summer (Embabi 1993).

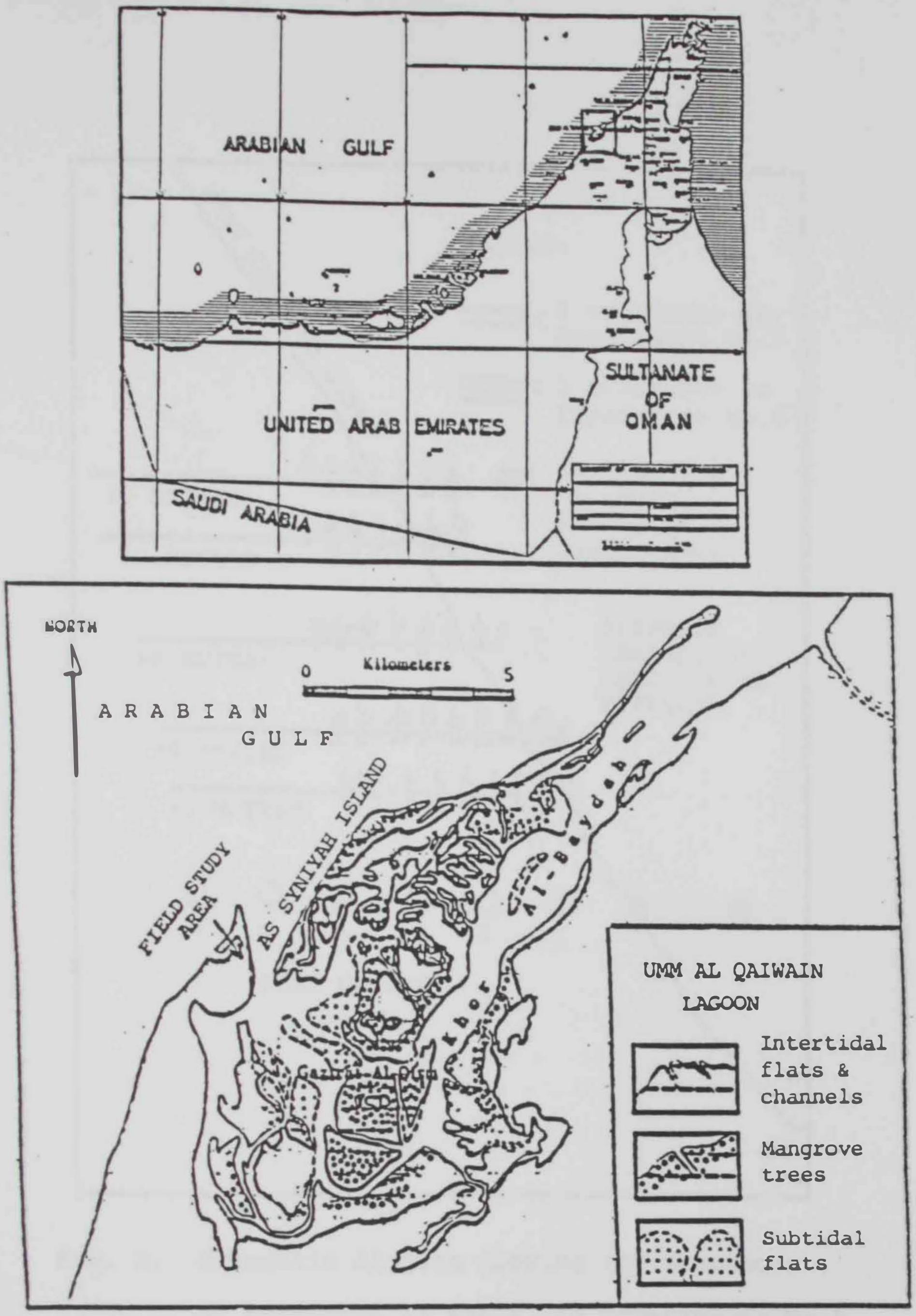

Fig. 1. Index map showing the area of field study.

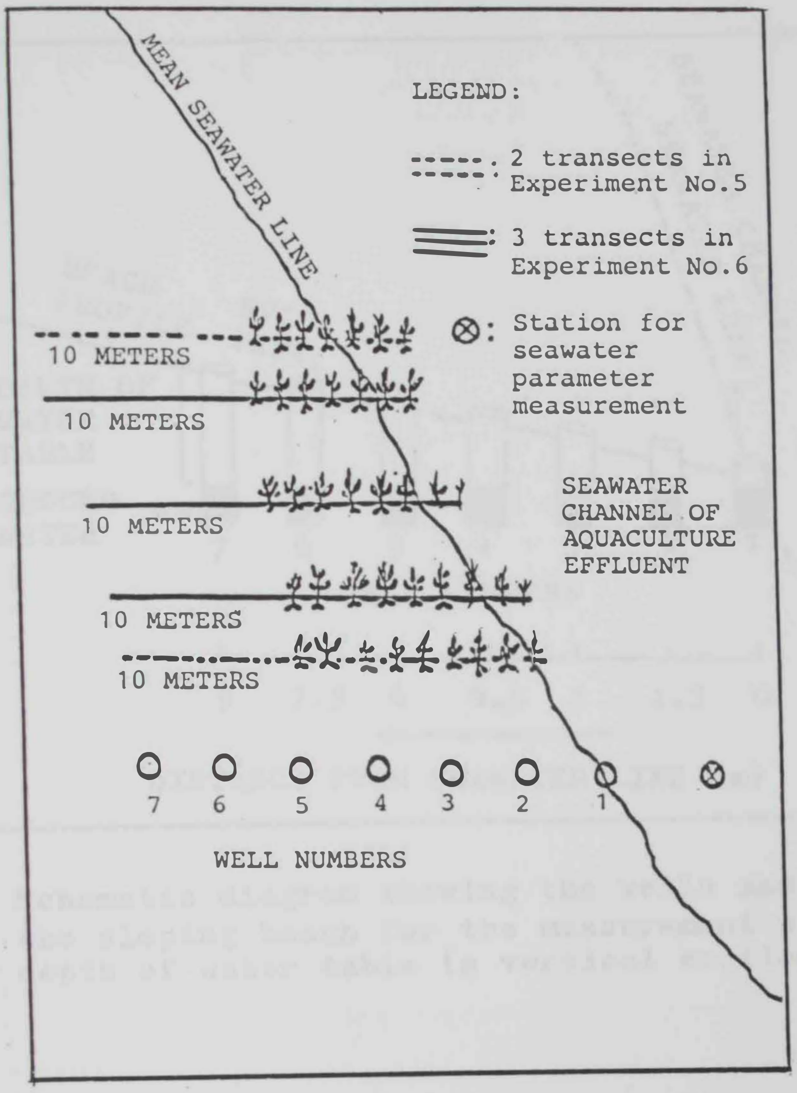

Fig. 2. Schematic diagram showing the transects of seedlings in the Field Experiments No.5 and 6, and the location of "WELLS" on the sloping beach at Umm Al Qaiwain.

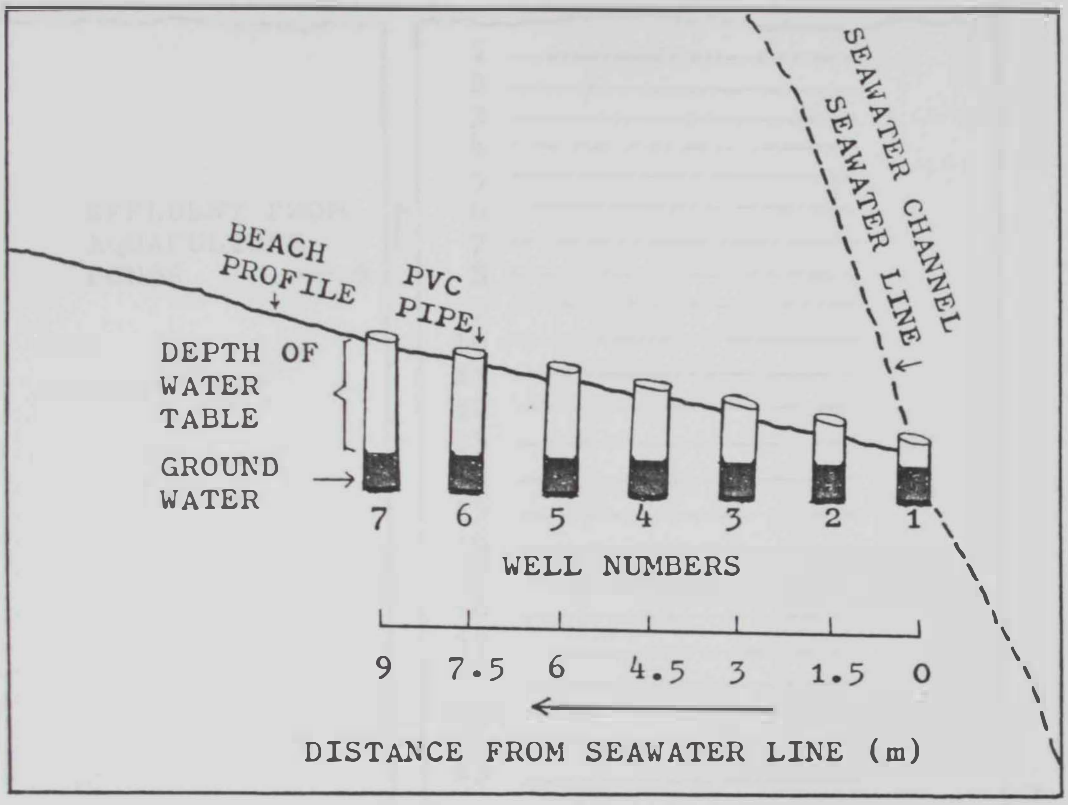

Fig. 3. Schematic diagram showing the wells made on the sloping beach for the measurement of the depth of water table (a vertical section).

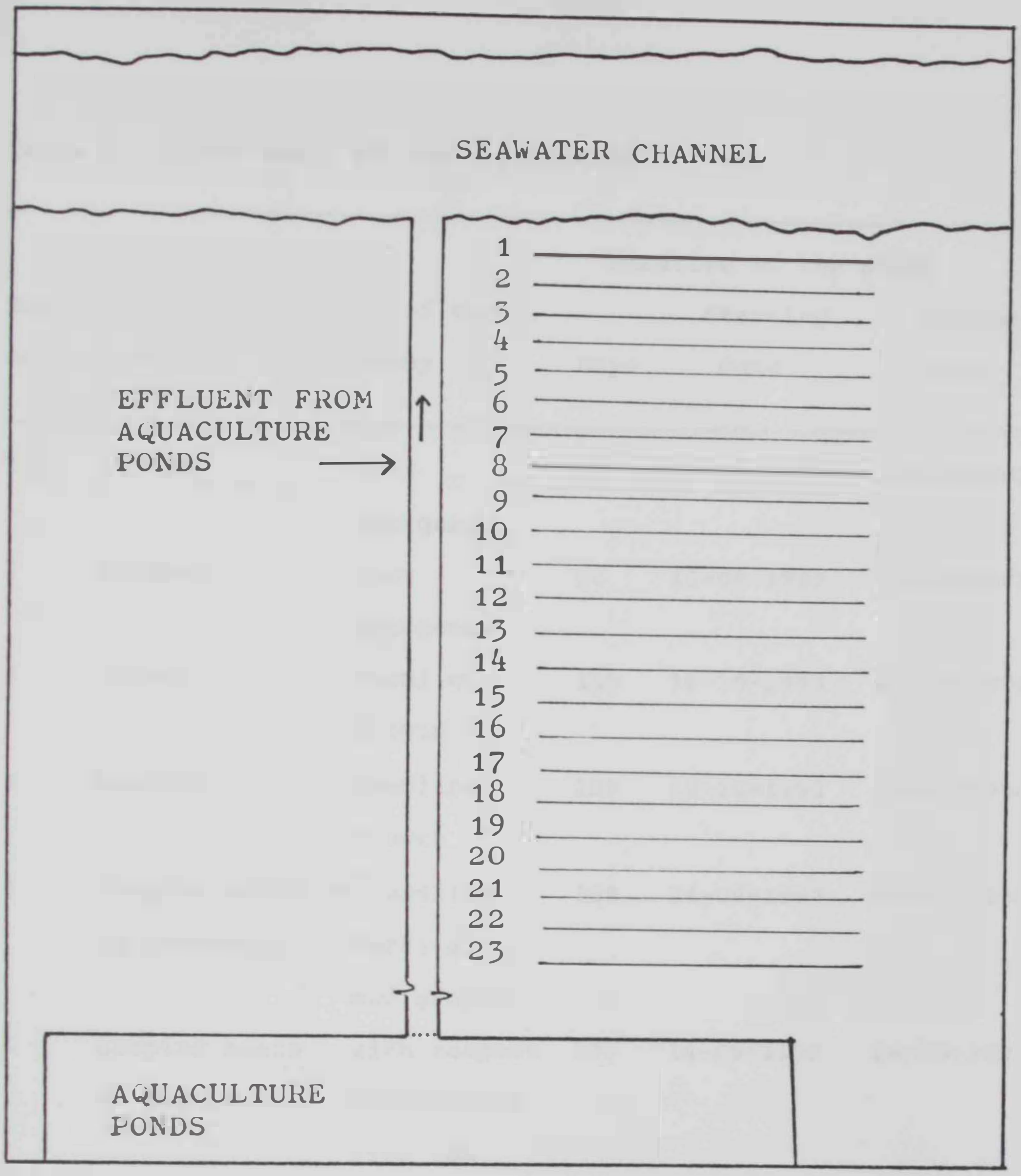

Fig. 4. Schematic diagram showing the twenty-three lines which were sown with about sixty mangrove seeds per line of experiment No. 7 on a flat beach.

Table 1. The summary of the experiments.

Expt. No.	Location	Title of the study	Duration of the study Days	Starting date	Ending date
1	Indoor	Seed emergence	29	19-09-1993	18-10-1993
2	Outdoor	Seed emergence	20	19-09-1993	9-10-1993
3	Indoor	Seedling growth	130	18-10-1993	25-02-1994
4	Outdoor	Seedling growth	128	18-10-1993	23-02-1994
5	Sloping beach (2 transects)	" Seedling survival and growth	138	24-09-1993	09-02-1994
6	Sloping beach (3 transects)	with respect to distance from sea	377	14-09-1992	26-09-1993
7	Flat beach (23 transects)	water line and water table"	326	1-10-1992	22-08-1993

Table 2. Monthly mean maximum and mean minimum values of climatological parameters in Umm Al-Qaiwain (1985-1991): Air temperature°C = AT°C, surface water temperature °C = SWT°C, relative humidity = RH%, surface water salinity in ppt = SWS, water dissolved oxygen in ppm = WDO, mean surface wind (1991), Km/hr = W.

	AT°C			RH%				
Month	Max.	Min.	Swt°C	Max.	Min.	SWS	WDO	W
Jan	22.9	14.5	20.0	90	49	40.1	5.5	8.7
Feb	23.2	15.6	19.6	85	50	40.4	6.5	10.3
Mar	25.6	17.8	24.4	86	45	40.0	6.4	6.4
Apr	28.9	20.8	28.0	87	36	39.9	5.8	8.7
May	33.5	24.2	30.0	90	37	41.4	5.6	12.0
Jun	35.9	27.0	32.4	83	39	41.6	5.8	10.5
Jul	37.8	27.0	33.2	85	43	42.0	5.8	8.3
Aug	38.1	30.3	33.4	87	47	42.5	5.0	9.7
Sep	36.1	27.7	32.1	88	43	42.4	4.3	9.9
Oct	33.1	29.4	30.4	86	41	41.7	4.0	7.5
Nov	29.4	20.1	25.0	87	38	40.6	5.8	8.2
Dec	25.1	16.7	19.5	85	42	39.4	6.6	8.7

Data source: Climatological data, Ministry of Agriculture and Fisheries, U.A.E. (1993), and technical report No.9, Fisheries Department, Ministry of Agriculture and fisheries, U.A.E.

Table 3. Rainfall data for Umm Al Qaiwain station.

Year	Total annual rainfall (mm)
1981	32.9
1982	285.4
1983	117.2
1984	39.1
1985	16.4
1986	58.0
1987	103.9
1988	173.7
1989	173.5
1990	114.5
1991	83.3
Average	108.9

Data collected at Marine Resources Research Centre, Ministry of Agriculture and Fisheries Umm Al Qaiwain, United Arab Emirates.

For eleven years (1981- 1991) the average annual rainfall for Umm Al Qaiwain was 108.9 mm (Table 3).

OCEANOGRAPHIC CONDITIONS

There are many lagoons of various origins along the coast of UAE. Many of these lagoons are semi-closed by barrier islands which protect the coast from high waves, on-shore winds and strong tidal currents. A typical example is the Umm Al Qaiwain lagoon along the west coast of UAE. Fine particles of silt and sand that enter the lagoon by tidal currents are allowed to settle down on the bottom of the lagoons and along the coastline. Such conditions usually favour the growth of mangroves. Local distribution of mangrove in UAE lagoons is found to be associated with sheltered intertidal flats characterised by loose muddy to sandy soils, not rising more than 2 m above low tide, diurnal tide with speeds not exceeding 0.5 knot and underground water seepage (Embabi 1993). Oceanographic parameters of the nearshore waters play an important role in the development of mangroves along the coast of UAE. Table 2 gives the monthly values of water parameters observed at surface layers in Umm Al Qaiwain lagoon during 1982. Average surface water temperature ranged from 19.6 to 33.4°C, surface water salinity from 39.4 to 42.5 ppt and surface water dissolved oxygen from

4.0 to 6.6 ppm in Umm Al Qaiwain lagoon (Ali and Cherian 1983). These ranges are quite suitable for mangrove growth. Leith and Barth (1983) reported that mangrove can grow when temperatures in the root zone are kept below 50°C. High water temperatures can be limiting for mangrove growth. Mc Millan (1971) reported that seedlings of black mangrove (*Avicennia germinans*) were killed by temperatures of 39°C to 40°C although established seedlings and trees were not damaged. High temperature tolerance range for adult mangroves is not well known. Yet it is suspected that water temperatures in the range 42 to 45°C may be limiting (Odum *et. al.* 1982). Salinity of lagoon water is higher than that of nearshore waters in U.A.E (Rifat Ali and Thomas Cherian 1983). It is reported that an individual mangrove species utilizes a variety of mechanisms to maintain suitable salt balance (Albert 1975) which could be salt excretion.

CHAPTER II

CHAPTER II

REVIEW OF LITERATURE

Substantial amount of work was reported on different aspects of mangroves. On a worldwide basis distribution, diversity and zonation of mangrove vegetation have been described by many authors (Macnae 1968, Walsh 1974, Chapman 1976, Semeniuk 1983, Ruwa 1993). Air temperature, ocean currents, protection, shallow shores, salt water tidal range and muddy substratum are basic requirements on which mangrove formation depends (Dagar. *et. al.* 1993). Chapman (1975) indicated that the nature of mangrove zonation depends on tidal movements, soil type, salt contents of soil and water, and light. Waisel (1972) reported that mangroves do not satisfactorily develop in regions where the annual average temperature is below 19°C. Lugo and Zucca (1977) studied the impact of low temperature stress on Florida mangroves. Excessive high temperature may be important constraint to a successful establishment of mangroves. Craighead (1964) reported that areas where temperature may exceed 43°C remain barren. Temperature over 37°C inhibited rooting of black mangrove. Exposure to temperatures of 39-43°C for 48 hours causes the death of rooted but stemless seedlings (Mc Millan 1971). According to Mc Millan (1971) high water temperature could be a limiting factor for mangrove growth. Tomlinson (1986) stated that the upper limit of salinity hardiness of any mangrove tree species is 90-100 ppt. Soto and Jimenez (1982) reported that some mangrove species were able to grow on a salinity as high as an annual average of 100 ppt, with maximum up to 150 ppt. The mechanism of salt exclusion in certain mangrove species was studied in detail by Scholander (1968). Salt secretion processes in some species were investigated by Scholander (1968) and Atkinson *et. al.* (1967). About 40% of the incoming salts were removed through secretion at the leaf and salt exclusion rates of 78-86% were reported in *A. marina*. Although current understanding of mangrove peats and soils is fragmentary and often contradictory, mangrove ecosystems appear to flourish only on muds and fine grained sands (Odum *et. al.* 1982). Mangrove vegetation promotes sediment accretion and one species prepares the way for another (Watson 1928; Rosevear 1947; Banijbatana 1958; Kuenzler 1974). Several studies regarded mangroves to be 'makers of land' (Curtis 1888; Hitchcock 1891; Philips 1903; Vaughan 1909; Davis 1938; Stephens 1962). Walsh's (1967) who worked on mangrove swamp in Hawaii documented the tendency of mangrove roots to act as a consumer of oxygen and a sink for nutrients. A similar view was supported by Carter *et. al.* (1973). Detritus from riverine and fringe mangroves are an important source of energy for adjacent tropical coastal lagoons (Odum *et. al.* 1982; Boto 1982; Twilley *et. al.* 1986). Only a small part of the mangrove production is consumed directly by organisms (Herald 1971) and often more energy and materials are flowing through detritus food webs than through grazer food webs (Schleyer 1986, Mann 1988). The functional attributes of mangrove forests in relation to environmental gradients have been studied by many investigators (De La Cruz and Benaag 1967; Snedaker and Lugo 1973; Golley *et. al.* 1975; Christensen 1978; Suzuki and Tagawa 1983; Woodroffe 1982 and 1985). The species distribution and physiognomy of mangroves seems to be directly related to land form and substrate condition (Mall *et. al.* 1987). Mangroves with greater tidal activity and water turnover have greater litter fall than mangrove in the areas with stagnant water (Pool *et. al.* 1975).

In U.A.E, studies on mangrove are quite few. Western (1989) mentioned mangrove tree as one of the species growing in the habitat of some tidal lagoons between Tarif and Abu Dhabi, near Al-Rams and at Khor Kalba. Mangrove growth was reported in some previous work on oceanography, ecology, geomorphology and sedimentation along mainland shorelines of Abu Dhabi where it occurs on intertidal flats (Purser and Evans 1973; Evans *et. al*. 1973). Abd-As-Salam (1978) in his study on the pattern of climate and vegetation in U.A.E, noticed that mangrove trees grow on the intertidal flats of Al-Qirm island, the southern coasts of the As-Syniyah Island in Khor Umm Al Qaiwain (Fig. 1), the coasts of Abu-Al-Abyad island, Halat Al Bahrani, Khor Ghanadah, the coasts of Ras Al Khaimah, the area between Al Rams and Khor Al-Khuwair and Khor Kalba. Leith and Barth (1983) carried out some laboratory and field experiments in Osnabruck (Germany) and Abu Dhabi to test the environmental conditions of mangrove growth. More recently the geographical distribution of mangroves was studied by (Embabi 1993) using land satellite images and topographic maps, while the microbenthic invertebrates associated with the mangrove *A. marina* along the east coast of the U.A.E were surveyed by Ismail *et. al*. (1993).

CHAPTER III

CHAPTER III

MATERIALS AND METHODS

COLLECTION OF MANGROVE SEEDS

Seeds of gray mangrove *A. marina* become ripe and suitable for sowing during September - October. Normally the seeds do not stay long on the trees, they start falling off right after ripening when the color of seed coat turns yellow. Matured seeds could be collected only for two months a year (September and October) for emergence and growth. In the present study, seeds were collected from 6-8 year old trees growing near the drainage area of the fish culture ponds of the Marine Resources Research Centre at Umm Al Qaiwain. Healthy seeds with uniform size were selected. The seeds had an average length of 3.2 cm, average width of 2.7 cm and average weight of 7.2 g.

EXPERIMENT NO. 1

SEED EMERGENCE STUDIES

(Indoor low temperature conditions: Average air temperature 19±1°C)

Round plastic containers of 56 cm diameter, 15 cm height were employed for seed emergence studies. Each container was filled with test solution (water) having salinities of 0.5, 10, 20, 40, 60, 80, or 100 ppt which were equivalent to 0.0125, 0.25, 0.5, 1.0, 1.5, 2.0 or 2.5 times seawater salinity, respectively. The level of salinity of the solution was measured by using Salinity Refractometer (Aquafauna Bio-Marine, Inc. CA USA). Each salinity level was represented by four replicates.

Each container carried ten liters of test solution and fifty soaked seeds of *A. marina*. The containers were placed in an air-conditioned room having a temperature of 19±1°C. Test containers were given a continuous supply of light from a mercury vapour lamp (average illumination 2200 lux) fixed at a height of 25 cm above the culture to test for a possible good nursery. The number of seedlings freed from the seed coats were observed daily as a first sign of emergence and recorded for each container. The shedded seed coats were removed to keep the solution clean. Water properties such as PH, water temperature, dissolved oxygen, electrical conductivity (EC) and turbidity were measured once daily using a water checker (Model U.7, Horiba, Japan) as shown in Appendix I. The water in the test containers was changed when the level of dissolved oxygen in the water was reduced. Water was exchanged with newly-prepared test solutions having the same salinity levels as used before. The water exchange was carried out every ten days when the dissolved oxygen values dropped below 2.5 ppm. Seedling emergence occurred when the two lobes of 'cotyledon' open, the 'epicotyl' appears with 'plumule' at the upper side and 'hypocotyl' produced radicles from the lower side. Daily observations were carried out and the number of the emerged seedlings in each container was recorded.

EXPERIMENT NO. 2

SEED EMERGENCE STUDIES

(Outdoor shaded condition:Average air temperature 19±1 to 28±4°C)

A second set of seven round plastic containers having the same dimensions as those of the exp. NO. 1 was used for the seed emergence under shaded conditions. The same procedure was followed as above and the salinity levels were fixed as mentioned for the first experiment. No artificial light was used under field conditions. The area was open to free natural air flow and natural ambient conditions and shading was prevalent throughout the experiment. The average air temperature was 28±4°C during day time and 19±1°C at night, relative humidity was measured to be 70±20% and the average day time light intensity was 2000 lux. Observations were taken daily on the seeds with shedded seed coat which were recorded for each salinity level. Measurements of pH, water temperature, dissolved oxygen, conductivity and turbidity were taken daily (Appendix II). The shedded seed coats were removed from the experimental containers to keep the water clean. The exchange of water was done with the same salinity level, whenever found necessary as mentioned in Exp. 1.

EXPERIMENT NO. 3

SEEDLING GROWTH STUDIES

(Indoor low temperature conditions)

Seedlings with uniform sizes were used after seedling emergence for subsequent growth studies under indoor low temperature conditions. Fresh saline solutions, having 0.5, 10, 20, 40, 60, 80 and 100 ppt were prepared. In this experiment, transparent jars with 11 cm diameter, 26 cm height and 3.9 liters capacity were used as culture containers. Each jar was covered with plastic coated net frame of 0.5" mesh, each was holding 5 seedlings. Seedlings were kept upright with roots and hypocotyl immersed in the test solution. The culture solutions were aerated continuously (aeration rate 62 ml/sec) from an air compressor using capillary tubes and control valves. Each treatment was represented by four jars (28 jars for all salinity levels). Growth conditions were similar to those applied for the seedling emergence indoor experiment.

Three observations were recorded on the 6th, 64th and 130th day from seedling subjection to different salinity levels. Shoot height, total number of roots, maximum root length, number of leaves, leaf area at the second node, number of branches and weight of the whole plant were recorded for each plant in each jar and the average values were calculated. Statistical analysis was carried out using analysis of variance for any significant difference between salinity levels and stages of growth and their interaction for each growth parameter. Water parameters like pH, water temperature, dissolved oxygen, conductivity and turbidity were recorded daily (Appendix III).

EXPERIMENT NO. 4

SEEDLING GROWTH STUDIES

(Outdoor shaded condition)

Homogeneous seedlings were used for seedling growth studies in the outdoor shaded area, following the same procedure as that in the indoor low temperature conditions. Each treatment was represented by four replicates.

Observations were recorded on days 3, 17, 63 and 128 for seedlings subjected to different salinity levels. Shoot height, number of roots, maximum root length, number of leaves, leaf area at the second node, number of branches and plant weight were recorded for each plant in each jar and the average values of four samples were calculated. Daily measurements of pH, water temperature, dissolved oxygen, conductivity and turbidity were carried out using a water checker (Appendix II).

EXPERIMENT NO. 5
FIELD STUDIES ON SLOPING BEACH
(Seeds sown on two transects)

Experiments were carried out on a sloping beach (4.5% slope) near a drainage area of the fish culture ponds of the Marine Resources Research Centre, Umm Al Qaiwain to assess the seedling emergence, survival and growth of *A. marina*. Mangrove seeds were sowed at a depth of one cm and of 10 cm spacing on two transverse lines to the shore line from low water line extending upwards to a distance of 5 m (Fig. 2). This experiment was conducted along with the indoor and outdoor controlled experiments. Observations included seedling emergence, number of seedlings survived, shoot height, number of leaves, leaf area and number of branches. Data were collected after the 96th and 138th day of the experiment and the averages were calculated.

EXPERIMENT NO. 6

FIELD STUDIES ON SLOPING BEACH

(Seeds sown on three transects)

The second experiment conducted on the same sloping beach near the Marine Resources Research Centre, Umm Al Qaiwain was by sowing mangrove seeds on three parallel lines starting from low water line and extending upwards to a distance of 10 meters from the shore line. The three lines were perpendicular to the shore line (Fig. 2). Seeds were sowed at a depth of one cm on these lines every 10 cm interval (100 seeds for each line). On a line parallel to the three lines, seven wells were digged at a spacing of about 1.5 m. Each was provided with 20 cm diameter polyvinyl chloride (PVC) pipes fixed vertically to a depth reaching the ground water even at a low tide. These pipes were projected for 10 cm above soil surface to protect wells from sand drift during high tide. This field experiment was protected from the outside interference by an appropriate fence.

Observations were recorded on seedling emergence. Most of the emergence took place within 20-25 days from sowing. Irrigation was applied once daily for only one week from sowing. Thereafter no water was provided and tidal movement was the only source of water supply. Seedling growth was recorded by measuring shoot height, number of leaves and branches at intervals for a period of 377 days. The average values of the data from the three lines were used to compute the final averages for every one meter interval from the sea water line upward. Measurements of water table and water parameters such as temperature, salinity, dissolved oxygen, pH, conductivity and turbidity were made from 'wells' throughout the growth period (Appendix IV). Depth of water table was taken as the distance between the ground level and surface level of the ground water (Fig. 3).

EXPERIMENT NO. 7

FIELD STUDIES ON FLAT BEACH

(Seeds sowed on 23 transects parallel to the shore line)

Mangrove seeds were sown on 23 transects parallel to the coast line on almost a flat area of the beach (2.25% slope). Each line was 13 meters long and the distance between the adjacent lines was one meter (Fig. 4). The first line represented the mean sea-water line. Seeds were sown at 20 cm apart on each line at a depth of one centimeter from the soil surface. The borders of the experimental area were protected by means of an appropriate fence. Seedling emergence and their survival rates were recorded periodically throughout one year period.

MOISTURE CONTENT OF SEEDLING PARTS

Four plant samples were collected at random from each line and washed thoroughly, blotted, then excised into three parts; leaves, stem and roots. Each part was weighed separately by means of a precision balance (accuracy 0.01 g) to determine the fresh weights. The samples were dried in an air-driven oven at 80°C to a constant dry weight. The percentage moisture content was calculated for each part of the plant growing at different distances from the seawater line.

SOIL MOISTURE CONTENT

A suitable amount of top soil (0-6 cm) was collected using an aluminum can (volume 185 cm^3), to measure its moisture content. Seven soil samples were collected from the middle line of the sloping beach and 69 (3 from each line) from the flat beach area. Samples were weighed immediately and their wet weight were determined. The samples were then spread on aluminum foil strips and heated in air-driven oven at 105°C to a constant weight. The final dry weight was measured and the percentage of moisture content was calculated.

SOIL ANALYSIS

Soil samples collected from the field study areas were dried properly under sun light. The grain size distribution of sediment samples were determined by standard methods of Day (1965). Dried sediment samples were passed through 2 mm mesh and analysis of the physical and chemical properties were carried out following the standard procedures. Phosphorus was analyzed using spectrophotometer DU-70 Beckman U.S.A (1988); sodium and potassium were determined by means of a Flame Photometer 410 (Corning) U.K. Copper, Iron, and Zinc were measured using an Atomic Absorption Spectrophotometer AA 1475 Series (VARIAN) Switzerland. Calcium carbonate was determined gravimetrically, while calcium and magnesium were determined by using Titration method. Nirogen analysis was not carried out because of some technical dificulties.

WATER ANALYSIS

Water samples collected from the test containers of different salinity media used in indoor and outdoor experiments as well as those from the field areas, and 'wells' at the experimental site were analysed for their chemical composition. Hardiness, sodium, calcium, magnesium, potassium and iron were measured using ICP Plasma 400 instrument (Inductively Coupled Plasma, Perkin Elmer, U.S.A.) following the filtration and dilution procedures. Sulphate, chloride, nitrite, fluoride, phosphorus and carbonate were analysed using Iron Chromatograph CMA-2 (Dionex, U.S.A.).

CHLOROPHYLL ANALYSIS

Total chlorophyll was measured in the fresh leaves of *A. marina* from the survived seedlings under different salinity levels using the method described by Allen et.

al. (1974). Samples were extracted with aqueous acetone, transferred into ether and measured at the optical densities (o.d.) of 643 and 660 nm and using UV 2101 BC Spectrophotometer, Shimadzu, Japan. Total chlorophyll (TC %) was calculated using the following formula:

$$TC\ (\%) = \frac{C \times \text{ether solution} \times \text{acetone extract}}{10^4 \times \text{acetone aliquot} \times \text{sample weight}}$$

where C = Total chlorophyll in ether solution (mg/l) = 7.12 x o.d at 660 nm + 16.8 x o.d at 643 nm.

From TC, chl a and chl. b were calculated using the following equations:

Chl. a = 9.93 x o.d(660 nm) - 0.777 x o.d(643 nm)

Chl. b = 17.60 x o.d(643 nm) - 2.810 x o.d(660 nm)

All water parameters were checked as shown in Appendix V.

CHAPTER IV

CHAPTER IV

RESULTS

EXPERIMENT NO.1: Seed Emergence Studies (Indoor low Temperature conditions)

The rate of seed coat shedding of mangrove seeds was very slow in indoor low temperature area. The time taken for 100% shedding of seed coat in 0.5 to 40 ppt salinity levels was 13 days after sowing (Table 4). The shedding of seed coat in 60 ppt salinity was 28% while in salinity levels 80 ppt and 100 ppt, the shedding rate was as low as 4% during the same period. Emergence of seeds started in indoor location from 20 to 28 days after sowing. Initially, the seeds in lower salinities germinate faster than those in higher salinities. At the end of the experiment, however, 76% of seeds germinated in 40 ppt, 74% in 0.5 ppt, 50% in 10 ppt, 40% in 20 ppt salinity and no seeds germinated in salinities higher than 40 ppt salinity (Table 5).

EXPERIMENT NO. 2: Seed Emergence Studies (Outdoor shaded conditions)

Relatively quicker seed coat shedding was observed

Table 4. Seed coat shedding (%) at different salinities in experiment No. 1 located at indoor low temperature condition with average air temperature 19±1°C, (n=50, sowing date 19/9/93).

Days After Sowing	Salinity Levels (ppt)*						
	0.5	10	20	40	60	80	100
1	26	18	18	12	2	0	0
2	36	22	22	26	6	0	0
3	42	34	30	34	18	2	2
4	44	38	32	44	28	2	2
6	58	42	50	60	28	4	2
8	76	46	68	64	28	4	2
9	86	56	78	66	28	4	2
10	96	70	80	66	28	4	2
11	100	88	94	92	28	4	4
13	100	100	100	100	28	4	4

* The percentage of seed coat shedding decreased with the increase in the salinity levels.

Table 5. Seed emergence (%) at different salinities in experiment No.1 located at indoor low temperature condition with average air temperature 19±1°C, (n=50, sowing date 19/9/93).

Days After Sowing	Salinity Levels (ppt)			
	0.5	10	20	40
20	10	6	4	2
21	12	10	12	8
22	22	20	20	12
23	48	26	24	30
24	52	38	30	40
25	60	40	38	58
26	66	40	38	70
27	70	48	38	74
28	74	50	40	76

Note: At 60 ppt or higher salinity resulted in zero seed emergence.

at outdoor shaded area condition where 100% shedding occurred in 0.5 to 40 ppt salinity levels in about 11 days (Table 6) after sowing. The rate of seed coat shedding was 30, 18, and 6% in 60, 80, and 100 ppt salinity levels, respectively, during this period.
Seed emergence started about 9 days after sowing which continued to day 20 when the percent emergence observed in 0.5, 10, 20, and 40 ppt salinities were 76, 56, 50, and 80%, respectively (Table 7). No emergence occurred in salinities higher than 40 ppt.

EXPERIMENT NO. 3: SEEDLING GROWTH STUDIES (Indoor low temperature conditions)

Growth of mangrove seedling at the indoor area indicated maximum increase in shoot height in 0.5 ppt salinity where it reached an average height of 7.8 cm from an initial height of 2.1 cm. The seedling growth rate (shoot height increase) decreased with salinity. The average heights reached after 130 d of the experiment were 6, 5.6, and 4.8 cm from initial ones of 2.3, 2.1, and 2.3 cm in 10, 20, and 40 ppt salinity levels, respectively (Fig 5., Table 8). Under 60 ppt salinity, few plants only survived at the second observation (64 d) and none survived during the final observation (130 d).

Table 6. Percentage of seed coat shedding in different salinities in experiment No. 2 located at outdoor shaded condition with average air temperature ranged 19±1 to 28±4 °C, (n = 50, sowing date 19/09/1993).

Days After Sowing	Salinity Levels (ppt) *						
	0.5	10	20	40	60	80	100
1	36	56	32	12	10	00	0
2	38	72	54	18	12	2	0
3	40	74	66	28	12	12	2
4	52	86	82	50	12	12	2
6	74	96	90	66	24	14	2
8	94	100	100	68	24	14	2
9	98	100	100	74	24	14	4
10	98	100	100	78	30	18	6
11	100	100	100	100	30	18	6

* The percentages of the seed coat shedding decreased with the increase in the salinity levels.

Table 7. Percentage of seed emergence at different salinities in experiment No. 2 located at outdoor shaded condition with average air temperature ranged 19±1 to 28±4°C, (n = 50 sowing date 19/09/1993).

Days After Sowing	Salinity Levels (ppt)						
	0.5	10	20	40	60	80	100
9	8	4	4	10	0	0	0
10	14	10	6	20	0	0	0
11	26	20	16	42	0	0	0
13	54	20	22	52	0	0	0
15	54	26	22	62	0	0	0
17	70	38	40	76	0	0	0
18	70	50	44	80	0	0	0
20	76	56	50	80	0	0	0

Note: At 60 ppt or higher salinity resulted in zero seed emergence.

Table 8. Average shoot height (cm)= SH and plant weight (g)=PW of *Avicennia marina* at different stages of growth in experiment No. 3 located at indoor low temperature conditions with average air temperature 19±1°C.

Salinity Level (ppt)	Days after planting					
	6		64		130	
	SH	PW	SH	PW	SH	PW
0.5	2.1	4.1	5.9	6.1	7.8	7.5
10	2.3	3.9	5.4	5.8	6.0	7.2
20	2.1	4.9	4.3	7.8	5.6	7.9
40	2.3	6.7	2.9	7.7	4.8	9.2
60	2.1	6.7	1.5	5.2	Died	Died
80	2.1	7.4	Died	Died	"	"
100	2.4	8.8	"	"	"	"

Anova table: Two way analysis of varience

	Shoot height	Plant weight
Effect of salinity	*	*
Effect of time	*	*
Interaction salinity x Time	*	*

* Significant difference at $P < 0.05$.

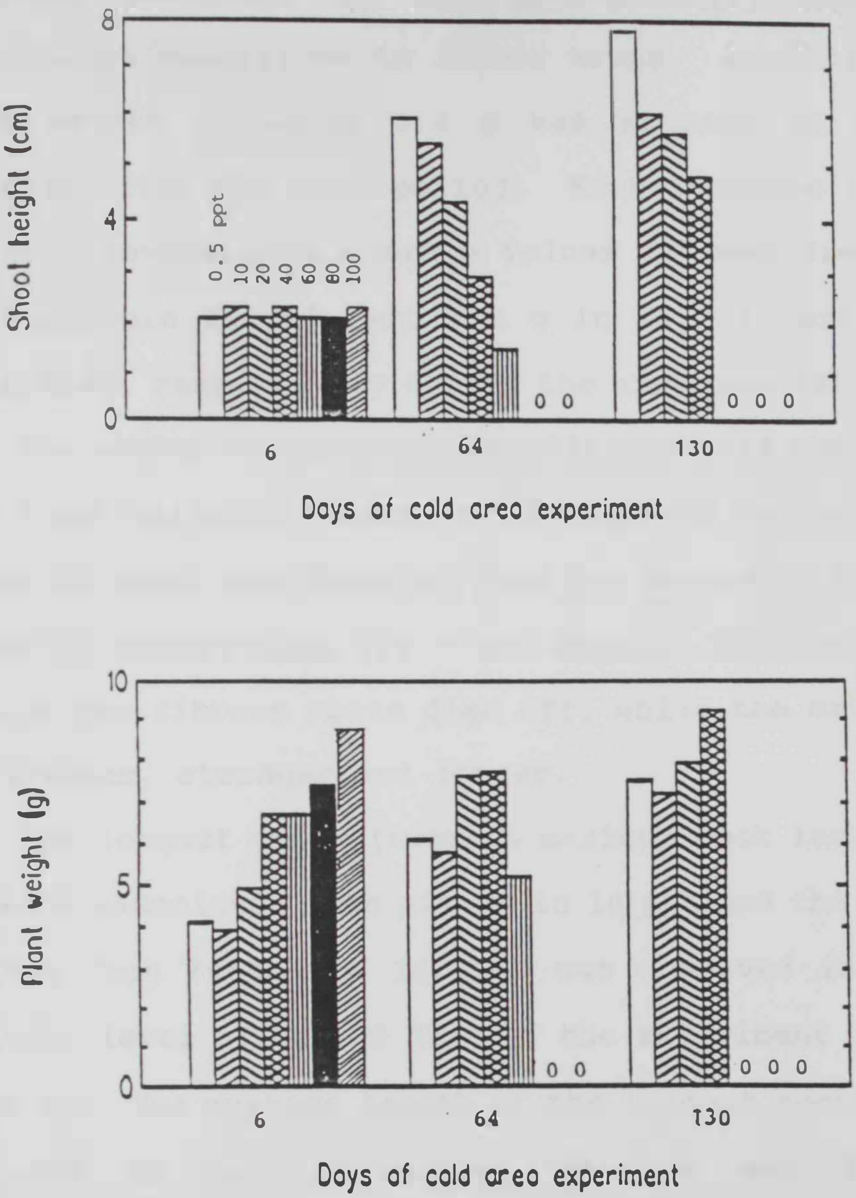

Fig. 5. Average shoot height and plant weight of *A. marina* at different stages of the indoor cold area experiment No.3 where the average air temperature was 19±1°C.

No plant survived at 80 and 100 ppt salinity levels. Average plant weight indicated better growth of the mangrove seedlings at 0.5 ppt salinity under low temperature conditions in indoor areas. An increase in plant weight of about 3.4 g was noticed in 0.5 ppt salinity after 130 days period. With increase in plant salinity levels, the average values of seedling weight increase were 3.3, 3, and 2.5 g in 10, 20, and 40 ppt salinities, respectively during the experimental period.

The number of roots per seedling reached the maximum in 0.5 ppt salinity (Table 9). A decrease in the average number of roots was detected from the second to the third period of observation (64 - 130 days). This is because some of the fibrous roots died off, while the main roots got thicker, stronger and longer.

The longest roots (Average maximum root length 18.2 cm) were associated with plants in 10 ppt and the average maximum root length of 16.3 cm was observed in 20 ppt salinity level after 130 days of the experiment (Fig. 6, Table 9). The average length of the longest roots in 0.5 ppt and 40 ppt salinities were 9 and 9.9 cm, respectively. The average number of leaves per plant was relatively greater in plants of 0.5 ppt salinity level (5.1). Average number of leaves of plants in 10 and 20 ppt salinities were 4 and 4.5, respectively, whereas the

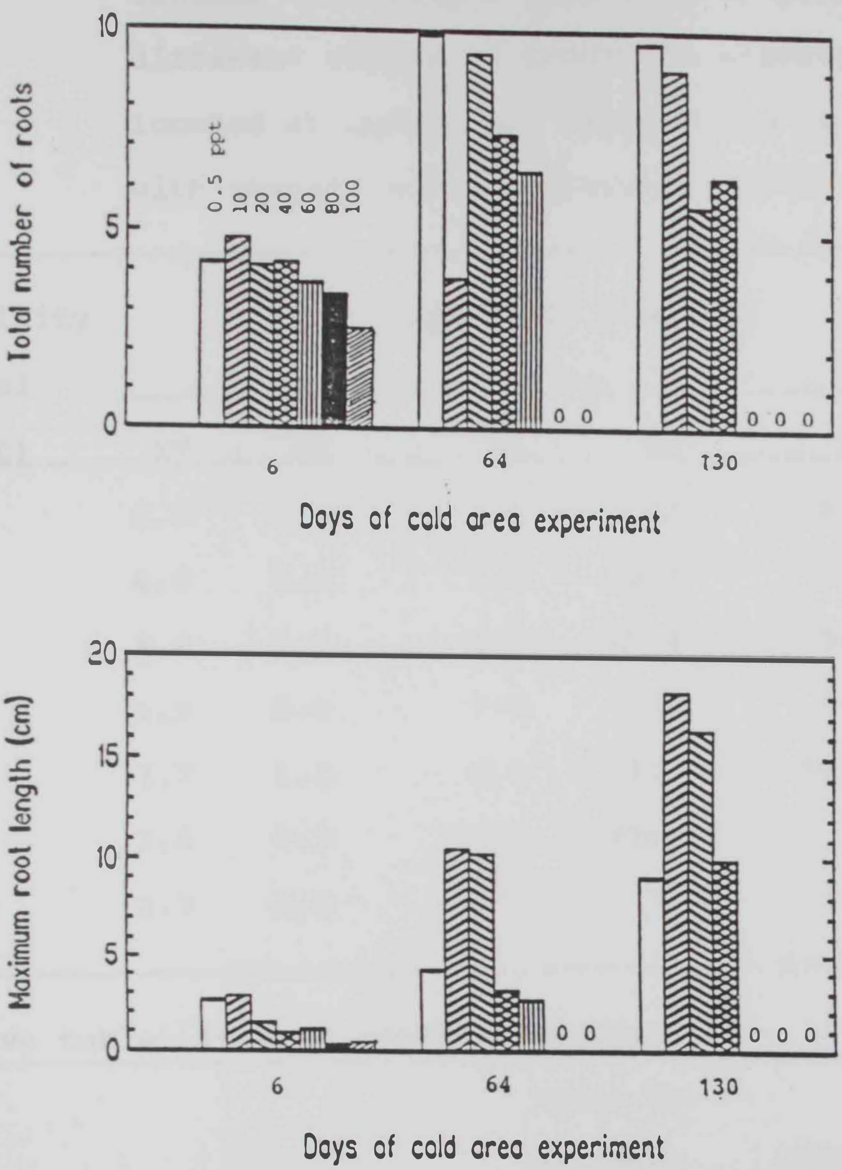

Fig. 6. Average number of roots and maximum root length of *A. marina* seedlings at different stages of indoor cold area experiment No. 3 where the average air temperature was 19±1°C.

Table 9. Average of the total number of roots = RN and maximum root length (cm) = RL of seedlings at different stages of growth in experiment No.3 located at indoor low temperature condition with average air temperature 19±1°C.

Salinity Level (ppt)	Days after planting 6		64		130	
	RN	RL	RN	RL	RN	RL
0.5	4.2	2.6	9.9	4.2	9.7	9.0
10	4.8	2.8	9.8	10.5	9.0	18.2
20	4.1	1.4	9.4	10.2	9.1	16.3
40	4.2	0.9	7.3	3.1	6.3	9.9
60	3.7	1.1	6.4	2.6	Died	Died
80	3.4	0.3	Died	Died	"	"
100	2.7	0.3	"	"	"	"

Anova table: Two-way analysis of variance

	Total No. of Roots	Maximum Root length
Effect of salinity	*	*
Effect of Time	*	*
Interaction salinity x Time	*	*

* Significant difference at $P < 0.05$.

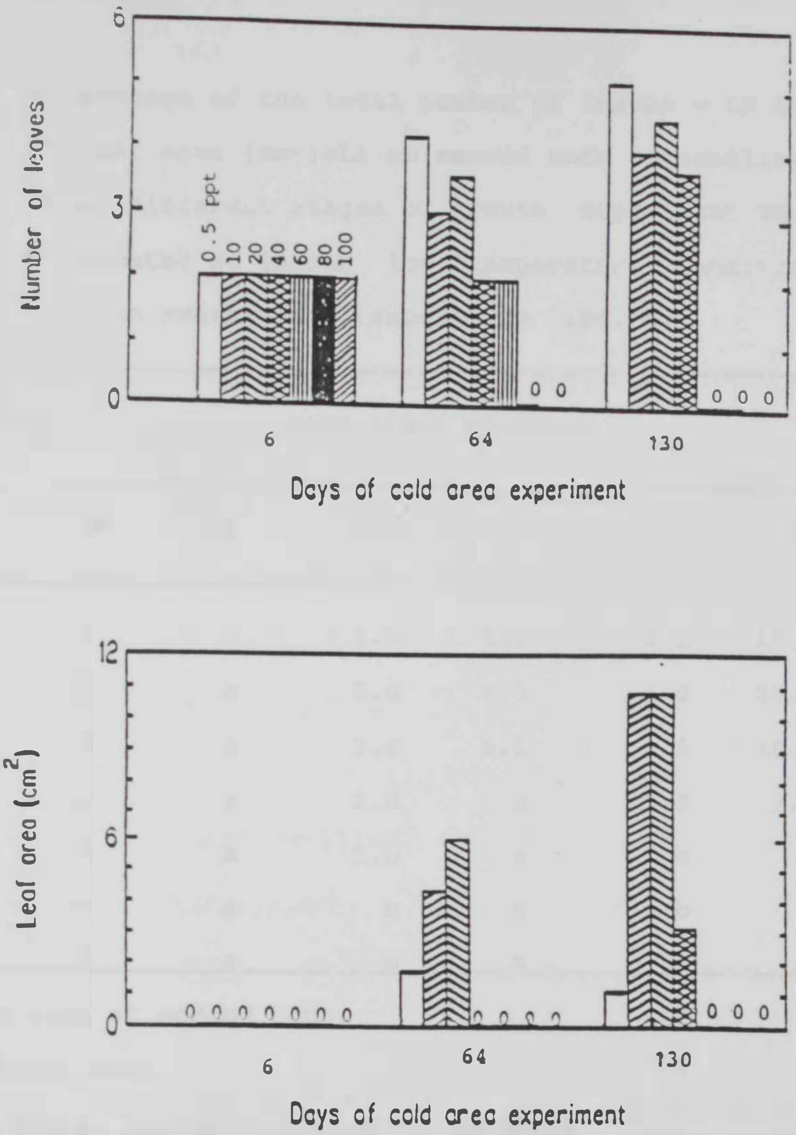

Fig. 7. Average number of leaves and leaf area of *A. marina* seedlings at different stages of the indoor cold area experiment No.3 where the average air temperature was 19±1°C.

Table 10. Average of the total number of leaves = LN and leaf area (cm^2)=LA at second node of seedlings at different stages of growth experiment No.3 located at indoor low temperature condition with average air temperature 19±1°C.

Salinity Level (ppt)	Days after planting 6 LN	6 LA	64 LN	64 LA	130 LN	130 LA
0.5	2	a	3.6	1.7	5.1	10.7
10	2	a	3.0	4.3	4.0	10.8
20	2	a	3.6	6.0	4.5	10.8
40	2	a	2.0	a	3.7	3.1
60	2	a	2.0	a	b	a
80	2	a	b	a	b	a
100	2	a	b	a	b	a

a= No leaf at second node.

b= Plants died.

Anova table: Two way analysis of variance

	Total No. of leaves	Leaf area
Effect of salinity	*	*
Effect of Time	*	*
Interaction salinity x Time	*	*

* Significant difference at $P < 0.05$.

average number was 3.7 in 40 ppt salinity at the end of the experiment (Fig. 7, Table 10). Larger leaves were encountered with seedlings planted in 0.5, 10, and 20 ppt salinities as indicated by the data on leaf area at the second node of the plant. The average leaf surface area after 130 d were 10.7, 10.8, and 10.8 cm^2, respectively at the three above mentioned concentrations. Relatively small leaves were observed in plants grown in 40 ppt salinity where the average leaf area was 3.1 cm^2.

Data in Table 11 show the percentages of survival of seedlings at different stages of the experimental period and under different treated salinity levels. Percent survival of plants in 0.5, 10, and 20 ppt salinities were 100% at the end of the experiment. 45% only of plants survived in 40 ppt salinity level for 128 days after the emergence of seedlings. In 60 ppt salinity, about 40% only of the plants survived only for two months.

The moisture content of the leaf,stem and root of the seedlings subjected to 0.5 to 40 ppt ranged from 53.8 to 74%, 66.7 to 74.4% and 68.2 to 75% respectively. As the salinity of the seedling growing medium increased, moisture content decreased (Table 12).

Water parameters from the experimental tanks were recorded daily and their weekly averages are shown in Appendix III.

Table 11. Percentage of seedling emergence at various stages of the experiment No.3 in different salinity levels located at indoor low temperature condition with average air temperature 19±1°C.

Salinity Level (ppt)	Days after planting		
	6	64	130
0.5	100	100	100
10	100	100	100
20	100	100	100
40	100	95	45
60	100	40	0
80	100	0	0
100	100	0	0

Note: At 60 ppt or higher salinity no seedling emergence occured even after 130 days.

Table 12. Percentage of moisture in root, stem and leaf of mangroves (*Avicennia marina*) grown in indoor low temperature conditions in experiment No.3 (130 days) (n=4, starting date 18/10/93, final date 25/2/94)

Salinity level of test medium (ppt)**	Root	Stem	Leaf
0.5	75.0	74.4	74.0
10	75.0	74.1	73.8
20	71.4	66.7	65.5
40	68.2	66.7	53.8
60	*	*	*
80	*	*	*
100	*	*	*

* No surviving plant for sampling.

** The percentage of moisture in the root, stem and leaf decreased with the increase in the salinity levels.

EXPERIMENT NO. 4: SEEDLING GROWTH STUDIES (Outdoor shaded conditions).

Since relatively faster growth rates were observed in mangrove seedlings kept in outdoor shaded conditions (compared to those in indoor conditions), four evaluations were made during the 128 days experimental period. Seedlings at 0.5 ppt salinity showed better growth for about two months, reaching an average height of 15.8 cm from its initial average height of 2.1 cm. By the end of the experiment (128 days). However, the seedlings under 20 ppt salinity gave the maximum average height (19.1 cm), while the initial shoot height at the beginning of the experiment was 2.1 cm. The maximum height for seedlings treated with 0.5, 10, and 40 ppt salinities were 18, 18.4, and 11.2 cm compared to their initial height of 2.1 cm (Table 13). At 60 ppt salinity, the seedling growth declined where the average shoot height increased from 1.9 cm to 3.1 cm only during 128 days. Seedlings planted at 80 ppt salinity did not show any growth and their average initial and final height remained the same. All plants subjected to 100 ppt salinity died after 2 months. A maximum average plant weight of 12.6 g was observed for seedlings planted in 20 ppt salinity during the fourth evaluation period (128 days). The average initial weight of this group was 4.8

g. The seedlings weight at 0.5, 10, and 40 ppt salinity levels were 10.7, 11.7, and 9.4 g, respectively at the end of the experiment, while their average weights at the beginning were 4.5, 5.2, and 4.9 g, respectively (Fig. 8, Table 13). The increase in plant weight at 60 ppt and 80 ppt salinities was very slight and the average weight gain per plant was 0.7 and 0.9 g, respectively. The average weight of seedlings with 100 ppt salinity showed an increase of 0.5 g in about two months, but the plant failed to survive until the end of the experiment. The average number of plant roots increased approximately from 5 to 8 under salinities of 10, 20, and 40 ppt (Fig.9, Table 14).

In general, the average number of roots tend to decrease with the increase in the salinity level of the medium, especially for salinity levels higher than 40 ppt. The increase in the length of the longest root was about 35.2 cm for the seedlings at 40 ppt salinity which was the maximum increase recorded for any group in this experiment. The seedlings at salinities higher than 40 ppt had shorter roots. All plants had two leaves at the beginning of the experiment. After 128 days seedlings grown at 10 ppt salinity had the maximum average number of leaves (6.2) followed by an average of 6.1 in those planted at 20 ppt salinity.

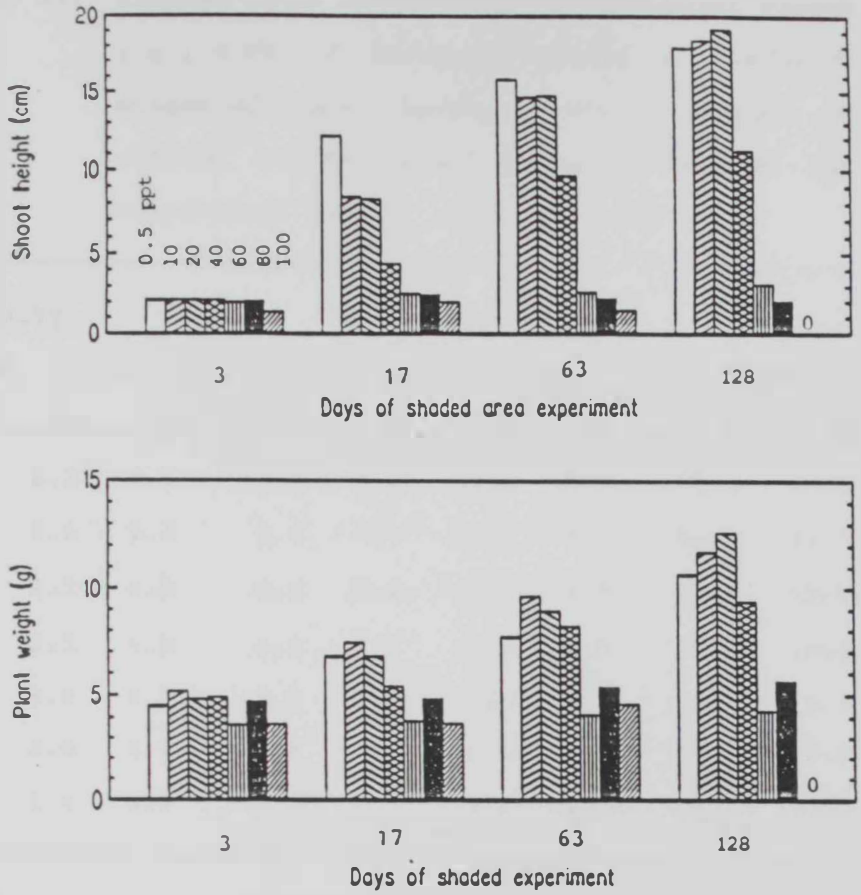

Fig. 8. Average shoot height and plant weight of *A. marina* at different stages of the outdoor shaded area experiment No. 4 where the average air temperature ranged from 19±1°C to 28±4°C.

Table 13. Average shoot height (cm)=SH, and plant weight (g) = PW of *Avicennia marina* at different stages of growth experiment No. 4 located at outdoor shaded condition with average air temperature ranged 19±1 to 28±4 °C.

Salinity Level	Days after planting							
	3		17		63		128	
(ppt)	SH	PW	SH	PW	SH	PW	SH	PW
0.5	2.1	4.5	12.1	6.8	15.8	7.7	18.0	10.7
10	2.1	5.2	8.3	7.4	14.6	9.7	18.4	11.7
20	2.1	4.8	8.2	6.8	14.7	8.9	19.1	12.6
40	2.1	4.9	4.3	5.4	9.6	8.2	11.2	9.4
60	1.9	3.6	2.5	3.8	2.6	4.1	3.1	4.3
80	2.0	4.7	2.4	4.8	2.1	5.3	2.0	5.6
100	1.4	3.7	1.9	3.7	1.4	4.2	Died	Died

Anova table: Two-way analysis of variance

	Shoot height	Plant weight
Effect of salinity	*	*
Effect of Time	*	*
Interaction salinity x Time	*	*

* Significant difference at $P < 0.05$

The average number of plant leaves for 0.5, 40, and 60 ppt salinities were 4.7, 4.6 and 3.8, respectively (Fig. 10, Table 15).

The largest leaves were observed in plant groups at 20 ppt salinity, where the average leaf area at the second node was 30.1 cm^2 while the smallest leaves with an average surface area of 4 cm^2 were encountered with seedlings at 60 ppt salinity level. The average leaf areas for 0.5, 10, and 40 ppt salinities were 27.5, 29.4, and 15.9 cm^2, respectively. Throughout the experimental period all the seedlings at 0.5, 10, 20, and 40 ppt salinities were in good condition and 100% survival rates were recorded. At 60 ppt salinity, all plants were alive until the 63^{th} day, but the survival rate was 35% only at the end of the experiment. After the 63^{th} day of the experiment, 85% of the seedlings were found alive at 80 ppt salinity, which was reduced to 10% at the final evaluation period. About 25% of the plants at 100 ppt salinity survived until the third observation on the 63^{rd}, day but no seedlings survived at the final observation (Table 16).

The percent moisture in the leaf, stem and root of the seedlings grown from 0.5 to 60 ppt salinity levels were 33.3 to 76.2%, 75 to 76.9% and 76.2 to 79.6%, respectively.

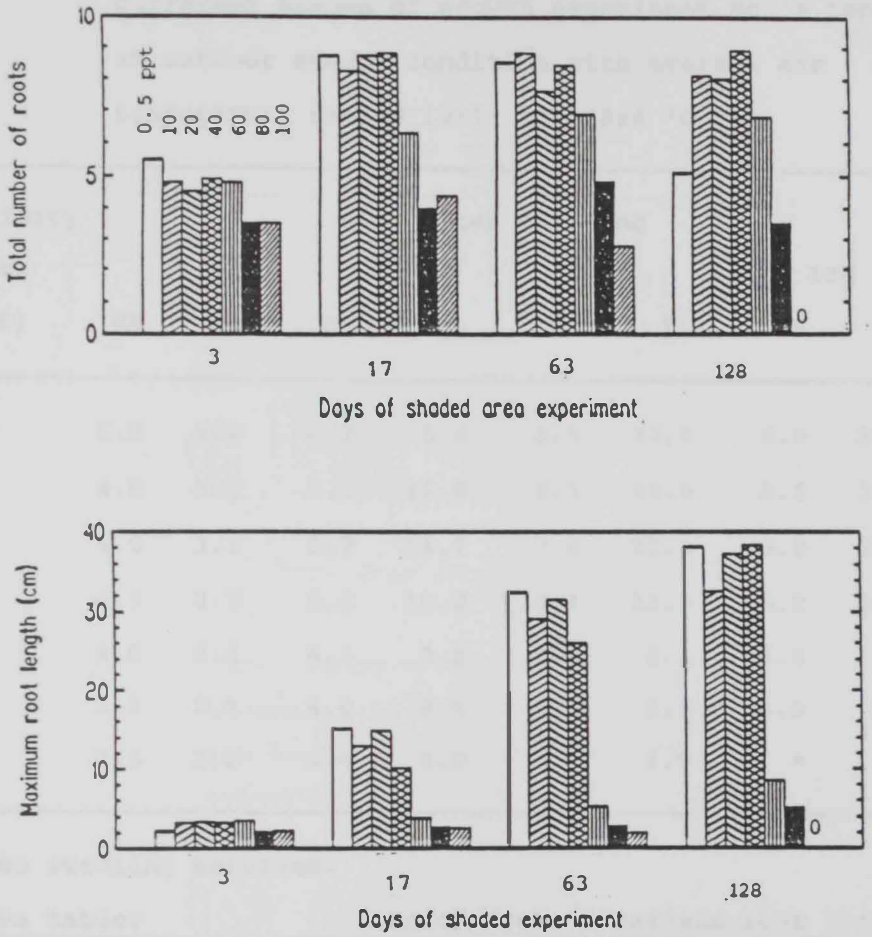

Fig. 9. Average number of roots and maximum root length of *A. marina* seedlings at different stages of outdoor shaded area experiment No. 4 where the average air temperature ranged from 19±1°C to 28±4°C.

Table 14. Average number of roots = NR and average of the maximum root length (cm) = RL of seedlings at different stages of growth experiment No. 4 located at outdoor shaded condition with average air temperature ranged 19±1 to 28±4 °C.

Salinity Level (ppt)	Days after planting 3 NR	3 RL	17 NR	17 RL	63 NR	63 RL	128 NR	128 RL
0.5	5.5	2.2	8.7	15.0	8.5	32.4	5.0	32.5
10	4.8	3.2	8.2	12.9	8.1	29.0	8.1	32.5
20	4.5	3.3	8.7	14.7	7.6	31.4	8.0	37.2
40	4.9	3.2	8.8	10.0	8.4	25.9	8.2	38.4
60	4.8	3.4	6.3	3.8	6.9	5.1	6.8	8.5
80	3.5	2.1	4.0	2.6	4.8	2.7	3.5	5.0
100	3.5	2.2	4.4	2.5	2.8	1.9	*	*

* No seedling survived.

Anova table:	No.of roots	Maximum root length
Effect of salinity	**	**
Effect of Time	**	**
Interaction salinity x Time	**	**

** = Significant difference at $P < 0.05$

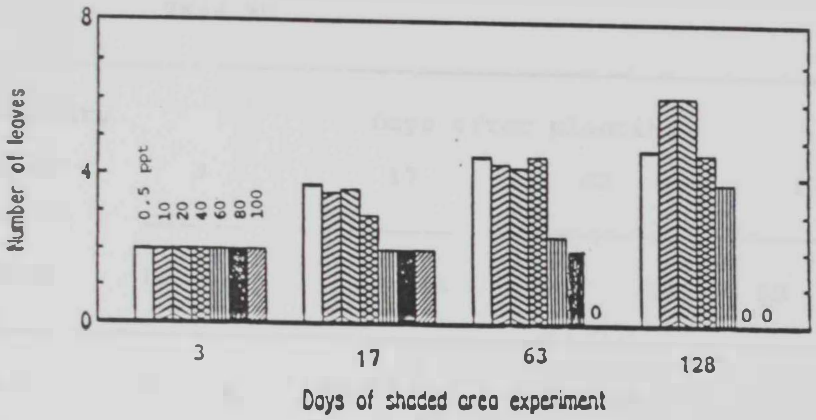

Fig. 10. Average number of leaves of *A. marina* at different stages of the outdoor shaded area experiment No.4 where the average air temperature ranged from 19±1°C to 28±4°C.

Table 15. Average of the total number of leaves = LN and average leaf area (cm^2) = LA at second node of seedlings at different stages of growth experiment No.4 located at outdoor shaded condition with average air temperature ranging from 19±1 to 28±4 °C.

Salinity Level (ppt)	Days after planting 3 LN	3 LA	17 LN	17 LA	63 LN	63 LA	128 LN	128 LA
0.5	2	a	3.7	a	4.5	19.8	4.7	27.5
10	2	a	3.5	a	4.3	21.2	6.2	29.4
20	2	a	3.6	a	4.2	22.8	6.1	30.1
40	2	a	2.9	a	4.5	13.2	4.6	15.9
60	2	a	2.0	a	2.4	0.4	3.8	4.0
80	2	a	2.0	a	2.7	a	a	a
100	2	a	2.0	a	a	a	b	b

a = No leaf at second node. b = No seedling survived.

Statistical analysis	No. of leaves	Leaf area
Effect of salinity	*	*
Effect of Time	*	*
Interaction salinity x Time	*	*

* = Significant difference at $P < 0.05$

Table 16. Percentage of seedling emergence at various stages of the experiment No. 4 and in different salinity levels located at outdoor shaded condition with average air temperature ranged 19±1°C to 28±4°C, (n = 20, planting day 130).

Salinity level (ppt)	Days after planting		
	17	63	128
0.5	100	100	100
10	100	100	100
20	100	100	100
40	100	100	100
60	100	100	35
80	100	85	10
100	100	25	0

Significant difference at $P < 0.05$.

However, the moisture content of these seedling parts decreased with an increase in the salinity level (Table 17).

The average shoot height increased for the seedlings grown in indoor low temperatures and outdoor shaded conditions as presented in Table 18. The water samples from the experimental tanks representing the seven salinity levels in experiment No. 3 and 4 were analyzed for their chemical composition.

Hardiness of water increased from 84.2 to 9663.6 ppm, sodium from 9.9 to 21,200 ppm, calcium from 8.2 to 896.4 ppm, magnesium from 15.5 to 1804 ppm, potassium from 5.9 to 581.5 ppm. and Iron from 0.004 to 0.907 ppm for the test water having salinity levels ranging from 0.5 to 100 ppt (Table 19). The water parameters of the experimental tanks were observed daily and weekly and the averages are presented in Appendix IV.

The leaf chlorophyll was measured by collecting leaves from four plants at each salinity level from the indoor and outdoor conditions and their values are given in Table 20.

EXPERIMENT NO. 5: FIELD STUDIES ON A SLOPING BEACH (Seeds sown on two transects):

Data on seed emergence and seedling parameters of *A. marina* collected from two transects (Table 21)

Table 17. Percentage of moisture in root, stem and leaf of mangroves (*Avicennia marina*) grown in outdoor shaded condition in experiment No.4

Salinity level of test medium (ppt)* plant	Root	Stem	Leaf	Whole
0.5	79.6	76.9	76.2	
10	79.0	75.8	75.6	
20	77.5	75.7	70.5	
40	77.0	75.7	70.2	
60	76.2	75.0	33.3	
80	**	**	**	78.8
100	***	***	***	

* The percentage of moisture in the root, stem and leaf decreased with the increase in the salinity levels.

** Plant parts could not be separated due to low growth.

*** No surviving plants for sampling.

Table 18. Average shoot height increase (mm/day) in *Avicennia marina* at indoor and outdoor conditions in experiment No.3 and 4, (air T°C= 19±1°C for indoor, and 19±1 - 28±4°C for outdoor area). Seed sowed on 19/9/93.

Salinity Level (ppt)	Indoor low temperature area (130 days after sowing).	Outdoor shaded area (128 days after sowing
0.5	0.4	1.2
10	0.3	1.3
20	0.3	1.3
40	0.2	0.7
60	*	**
80	*	**
100	*	*

Significant differece at $P < 0.05$.

* Negligible growth.

** No surviving seedling.

Table 19. Chemical composition of water having different salinity levels from experimental tanks used for mangrove seedling growth studies in indoor and outdoor conditions.

Salinity Level (ppt)	Chemical parameters (ppm)*					
	Hardness	Na	Ca	Mg	K	Fe
0.5	84.2	9.9	8.2	15.5	5.9	0.004
10	3885.0	2550	191.0	828.0	228.2	0.054
20	3424.0	2840	331.1	631.0	259.6	0.054
40	5576.1	7580	535.3	1030.0	477.4	0.134
60	8224.8	10200	653.2	1602.0	509.8	0.359
80	8251.8	12750	548.6	1672.0	476.7	0.556
100	9663.6	21200	896.4	1804.0	581.5	0.907

* Since all the salinity levels (ppt) were prepared at the laboratory, their chemical analysis also showed increase in the values with the increase in their concentrations.

Table 20. A comparison of the values of chlorophyll contents in the leaves of *Avicennia marina* grown in indoor and outdoor conditions in Exp. No.3 and 4, (n=4).

Salinity level (ppt)	Chlorophyll "a" (mg/l)		Chlorophyll "b" (mg/l)		Total Chlorophyll (mg/l)	
	indoor	outdoor	indoor	outdoor	indoor	outdoor
0.5	5.956	6.068	2.330	2.941	8.286	9.009
10	4.628	3.871	2.445	1.617	7.073	5.488
20*	4.025	8.570	2.129	3.779	6.154	12.349
40	1.988	4.507	0.949	2.757	2.936	7.264

* At this salinity level the plant growth was the best.

Table 21. Average values of % seedling emergence = SE, shoot height (cm) = SH, number of leaves = LN, leaf area at second node (cm^2) = LA, and survival rate (%) = SR of mangrove seedlings at different stages of experiment No.5* on a sloping beach in the field.

Distance from mean seawater line	SE		SH		LN		LA		SR
	Days after sowing								
m	96	138	96	138	96	138	96	138	
0 - 1	100	12.5	22.6	6.5	9.8	5.3	6.1	50	50
1 - 2	75	12.2	18.1	6.8	9.0	7.1	10.8	60	45
2 - 3	70	8.5	12.4	6.1	7.0	6.7	10.9	65	45
3 - 4	55	3.7	9.9	5.2	6.2	4.8	7.6	50	40
4 - 5	35	1.4	5.0	1.6	5.9	2.1	2.8	30	20

Significant difference at $P < 0.05$.

* Data from two transects.

on the sloping beach were combined, and the average values were computed for every meter interval from the low tide level towards the landward direction. Data in Table 21 give the % seedling emergence values and other plant parameters studied and seedling emergence. All seeds were germinated in the first one meter distance from the seawater line, while the seedling emergence was 75% in the second meter, 70% in the third meter, 55% in the fourth meter, and 35% in the fifth meter. All seedlings emerged completely within a month after sowing. During the final evaluation time at the 138th day of the experiment, the average values of shoot heights were 22.6, 18.1, 12.4, 9.9, and 5 cm for each one-meter interval away from the seawater line in shoreward direction. The average number of leaves, leaf area and survival rates tended to decrease as the distance from low tide level towards onshore increases. At the end of the experiment the moisture content was determined for the different parts of the seedlings. The leaf moisture ranged between 69.7% to 73.1%, the stem from 70.8 to 73.8% and the roots from 76.3 to 83.5% (Table 22).

The soil moisture decreased on the sloping beach from 16.8% near the seawater line at low tide to 4.7% at 10 m distance away from the sea. The mangrove growth was

Table 22. Percentage of moisture in root, stem, and leaf of mangroves (*Avicennia marina*) grown on a sloping beach in experiment No.5.

Distance from seawater line (m)*	Root	Stem	Leaf
1	83.5	73.8	73.1
2	83.2	72.4	72.1
3	82.6	72.0	71.6
4	79.6	71.6	70.7
5	76.3	70.8	69.7

* The percentage of moisture in root, stem and leaf decreased with increase in the distance from the seawater line.

Table 23. Comparision of soil moisture content (%) between the sloping beach and the flat beach at different distances from sea water line.

Distance from sea water line (m)	Soil Moisture (%)	
	Sloping beach	Flat beach
1	16.8	18.4
2	14.8	17.3
3	12.0	16.2
4	11.2	14.8
5	10.8	10.9
6	9.9	11.9
7	8.4	15.1
8	7.9	10.0
9	7.6	13.4
10	4.7	12.6
10 - 15	*	11.5
15 - 20	*	9.8
20 - 23	*	7.4

* No plant was sown in this area on the sloping beach.

Table 24. Average values of chlorophyll content of leaves of mangroves *Avicennia marina* grown on a sloping beach = SB, and flat beach = FB in experiment No. 5 and 7.

Distance from sea water line (m)	Chlorophyll "a" (mg/l)		Chlorophyll "b" (mg/l)		Total Chlorophyll (mg/l)	
	SB	FB	SB	FB	SB	FB
1	11.071	**	3.785	**	14.856	**
2	5.883	**	1.585	**	7.468	**
3	3.086	**	0.517	**	3.603	**
4	4.134	**	0.079	**	1.213	**
5	1.038	**	0.036	**	1.074	**
00 - 05	*	1.948	*	0.311	*	2.259
05 - 10	*	1.401	*	0.344	*	1.745
10 - 15	*	1.455	*	0.282	*	1.737
15 - 19	*	0.365	*	0.033	*	0.398

* On the sloping beach, the leaf chlorophyll was measured for plants at every one meter interval.

** On the flat beach, the leaf chlorophyll was measured for plants at every five meter interval.

observed upto a distance of about 5 m, where the soil moisture was 10.8% (Table 23).

Data in table 24 show the chlorophyll 'a', chlorophyll 'b' and total chlorophyll contents for the seedlings representing every meter interval from the seawater line towards onshore. Total chlorophyll values decreased from 14.856 mg/l to 1.074 mg/l over a distance of five meters from seawater line.

EXPERIMENT NO. 6: FIELD STUDIES ON A SLOPING BEACH

(Seeds sown on three transects)

The second experiment carried out by sowing mangrove seeds on three transects on the sloping beach comprised of ten evaluations covering 377 days for the collection of relevant data on seedling emergence, survival and growth. The average values of the plant parameters were calculated for every meter spacing from low tide level in landward direction. About two months after sowing seeds, 100% seedling emergence was observed in an area up to two meters from seawater line (Fig. 11, Table 25). In general, the percentage of seedling emergence decreased with increasing distance from the seawater line. At the end of the experiment (on day 377) 100% seedling emergence was observed in the first two meters, 53.3% in the third meter, 33.3% in the fourth meter and 23.3% in the fifth meter distance. The average shoot height, average number of roots and number of leaves per plant were found decreasing from low tide level towards the elevated slope of the beach. On the final day of the experiment, seedlings with an average shoot height of 37.4 cm, average number of leaves of 127.2 and of 11.2 branches per plant were observed near the low water line, whereas at five meters away from this area on the landward side, the seedlings had only 12.1 cm shoot height, 24 leaves and 3.8 branches per plant (Table 22). The depth of the water table was also recorded during the various observation periods.

The water table during low tide was within 10 cm from the ground level for the first two meters distance from seawater line. The stretch of a distance from two to four meters had a water table of 16 to 28 cm. During the observation period, the depth of ground water level varied between 23 and 43 cm for the distance from four meters towards the higher level of the slope. The average shoot height increase per day was calculated for every meter spacing from the sea water line using the relevant data from the three transects. The growth rate of the seedlings showed a decrease with further distances from the seawater line. The initial shoot height growth rate was 0.24 cm/day in the first one meter distance for 26 day old plants which was reduced to 0.10 cm/day after

377 days. While five meters away, the values of the shoot height growth rate decreased from 0.08 to 0.03 cm/day (Fig. 12 - 16, Table 26).

Water parameters were determined from the wells and the nearshore water adjacent to the field experimental area. Increases in water temperature, salinity and conductivity were observed from the low tide area (Well No.1) to the up slope of the beach (Well No.7), which was located at a distance of nine meters from the shore line. Relatively high water temperature and salinity conditions towards the upper slope of the beach (Appendix V) were observed. The ground water samples from the seven 'wells' were analyzed for their chemical composition. Most of the parameters showed an increase in their values moving landward as the hardiness varied from 9521.1 to 12115.6 ppm, sodium from 14360 to 18930 ppm, calcium from 780 to 830 ppm, magnesium from 1840 to 2442 ppm, potassium from 2850 to 3110 ppm, sulphate from 4509 to 3345 ppm, chloride from 10404.5 to 12807 ppm, fluoride from 13 to 23 ppm, phosphorus from 443.5 to 735.5 ppm and carbonate from 150 to 165 ppm over a distance of 9 meters from the seawater line (Table 27). Analysis of soil texture indicated 94-96% sand, 1-2% silt and 2 - 4% clay fractions in the sediments of the area under study (Table 28).

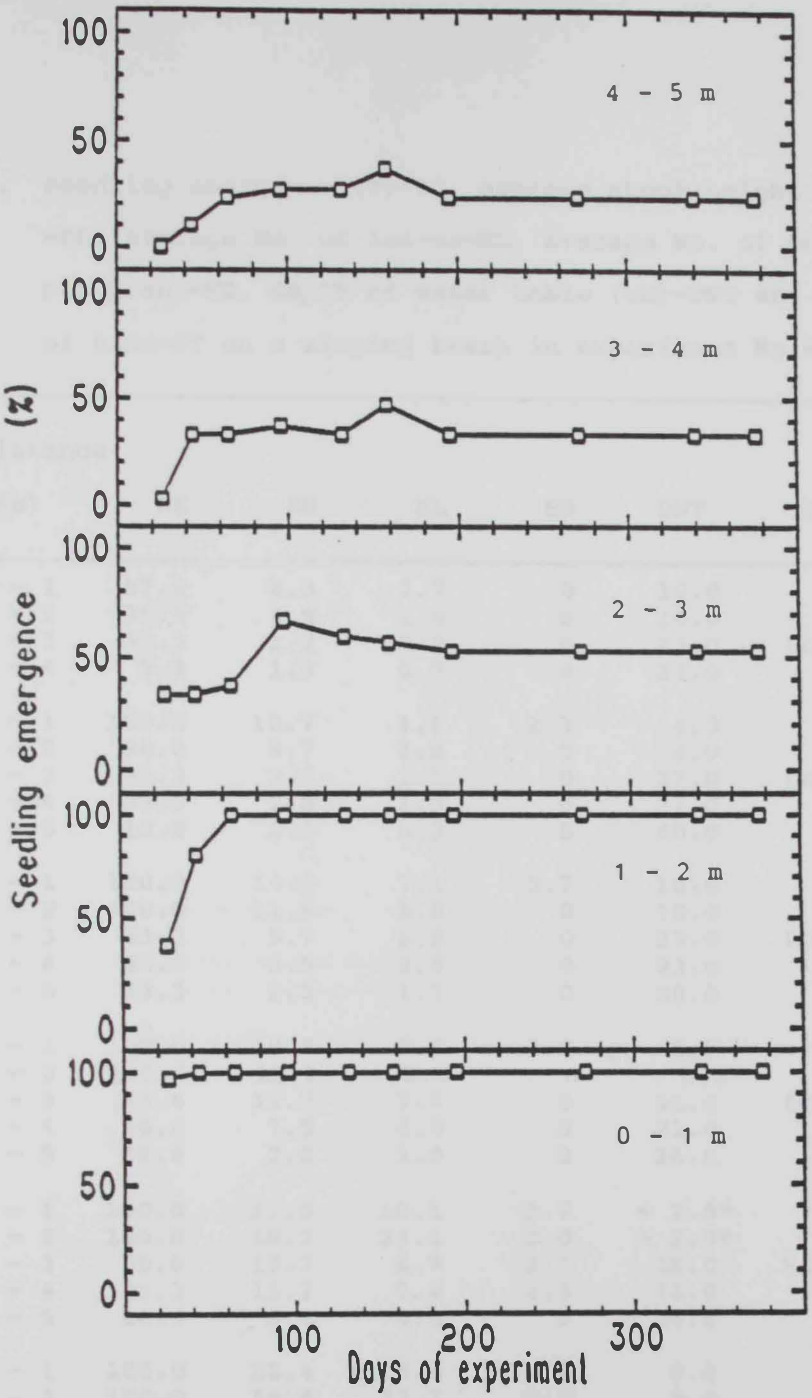

Fig. 11. Seedling emergence rate of *A. marina* at different intervals from the sea water line and at different stages of the experiment No. 6 on a sloping beach.

Table 25. Seedling emergence (%)=SE, average shoot height (cm) =SH, average No. of leaves=NL, average No. of branches per plant=NB, depth of water table (cm)=DWT and phase of tide=PT on a sloping beach in experiment No.6.

Age (days)	Distance (m)	SE	SH	NL	NB	DWT	PT
	0 - 1	97.0	6.3	2.7	0	10.0	
	1 - 2	36.6	2.9	1.6	0	10.0	
26	2 - 3	33.3	1.7	0.7	0	23.0	Low
	3 - 4	3.3	1.3	0.7	0	23.0	
	0 - 1	100.0	10.7	4.8	2.3	4.0	
	1 - 2	80.0	8.7	3.8	0	4.0	
44	2 - 3	33.3	3.2	1.5	0	27.0	Low
	3 - 4	33.3	2.8	1.3	0	27.0	
	4 - 5	10.0	2.1	0.3	0	40.0	
	0 - 1	100.0	14.2	7.1	2.7	10.0	
	1 - 2	100.0	11.9	5.9	0	10.0	
65	2 - 3	63.3	9.7	5.9	0	23.0	Low
	3 - 4	33.3	3.9	2.4	0	23.0	
	4 - 5	23.3	2.3	1.3	0	38.0	
	0 - 1	100.0	18.8	9.6	2.0	6.5	
	1 - 2	100.0	15.2	8.4	0	6.5	
96	2 - 3	66.6	11.7	7.9	0	21.0	Low
	3 - 4	36.6	7.5	5.0	0	21.0	
	4 - 5	26.6	2.2	1.8	0	36.0	
	0 - 1	100.0	22.0	10.1	2.7	+ 2.0*	
	1 - 2	100.0	18.3	11.4	2.0	+ 2.0*	
132	2 - 3	60.0	13.3	8.7	2.3	18.0	High
	3 - 4	33.3	11.7	9.2	2.3	18.0	
	4 - 5	26.6	8.2	6.3	0	33.0	
	0 - 1	100.0	22.4	15.6	2.8	8.0	
	1 - 2	100.0	18.6	12.1	2.2	8.0	
158	2 - 3	56.7	12.1	8.4	2.0	28.0	Low
	3 - 4	46.7	13.5	10.6	2.1	28.0	
	4 - 5	36.7	8.0	6.4	1.0	43.0	

Cont.

days	(m)	SE	SH	Nl	NB	DWT	PT
	0 - 1	100.0	26.2	18.0	3.4	+11.5*	
	1 - 2	100.0	19.8	13.2	2.4	+11.5*	
195	2 - 3	53.3	14.1	10.0	2.6	+ 3.5*	High
	3 - 4	33.3	13.1	7.9	3.0	+ 3.5*	
	4 - 5	23.3	7.4	6.0	1.0	14.0	
	0 - 1	100.0	30.6	39.2	6.6	7.0	
	1 - 2	100.0	26.9	29.6	4.0	7.0	
271	2 - 3	53.3	19.1	22.5	5.3	21.0	Low
	3 - 4	33.3	14.0	14.2	3.4	21.0	
	4 - 5	33.3	8.9	8.3	2.0	33.0	
	0 - 1	100.0	35.4	95.2	10.7	+ 2.0*	
	1 - 2	100.0	31.4	66.1	8.1	+ 2.0*	
340	2 - 3	53.3	23.1	39.0	5.9	16.0	High
	3 - 4	33.3	21.4	29.9	7.4	16.0	
	4 - 5	23.3	11.3	17.3	4.0	30.0	
	0 - 1	100.0	37.4	127.2	11.2	+ 1.0*	
	1 - 2	100.0	34.1	68.4	9.0	+ 1.0*	
377**	2 - 3	53.3	25.5	56.9	7.0	18.0	High
	3 - 4	33.3	23.3	40.2	6.1	18.0	
	4 - 5	23.3	12.1	24.0	3.8	30.0	

* The seawater level was above the ground level (+cm) due to the very high tide during the measuring time.

** Significant difference at $P < 0.05$ on 377th day (except for SE and NL).

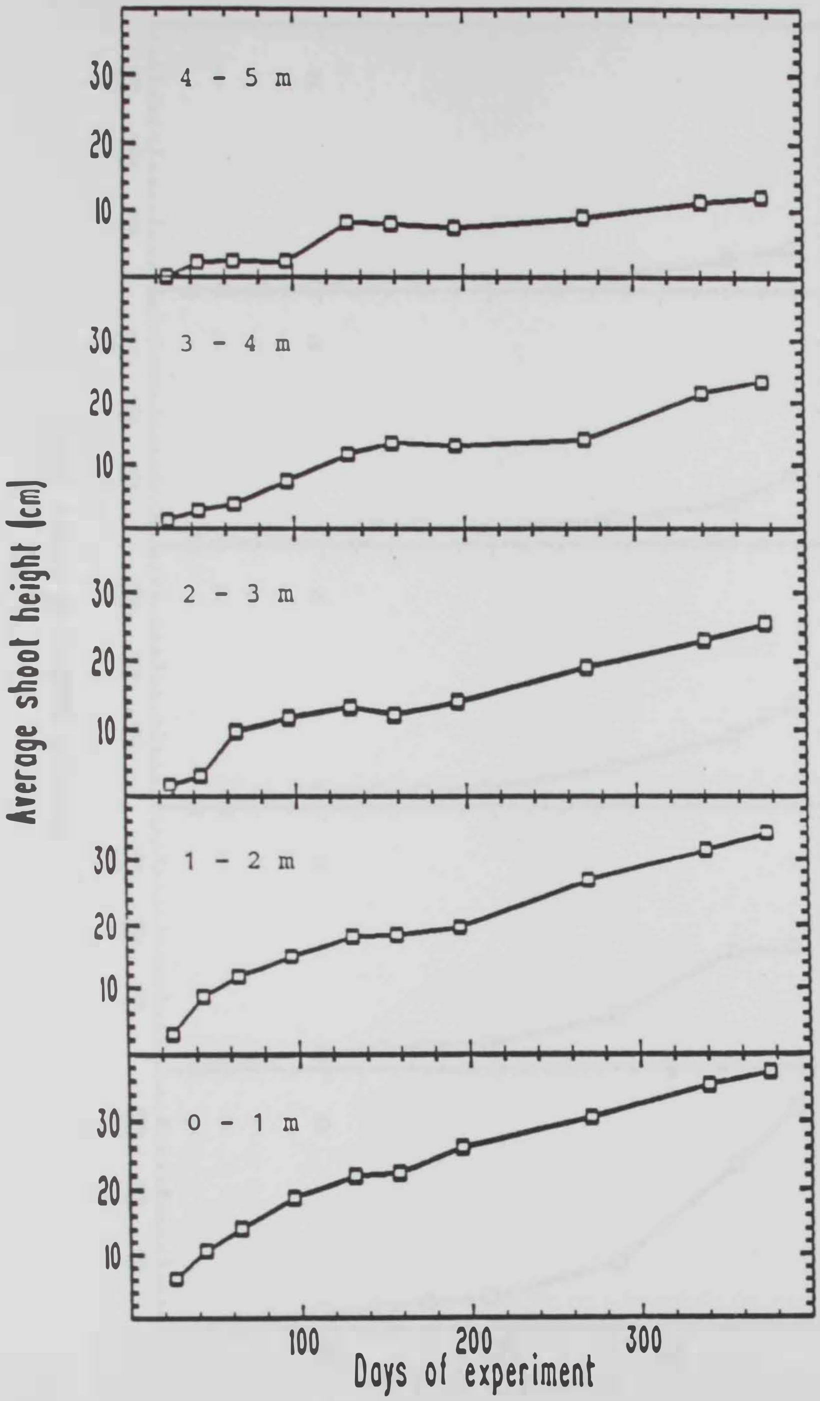

Fig. 12. Average shoot height of *A. marina* seedlings at different intervals from the sea water line and at different stages of the experiment No.6 on a sloping beach.

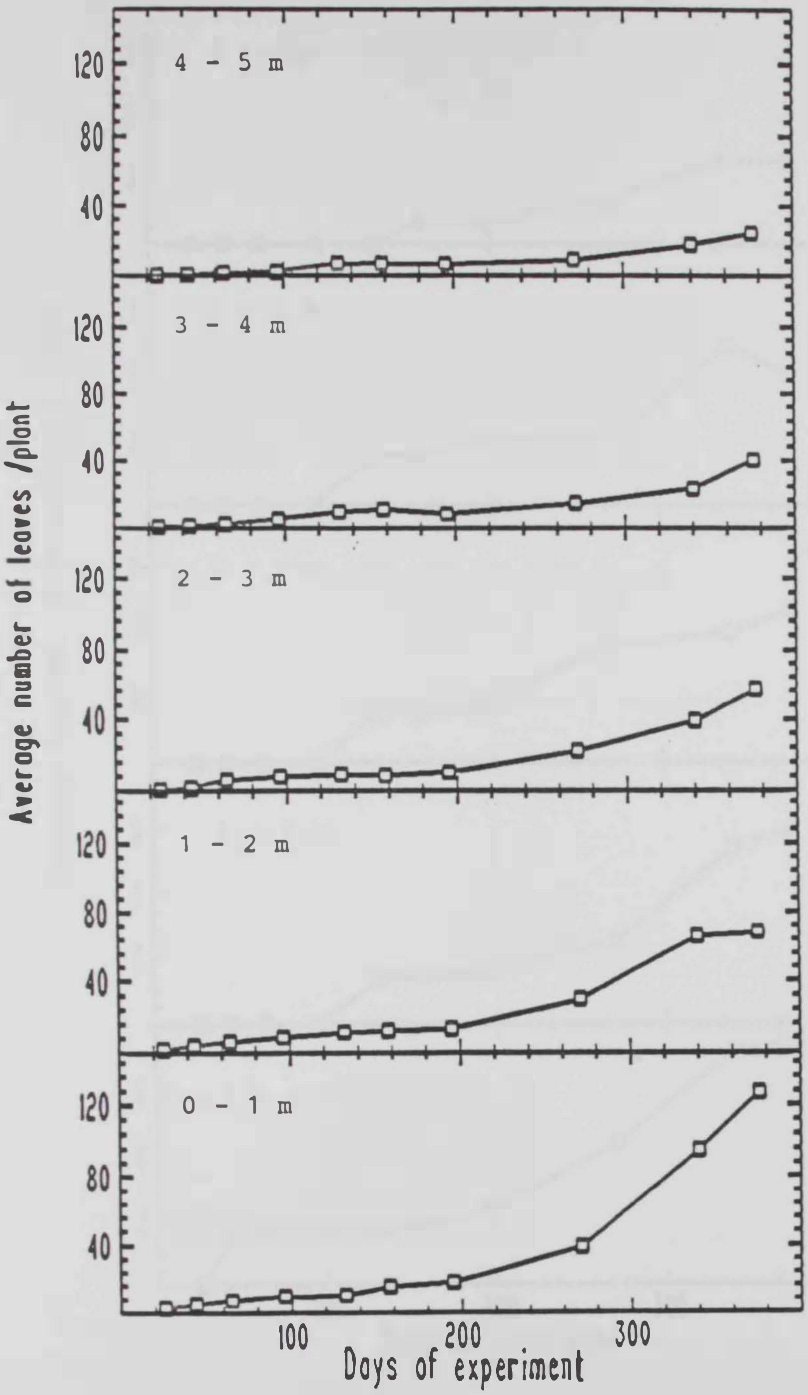

Fig. 13. Average number of leaves per plant of *A. marina* at different intervals from the sea water line at different stages of experiment No.6 on a sloping beach.

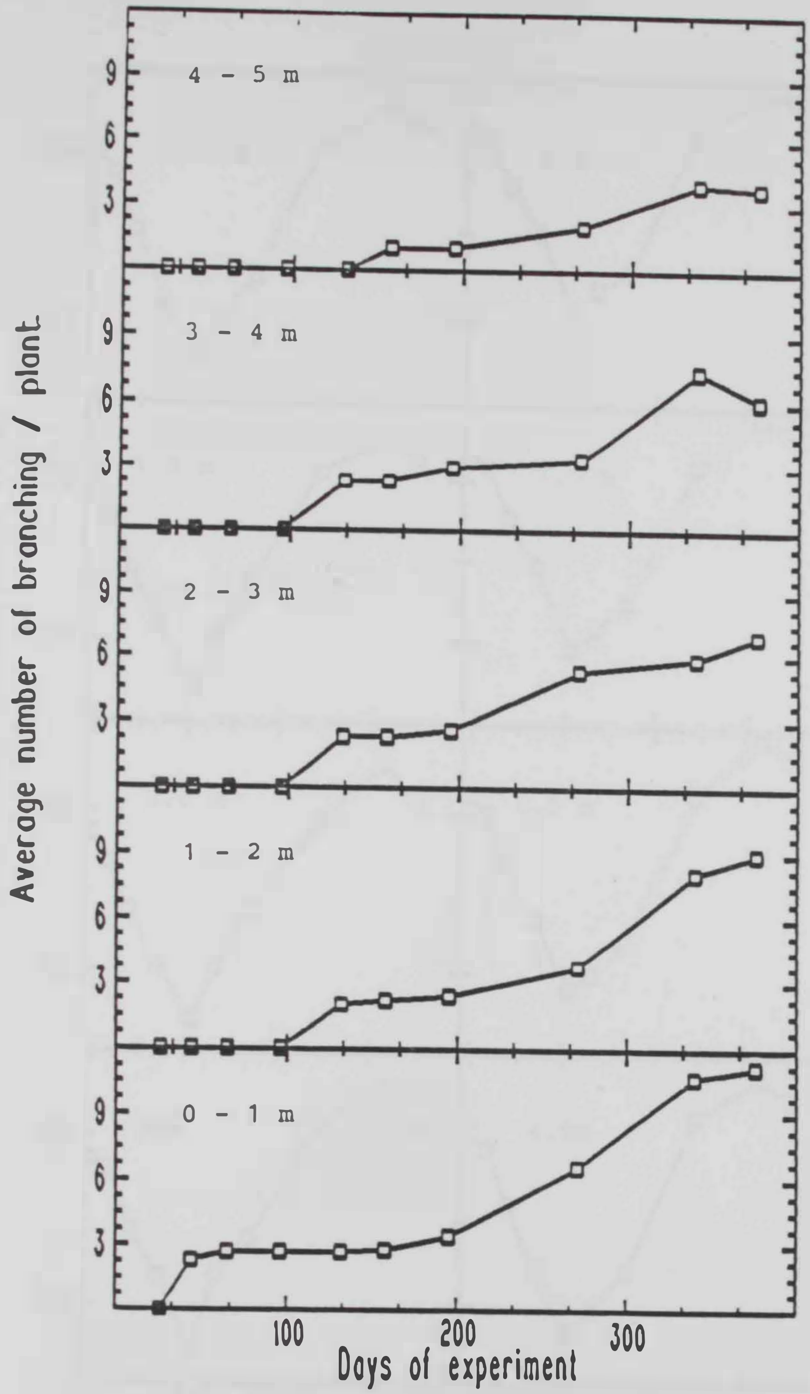

Fig. 14. Average number of branches per plant of *A. marina* at different intervals from the sea water line at different stages of the experiment No.6 on a sloping beach.

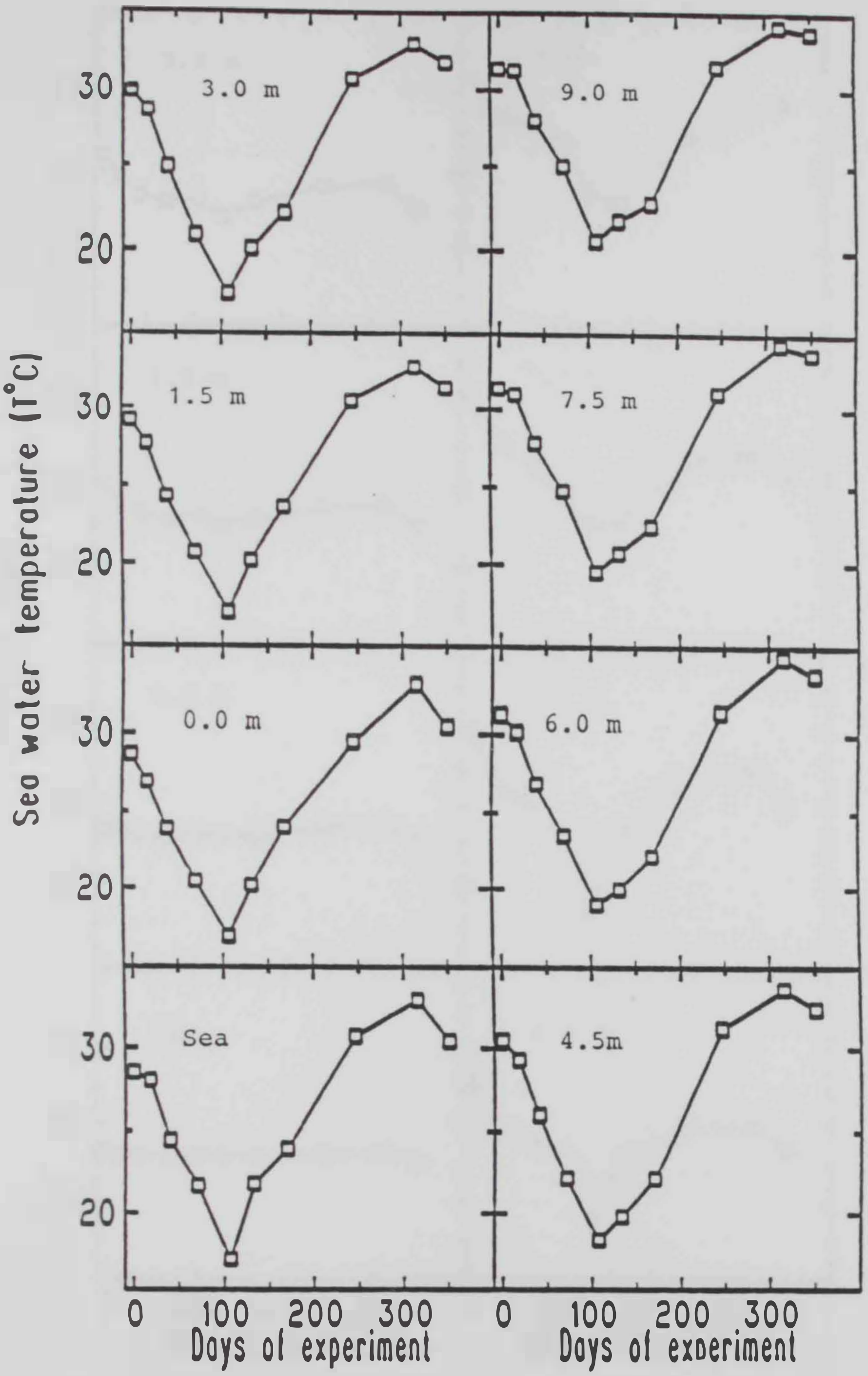

Fig. 15. Water temperature of the ground water at different intervals from the sea water line at different stages of experiment No. 5 and 6 on a sloping beach.

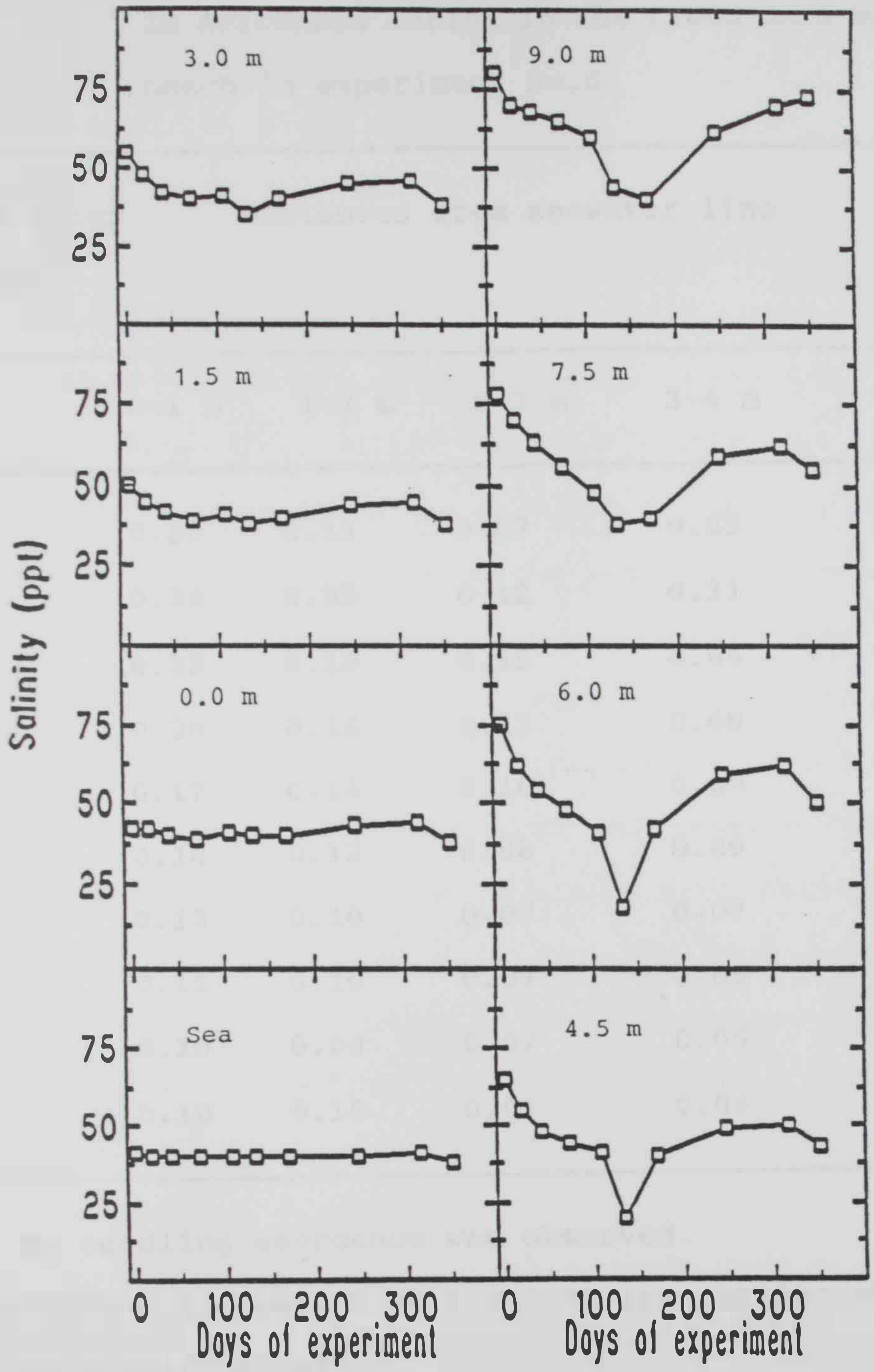

Fig. 16. Salinity of the ground water at different intervals from the sea water line at different stages of the experiment No. 5 and 6 on a sloping beach.

Table 26. Average shoot height growth rate (cm/day) in *Avicennia marina* in the field on a sloping beach in experiment No.6.

Days after sowing	Distances from seawater line				
	0-1 m	1-2 m	2-3 m	3-4 m	4-5 m
26	0.24	0.11	0.07	0.05	0.00*
44	0.24	0.33	0.12	0.11	0.08**
65	0.22	0.18	0.15	0.06	0.04
96	0.20	0.16	0.12	0.08	0.04
132	0.17	0.14	0.10	0.09	0.06
158	0.14	0.12	0.08	0.09	0.05
195	0.13	0.10	0.07	0.07	0.04
271	0.11	0.10	0.07	0.05	0.03
340	0.10	0.09	0.07	0.06	0.03
377	0.10	0.10	0.07	0.06	0.03

* No seedling emergence was observed.

Significant difference at P < 0.05 (except for ** which had no significance).

Physical and chemical characteristics of the soil were also analyzed and the results are shown in Figs. 17 and 18, and Table 29.

EXPERIMENT NO. 7: FIELD STUDIES ON A FLAT BEACH (Seeds sown on 23 transects):

Data on the percentage of seedling emergence calculated with respect to the number of seeds sown on each of the 23 transects drawn parallel to the shore line on a flat beach gave almost similar results as in the case of the sloping beach. A decrease in the percentage of seedling emergence was observed with the increase in distance from the shore line towards landward direction. After 326 days, when the values were averaged for every 5 meter spacing from the water line towards the onshore direction, 76.3% seedling emergence was observed for the first five meters, 35.2% for the next five meters, 33% for the next spacing and 9.1% for the last group of seedlings grown at a distance of 16 to 20 meters from the seawater line (Table 30). The seedling survival was observed only up to 19 meters from the sea water line after 326 days.

In order to collect data on seedling growth parameters, few plants were uprooted from every alternate line on the 537th day after sowing seeds,

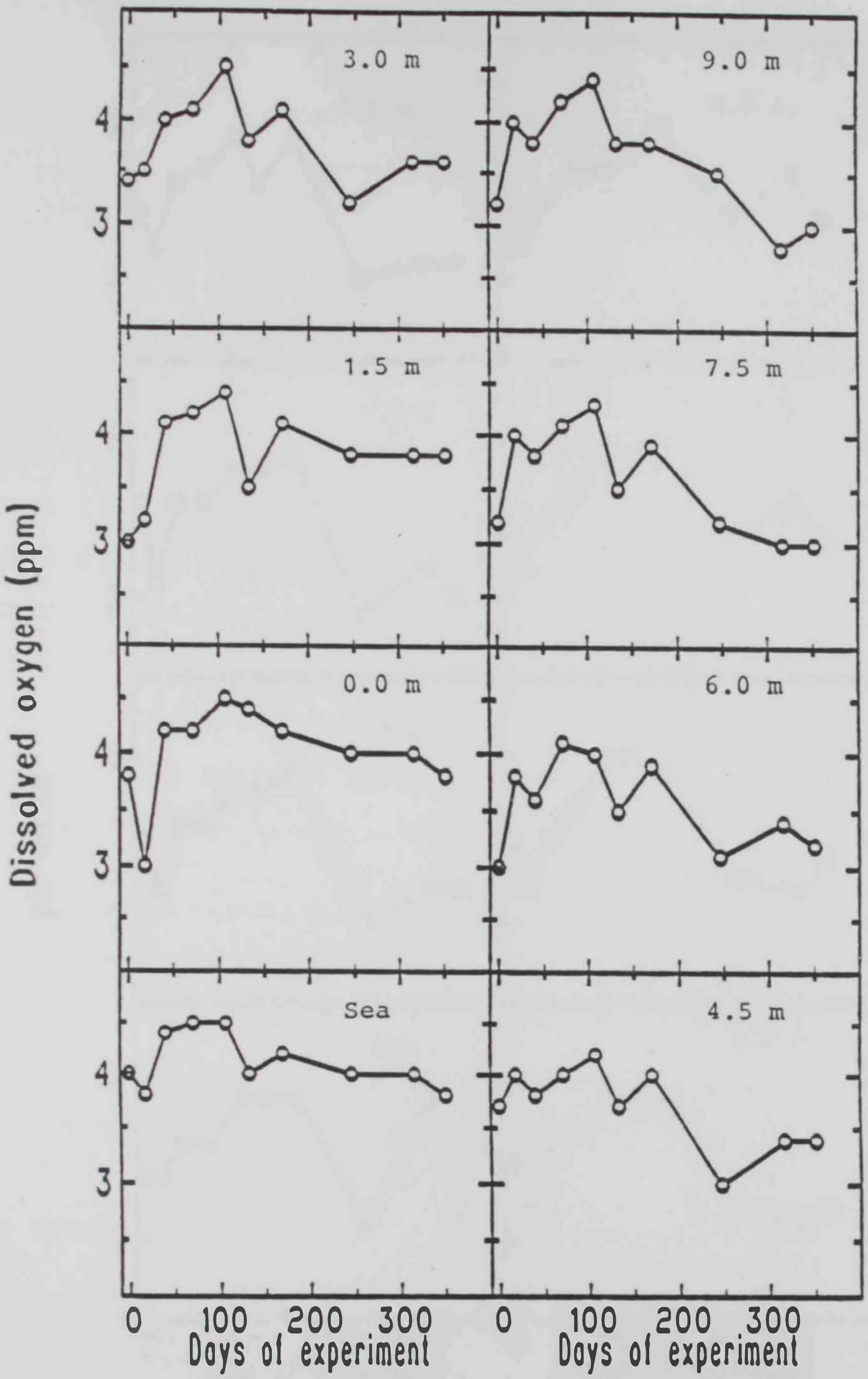

Fig. 17. Dissolved oxygen of the ground water at different intervals from the sea water line at different stages of the experiment No. 5 and 6 on a sloping beach.

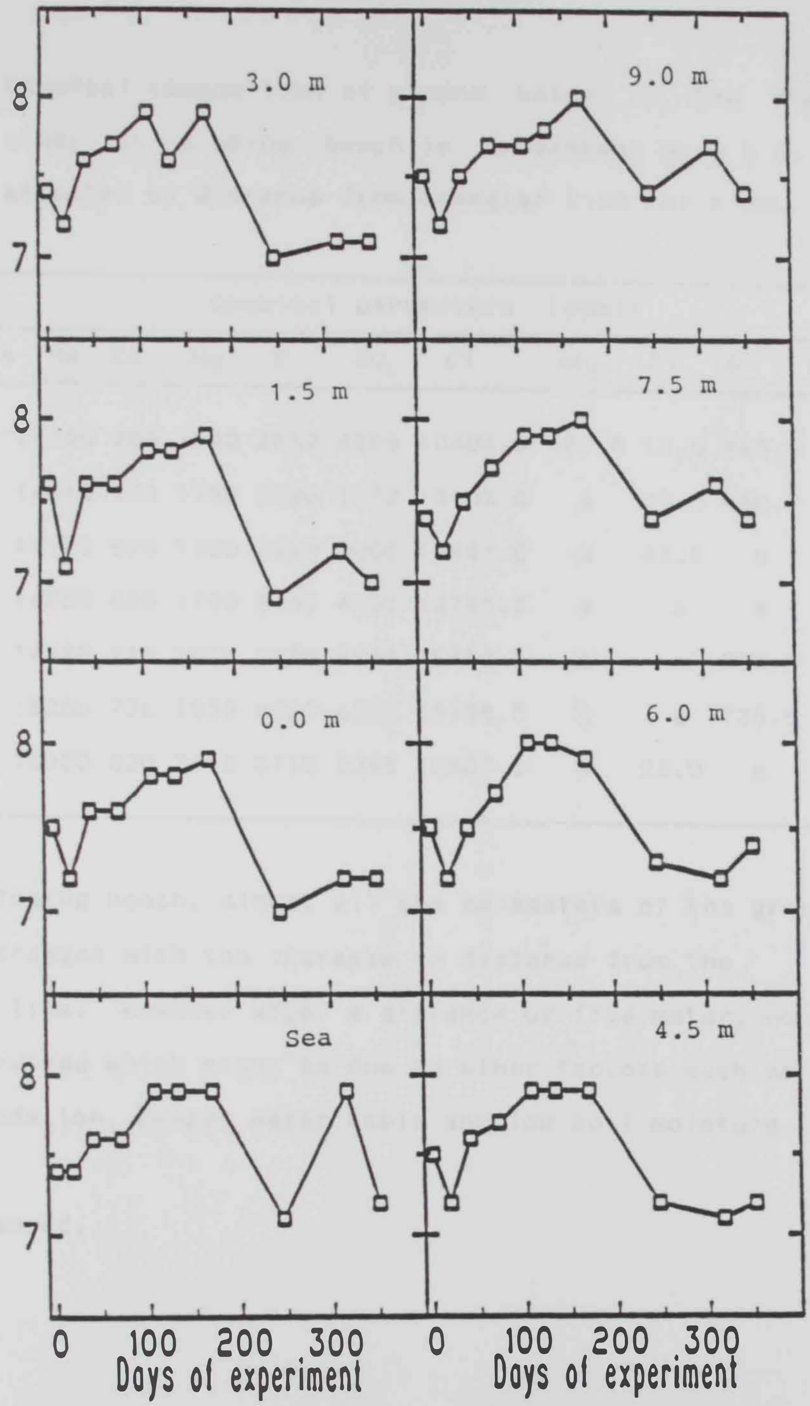

Fig. 18. pH of the ground water at different intervals from the sea water line at different stages of the experiment No. 5 and 6 on a sloping beach.

Table 27. Chemical composition of ground water in the field study on sloping beach in experiment No.5 & 6, as affected by distance from seawater line (m) = DWL.

DWL (m)	Chemical parameters (ppm)*										
	Hardness	Na	Ca	Mg	K	SO_4	Cl	NO_2	Fl	P	HCO_3
0.0	9521.1	14360	780	1840	2850	4509	10404.5	360.6	13.0	443.5	150
1.5	9000.8	14010	720	1750	2690	1772	13133.0	a	65.5	440.0	142
3.0	8875.9	14170	670	1750	2280	5066	16881.0	a	43.8	a	144
4.5	8890.0	14250	680	1790	2160	4305	13795.5	a	a	a	148
6.0	9552.1	14480	710	1890	2140	6137	15468.5	a	a	593.5	145
7.5	9866.6	15200	770	1930	2580	4305	13795.5	a	a	735.5	149
9.0	12115.6	18930	830	2442	3110	3345	12807.0	a	23.0	a	165

* On the sloping beach, almost all the parameters of the ground water increased with the increase in distance from the seawater line. However after a distance of five meter, no plant survived which might be due to other factors such as less inundation, deeper water table and low soil moisture.

a: Not measured.

Table 28. Soil texture of the field study area on a sloping beach = SB, and flat beach = FB in experiment No. 5 & 7.

Distance from mean seawater line (m)	Percentage composition							
	Sand		Silt		Clay		Soil Texture	
	SB	FB	SB	FB	SB	FB	SB	FB
01	96	93	2	2	2	5	Sandy	Sandy
02	96	93	2	1	2	5	,,	,,
03	96	94	1	2	3	4	,,	,,
04	94	94	2	2	4	4	,,	,,
05	95	94	1	1	4	5	,,	,,
06	94	94	2	2	4	4	,,	,,
07	94	95	2	1	4	4	,,	,,
08	a	95	a	1	a	4	a	,,
09	a	94	a	2	a	4	a	,,
10	a	95	a	1	a	4	a	,,
11	a	94	a	2	a	4	a	,,
12	a	94	a	2	a	4	a	,,
13	a	93	a	1	a	6	a	,,
14	a	95	a	1	a	4	a	,,
15	a	95	a	2	a	3	a	,,
16	a	96	a	1	a	3	a	,,
17	a	97	a	1	a	2	a	,,
18	a	96	a	1	a	3	a	,,
19	a	97	a	1	a	2	a	,,
20	a	98	a	1	a	1	a	,,
21	a	96	a	1	a	3	a	,,
22	a	95	a	2	a	3	a	,,
23	a	96	a	1	a	3	a	,,

a: On the sloping beach, no plant survived at more than a distance of five meter from the seawater line.

Table 29. Physical and chemical charecteristics of the soil in the field study area on a sloping beach in experiment No.5 & 6. Distance from mean seawater line (m)= DWL, bulk density (g/cm^3) = BD, pH, ECe (m mho/cm), Ca (meq/L), Mg (meq/L), Na (meq/L), K (meq/L), P (ppm), Cu (ppm), Fe (ppm), Zn (ppm), total $CaCO_3$ (%).

		1 : 2.5 Extract							Total Extract			Total
DWL	BD	pH	ECe	Ca	Mg	Na	K	P	Cu	Fe	Zn	$CaCO_3$
1	1.26	8.3	8.02	6.4	9.6	58.9	1.19	0.28	0.38	16.12	36.0	85.6
2	1.31	8.3	6.51	4.8	7.2	47.4	0.90	0.50	0.24	5.08	5.8	86.8
3	1.34	8.2	6.56	5.2	7.2	49.1	0.96	0.56	0.26	11.54	28.2	84.8
4	1.35	8.1	5.69	4.6	5.8	41.7	0.83	0.20	0.28	7.38	14.6	81.9
5	1.48	8.1	6.80	9.2	7.6	46.7	0.97	0.61	0.24	5.30	12.2	81.0
6	1.56	8.2	6.26	8.4	6.4	43.9	0.92	0.11	0.18	6.82	18.4	81.8
7	1.48	8.1	5.71	10.4	7.6	40.0	0.88	0.05	0.16	6.42	14.0	83.8

Note: On this sloping beach, most of the chemical elements of the soil decreased after five meter from the seawater line which might have affected the survival of plants especially with the effect of less inundation, deeper water table and low sand moisture content which were measured during the field studies.

Table 30. Percentage of seedling emergence= PSE, average for every five meter = Av/5m, distance from the sea water line (m) = DWL, and depth of water table at low tide (cm) = DWT on a flat beach in experiment No.7, (n=60).

	Days old										
	81		143		180		256		326		
DWL (m)	PSE	Av/5m	PSE	Av/5m	PSE	Av/5m	PSE	Av/5m	PSE	Av/5m	DWT cm
01	91.5		93.0		94.4		91.5		88.7		
02	47.1		69.1		70.6		77.9		77.9		
03	50.5	52.4	69.7	69.3	69.7	73.6	71.2	77.9	69.7	76.3	28
04	50.0		71.0		82.3		85.5		85.5		
05	22.8		43.9		50.9		63.2		59.6		
06	33.3		50.0		46.7		46.7		46.7		
07	22.8		31.5		33.3		35.1		33.3		
08	20.7	19.3	32.8	33.5	39.7	34.5	41.4	35.2	44.8	35.2	29
09	14.3		33.9		32.1		32.1		32.1		
10	5.2		19.0		20.7		20.7		19.0		
11	11.5		28.8		42.3		48.1		48.1		
12	10.0		28.8		28.8		27.5		26.3		
13	14.8	11.8	24.6	26.5	32.8	33.1	32.8	34.0	32.8	33.0	31
14	12.0		34.0		40.0		40.0		36.0		
15	10.9		16.4		21.8		21.8		21.8		
16	1.8		12.7		12.7		16.4		14.5		
17	1.6		4.9		6.6		6.6		4.9		
18	3.8	2.1	17.3	9.1	19.2	10.2	15.4	9.2	9.6	9.1	45
19	1.8		7.3		9.1		7.3		7.3		
20	1.6		3.2		3.2		3.2		3.2		
21	*		*		*		*		*		
22	*		*		*		*		*		
23	*		*		*		*		*		

* No seedling survived.

Significant difference at $P < 0.05$ (for the averages of every five meter spacing).

and measurements of shoot height, number of roots, maximum root length, stem thickness, root thickness, number of leaves and leaf area at the second node were taken. An average values were calculated for the respective lines (Table 31).

The maximum moisture content was observed in the root and ranged between 75 to 80.1%, followed by the shoot (60 to 73.4%) and the leaf (60 to 70.5%). There was a general decrease in the moisture content of the seedling parts away from the shoreline (Table 32).

The soil moisture on the flat beach decreased from 18.4% near the sea water line at low tide to 7.4% at 23 m distance away from the sea. The mangrove growth was observed up to a distance of about 19 m where the soil moisture was 9.8% (Table 33).

The chlorophyll content of the leaves was measured for samples from all the transects, and the average values of chlorophyll 'a', chlorophyll 'b' and total chlorophyll were calculated for every 5 meter interval from the seawater line shoreward. Chlorophyll 'a' decreased from 1.948 to 0.365 mg/l, chlorophyll 'b' from 0.311 to 0.033 mg/l and total chlorophyll from 2.259 to 0.398 mg/l over the 19 m distance from seawater line (Table 24).

Table 31. Average values of seedling growth parameters shoot height (cm) = SH, total number of roots = RN maximum root length (cm) = RL, stem thickness (mm) =ST, root thickness (mm) = RT, number of leaves=LN leaf area at second node (cm^2) = LA and distance from sea-water line (m) = DWL of *Avicennia marina* on a flat beach in experiment No. 7 as observed on 21-03-1994 (537 days after sowing seeds on 1-10-1992).

DWL	SH	RN	RL	*ST	RT	LN	LA
1	34.3	13.0	38.0	11.7	9.6	55.7	13.9
3	37.8	11.3	63.3	9.0	9.3	39.5	6.7
5	29.8	8.3	40.0	7.5	7.3	30.3	6.1
7	29.0	13.3	48.0	9.7	9.7	34.7	6.3
9	27.7	8.7	46.7	10.7	7.3	30.0	5.6
11	22.3	8.7	33.0	8.3	7.7	24.3	5.6
13	24.3	13.7	44.0	8.3	7.3	37.3	5.0
15	16.0	8.0	24.7	8.0	7.7	18.0	3.5
17	16.0	8.0	14.0	7.0	7.0	16.0	3.3
19	12.5	7.5	19.0	5.5	6.5	8.0	1.6

* Measured at 2 cm above the area of cotyledon.

Significant difference at $P < 0.05$ (except for RN).

Table 32. Percentage of moisture in root, stem and leaf of *Avicennia marina* grown in a flat beach in experiment No.7.

Distance (m)*	Root	Stem	Leaf
1	80.1	73.4	70.5
3	80.1	69.5	62.1
5	78.8	69.5	61.9
7	78.8	67.9	62.2
9	78.4	67.5	62.5
11	78.6	66.2	62.2
13	78.3	66.0	61.2
15	78.3	66.2	60.9
17	75.0	65.9	60.1
19	75.0	60.0	60.0

* The percentage of moisture in root ,stem and leaf decreased with the increase in the distance from the seawater line.

Soil samples from every meter interval starting from transects 1 to 23 were analysed for their mineral content. Texture class of samples was sandy since the sand fraction was 93 - 97%. Silt and clay fractions were 1 - 2% and 1 - 6% respectively (Table 28).

Physical and chemical parameters of the soil were analysed for the soil samples collected at one meter interval from the seawater line upward and the data are shown in Table 24.

Table 33. Physical and chemical charecteristics of the soil in field study area on a flat beach in experiment No. 7. Distance from mean seawater line (m) = DWL, bulk density (g/cm^3) = BD, pH, ECe (m mho/cm), Ca (meq/L), Mg (meq/L), Na (meq/L), K (meq/L), P (ppm), Cu (ppm), Fe (ppm), Zn (ppm), total $CaCO_3$ (%).

		1 : 2.5 Extract							Total Extract			Total
DWL	BD	pH	ECe	Ca	Mg	Na	K	P	Cu	Fe	Zn	$CaCO_3$
1	1.41	8.4	6.39	4.4	8.0	46.1	0.95	Nil	0.12	2.54	0.34	81.9
2	1.67	8.5	6.73	5.2	9.2	48.3	0.97	0.43	0.14	2.24	0.34	80.2
3	1.40	8.6	7.83	5.2	10.8	56.7	1.15	0.10	0.10	1.20	0.22	83.2
4	1.66	8.5	7.46	4.8	9.6	54.6	1.05	0.49	0.10	2.02	0.20	79.5
5	1.40	8.6	7.01	4.8	9.6	50.9	1.04	0.04	0.06	2.74	0.36	85.0
6	1.71	8.7	8.31	5.6	10.8	62.2	1.05	Nil	0.08	2.04	0.30	79.3
7	1.42	8.6	7.56	4.8	10.4	57.2	1.13	0.20	0.06	3.96	0.26	78.7
8	1.43	8.6	7.31	4.8	10.4	52.4	1.09	0.62	0.06	2.88	0.26	77.1
9	1.70	8.6	6.98	5.6	9.2	52.0	1.10	0.39	0.14	2.06	0.22	75.6
10	1.39	8.5	7.33	4.8	10.0	54.4	0.99	Nil	0.18	1.80	0.34	77.0
11	1.70	8.6	6.88	4.8	9.2	51.1	1.01	Nil	0.14	1.08	0.28	77.3
12	1.32	8.7	6.90	4.8	8.8	51.5	0.97	0.42	0.12	2.54	0.24	80.8
13	1.65	8.6	7.32	5.4	9.6	53.7	1.06	0.08	0.12	2.24	0.30	79.4
14	1.35	8.7	6.46	4.8	8.4	48.0	0.92	Nil	0.18	1.00	0.26	83.9
15	1.64	8.6	6.65	5.4	8.6	48.9	0.94	0.36	0.14	1.82	0.20	80.1
16	1.34	8.8	7.48	6.0	9.6	54.8	1.00	0.38	0.10	1.50	0.20	83.2
17	1.60	8.8	6.21	5.6	8.0	45.4	0.87	Nil	0.08	1.28	0.36	85.0
18	1.39	8.8	7.94	7.6	10.8	57.8	1.05	0.10	0.10	1.00	0.34	82.4
19	1.66	8.8	6.70	6.4	8.0	48.7	0.91	0.45	0.08	1.54	0.20	83.4
20	1.34	8.9	7.80	8.8	9.2	57.8	1.00	Nil	0.08	2.04	0.32	86.8
21	1.59	8.8	8.58	9.6	11.6	59.6	0.92	Nil	0.10	1.60	0.28	84.7
22	1.34	8.8	7.62	8.0	8.8	56.3	0.91	0.46	0.10	2.02	0.18	82.4
23	1.41	9.0	9.96	8.8	12.0	75.4	1.17	0.12	0.10	2.40	0.26	84.2

Note: Although the physical and chemical charecteristics of the soil did not show any definite changes on the flat beach with the distance from the seawater line, the plant survival was limited upto about 19 meters which might be due to the effect of other factors such as low inundation, deeper water table and low soil moisture content.

CHAPTER V

CHAPTER V

DISCUSSION

EXPERIMENTS NO. 1 and 2: (Emergence experiments under indoor and outdoor conditions):

Result of the present studies showed that the completion of seedling emergence in the indoor low temperature area was 28 days, while the corresponding time in the outdoor shaded area was only about 20 days. No seed emergence took place in salinities higher than 40 ppt at each area. Such observation indicates that the temperature of the air and water and salinity levels of the medium may affect the process of seedling emergence of *A. marina*. Low temperature seemed to retard the emergence process (propagular sprouting). under higher salinities (> 40 ppt). The mangrove seeds appeared to lose water due to salt stress. In this regard Farrant *et. al.* (1993) found that prior to acquisition of full emergence capacity, *A. marina* seeds became tolerant to slight water loss once they became fully germinated, after which desiccation sensitivity was not influenced by the stage of development. However, it was observed that the percentages of seed emergence were almost the same at 0.5 and 40 ppt salinity levels on the 28th day of the experiment which were higher than the percentages observed at 10 and 20 ppt salinity levels. This might be due to the triggering of the low salinity and seawater mechanisms which activated the seed emergence to the same level.

EXPERIMENTS NO. 3 and 4

(Growth studies under indoor and outdoor conditions):

Results on plant growth parameters including shoot height, number of roots and number of leaves showed that *A. marina* seedlings can grow well in salinity levels ranging from 0.5 ppt (tap water) to 40 ppt (sea water) in either indoor or outdoor areas. In the indoor area, better plant growth was observed with 0.5 ppt salinity. In fact, seedlings were subjected to two types of stresses: one was the low air and water temperatures which were 19±1°C and 16 - 17.6°C, respectively, and the second was salinity. The first stress was the same for all the seedlings in the indoor experiment, whereas the second one varied with test solution. Seedlings subjected to the least salinity stress (those with 0.5 ppt salinity) exhibited relatively better growth. Ungar (1978) and Rozema (1978) reported that several obligate halophytes germinate better in distilled water. In general, seedlings growing in indoor low temperature showed very slow growth rate compared to those in outdoor area. Even with 0.5 ppt salinity, where the better growth was observed, the average rate of increase in shoot height was only 0.4 mm/day in the former area.

In the indoor shaded area, relatively higher air and water temperatures (19±1 to 28±4°C) and (19 - 29.8°C), respectively, brought about higher seedling growth rate. An average increase in shoot height of 1.3 mm/day was observed for seedlings subjected to 20 ppt salinity, which was approximately 50% of the seawater salinity prevailing in the U.A.E. waters. Such observations agreed with those of Jashimuddin Karim *et. al.* (1993) who reported greatest increases in most of the growth parameters of the mangrove *A. marina* seedlings which were watered with 50% seawater besides a stem height increase of 0.8 mm/day, during a 45-day experiment.

Subjection of *A. marina* seedlings to different salinities of the indoor and outdoor areas indicated that shoot height decreased with the increase in salinity of the medium. Similar results were reported by Cintron *et. al.* (1978), who observed a significant negative correlation between the mangrove tree height (*Rhizophora sp.*) and soil salinity during a study carried out in Puerto Rico and adjacent islands. It can be expected that the energy lost during respiration of plants should be higher at higher salinities (Von Willert 1970 and Lugo *et. al.* 1975) which in turn reduces the energy available for developmental processes, leading to stunted, dwarf trees. Under these high salinity conditions, Burns (1975) and Hicko *et. al.* (1975) reported a decrease in transpiration and net productivity. In the present study under the indoor low temperature conditions, seedlings of 60 ppt salinity level were alive for about two months only and the seedlings subjected to 80 ppt and 100 ppt salinities were unable to withstand the salt stress. Under outdoor conditions, however, the seedling subjected to 80 ppt showed retarded growth and those of 100 ppt level survived about two months only. Ball (1988) indicated that as the seedling matures and uses up its reserves, its salinity tolerance decreases. Macnae (1968) has investigated the salinity hardiness of mangroves in West Pacific region and reported that dwarf and stunted growth of *A. marina* were observed in soil having salinity over 90 ppt. Cintron *et. al.* (1978) found more dead than living red mangrove trees (*Rhizophora mangle*) where interstitial soil salinities exceeded 65 ppt. Teas (1979) reported dwarfed and gnarled black and white mangroves occurring in Florida at 80 ppt soil salinity.

The average number of roots per seedling under indoor and outdoor conditions tended to decrease with increasing salinity of test solutions. The average length of roots measured for seedlings grown under outdoor shaded conditions showed an increase from salinity levels 0.5 to 40 ppt wereas at 60 ppt it was reduced appreciably. In this regard, Jashimuddin Karim *et. al*. (1993) observed an increase in root length of *A. marina* with increasing salinity upto a seawater concentration equal to 75% of seawater.

The average number of leaves per seedling under indoor conditions reached its maximum with 0.5 ppt salinity, whereas under outdoor conditions seedlings attained the maximum number of leaves with 10 ppt and 20 ppt levels (Tables 12 and 18). The average leaf area at the second node of the plant increased from 0.5 to 20 ppt salinity level in either indoor or outdoor experiments. The maximum average leaf surface area was 10.8 cm^2 at the second node under indoor low temperature conditions, in both 10 and 20 ppt salinity levels, while under outdoor shaded conditions the largest plants attained an average of as much as leaf area of 30.1 cm^2 with 20 ppt level, which is almost half the sea water concentration. According to Karim *et. al*. (1993), a maximum increase of leaf area per plant (32.2 cm^2) was observed in plants irrigated with 50% sea water. In salinities higher than 20 ppt, the average leaf area of the seedlings, in either indoor or outdoor conditions, decreased with the increase in salinity. Giberto (1993) reported a decrease in leaf length with the increase in interstitial salinity, while studying three main mangrove species in the Caribbean namely; *A. germinans* (black mangrove), *Rhizophora* *mangle* (red mangrove) and *L. racemosa* (white mangrove). Lugo and Snedaker (1974) showed that mangrove leaf length was influenced by stresses, such as salinity.

Higher moisture content was attained by roots than either stems or leaves under both indoor and outdoor conditions. However, an inverse correlation was observed with salinity of the growing medium where the moisture content decreased with the increasing salinity.

The maximum total chlorophyll content of the seedling leaves (8.286 mg/l) was observed at 0.5 ppt salinity level under indoor conditions, whereas the leaf chlorophyll was maximum (12.349 mg/l) in 20 ppt level under outdoor shaded conditions. The seedlings in these salinity levels showed better growth conditions such as higher shoot height, number of leaves and leaf area.

EXPERIMENTS NO. 5 and 6: Field studies on a sloping beach:

The percentage of seedling emergence decreased from 100% in the first one meter distance to about 35% at about five meters away from the seawater line on the sloping beach. The result of the two experiments carried out on the sloping beach (slope rate of 4.5%) were quite comparable with respect to the growth parameters. Survival of seedling was restricted to about five meters distance from the water line. The survival rate, shoot height, number of leaves and number of branches per plant tended to decrease with further distances from the low water line upwards. Evaluation of the conditions when the seedlings were about four months old in both experiments indicated that the average shoot height was about 22 cm, and the number of leaves per plant was 10 for the first one meter distance from the low tide level. No published data are available on the growth of *A. marina* with respect to distances from the water line for comparison.

Ghowail *et. al.* (1993) observed an average shoot height of 20.6 cm of *A. marina* seedling grown in 100% seawater after 3 months from the planting date. The survival rate of seedlings in the sloping beach decreased gradually from 100% at the low tide level to about 23% at a distance of about five meters towards the onshore direction. A maximum average shoot height increase per day of 0.24 cm was observed in the first one meter distance from low water in 44 days after sowing. The rate of plant growth was decreased with time, as the increase of shoot height was 0.1 cm/day only when seedlings were about 377 days old. Also, the seedling growth rate decreased with further distances from the sea water line. The probable reason for the mortality of seedlings beyond five meter distance from the low tidal level could be due to the depth of water table which was observed to be deeper than 40 cms from the ground level. In this respect Thom, (1967) reported that mangroves responded to very slight elevation differences. As the beach elevation became higher, salinity of ground water became also higher due to poor inundation which again can be attributed to unfavourable conditions for plant survival and growth. At high ground level where seawater does not often come even at high tide, is unsuitable for afforestation, because the soil salinity is high and underground water level is deep (Suda *et. al*. 1990). Semeniuk (1983) has investigated the salinity variation from the sea inland in a mangrove forest under arid climatic conditions of Northwest Australia and noted that the soil salinity of the elevation lower than the mean neap tide did not become concentrated because of frequent inundation. Again Peng and Xin-men (1983) reported that *Kandelia candel* showed vigorous growth in soil salinity ranging from 7 to 21 ppt, but abnormality in blooming took place between 25.6 and 37.4 ppt. Kazuhiko Ogino (1993) stated that soil salinity might cause a lethal limit to any mangrove plant. However, in the present study, salinity data from the 'well' water suggested that the five meter stretch of beach extending upwards from the low tidal line might be subjected to frequent and prolonged inundation whereas the salinity of ground water beyond this area up to about nine meters was very high (75 - 84 ppt) due to evaporation and poor inundation.

The percentage of moisture content of roots was higher than stem, and the latter contained more moisture than the leaf. These results agreed with those found by Jayasekera (1988) who reported 80.1, 63.4, and 76.6% moisture for root, stem and leaf respectively, in *Rhizophora mangle*. The moisture content of root, stem and leaf in *A. marina* decreased from the low tidal level towards the upward slope of the beach.

In a recent study of mangroves in a wide range of environments, Clough and Sim (1989) found that photosynthetic rates and stomatal conductance both decreased linearly with increasing salinity and with increasing vapour pressure deficit. A significant negative correlation (r= -0.88, P < 0.05) between chlorophyll (Y mg/l) and salinity (S ppt) of tidal water was obtained by Jana T.K. *et. al.* (1993), while studying the primary production of Sundarban mangrove forest in West Bengal, India, and the regression equation calculated by them was Y=16.98 - 0.61xS.

Seedlings near the sea-water line showed higher values of total chlorophyll (14.856 mg/l) which decreased significantly with increasing distance from the low water line, which can be correlated well with growth parameters.

EXPERIMENT NO. 7: FIELD STUDIES ON A FLAT BEACH

Seedling emergence was observed to take place up to a distance of about 19 meters in the landward direction from the seawater line. The high salinity of interstitial water (> 50 ppt) and the depth of water table in this area (45 cm) at low tide could be the probable reasons for restricting the seedling emergence and survival upto 19 meters from the sea water line. It was observed that the seedling survival extended on this flat beach about four times more than that observed on the sloping beach due to more frequent inundation as a result of the lower beach elevation in the flat beach (Experiment No. 5 and 6). When the percentage of surviving seedlings were averaged for each set of five transects, the survival rates observed after 326 days of the experiment for every five meter distance from the seawater line were 76.3, 35.2, 33, and 7.9%, respectively, in the landward direction. In general, the best growth rate was observed with seedlings close to the seawater line and the growth rate decreased gradually landward. This was indicated by the results of the observations made 537 days after sowing the seeds where the average shoot height decreased from 37.8 to 12.5 cm, average stem thickness from 11.7 to 5.5 mm, average number of leaves from 55.7 to 8 and the average leaf area from 13.9 to 1.6 cm^2 from the seawater line to a distance of 19 m in the landward direction.

Retardation of seedling growth landward could be attributed to the decrease in the inundation frequency and the higher salinity conditions of the ground water.

The moisture content of the root was found to be higher than the stem or the leaf of the seedlings and decreased with increasing distances from the sea-water line.

The average total chlorophyll of 2.259 mg/l was observed for the seedlings grown in the first five meter distance from the seawater line which decreased with distance from the sea-water line towards onshore direction. The average chlorophyll value for the seedlings at a distance of 15 to 19 meters was only 0.398 mg/l. The total chlorophyll content can be considered as a good indicator for *A. marina* growth. In this regard, Patterson *et. al.* (1993) indicated that the diameter growth, height growth and the shoot and root biomass of *Avicennia* transplants were significantly lower in *Spartina* zones than the *Avicennia* zone in a mangal salt marsh community.

SOIL OF THE FIELD STUDY AREA

The soil texture of the field study area was sandy since the percentage of sand fraction was between 94 and 96% in the sloping beach, and ranged from 93 to 98% in the flat beach. The bulk density of the sediment in the sloping beach was between 1.26 and 1.56 g/cm^3, while it ranged between 1.32 to 1.71 g/cm^3 in the flat beach field study area. The soil pH of the sloping beach ranged between 8.1 and 8.3, whereas that of flat beach varied between 8.4 and 9.0. The encountered pH high values might be due to the high calcium carbonate content of the soil samples. Chemical analysis indicated the dominance of sodium (between 40 and 75.4 meq/L) among the constituents of the soil. Very high percentage of total calcium carbonate (between 76 and 87%) was found in almost all soil samples, probably due to the enormous quantity of shell fragments in the area.

CHAPTER VI

CHAPTER VI

CONCLUSIONS

The present study indicated a time lag of about 30% in seedling emergence under indoor low temperature condition (19±1°C), which required about 28 days compared to that under outdoor shaded condition (19±1 to 28±4°C), which took about 20 days. Seeds sown under high saline water (salinity > 40 ppt) did not emerge either under indoor or outdoor conditions. With respect to the shoot height data, the best seedling growth under indoor low temperature condition was observed at 0.5 ppt, whereas 20 ppt salinity test solution (50% sea-water salinity) gave the best plant growth under the outdoor shaded condition.

Higher average growth rate in shoot height was found under outdoor shaded conditions at all salinity levels where the seedlings survived. A maximum shoot height increase per day of 0.4 mm was observed at 0.5 ppt salinity under indoor condition, whereas maximum shoot height increase of 1.3 mm/day was noted at 20 ppt salinity under the outdoor conditions.

In general, the average number of roots of mangrove seedlings showed a decreasing tendency with increasing salinity under both indoor and outdoor conditions. The maximum root length of a seedling appeared to increase with increasing salinity under outdoor shaded conditions up to 40 ppt salinity level.

In association with the trend in seedling growth, the maximum average number of leaves per plant (5.1) was observed with 0.5 ppt salinity under indoor condition, while the plant grown at 10 and 20 ppt salinity levels under outdoor conditions had the maximum average number of leaves (6.2).

Plants grown under the indoor low temperature had smaller leaves compared to those under outdoor shaded conditions. Maximum average leaf area of 10.8 cm^2 was observed under indoor conditions, with plants at 10 ppt and 20 ppt salinity levels, while the corresponding leaf area was 30.1 cm^2 with plants at 20 ppt salinity level under outdoor shade conditions.

At higher salinity levels (salinity > 40 ppt), the survival rate of seedlings was reduced with increasing salinity and time.

The seedling emergence, survival and growth of mangrove on a sloping beach were influenced by environmental factors such as the distance from seawater line, depth of water table and salinity of ground water. The percentage of seedling emergence decreased progressively from 100% near the seawater line to about 35% at a distance of about five meters away from the low seawater line. Results of the two field experiments conducted on a sloping beach indicated that when mangrove seedlings reached four months old their shoot height became 22 cm and had an average about 10 leaves. Most of growth parameters of the seedlings decreased with distance from the seawater line, and seedlings survival was observed up to a distance of about five meters only from the water line. Salinity of ground water was more than 50 ppt after a distance of about five meters from the sea-water line. The rate of increase of seedling shoot height showed also a decreasing tendency with further distance from the seawater line, since the growth rate was 0.10 and 0.03 cm/day at one and five meters distance from the seawater line, respectively, after 377 days from sowing.

In the case of flat beach, the seedling survival was observed up to a landward distance of about 20 meters from the shoreline. The survival rate reduced gradually from 88.7% near sea water line to 3.2% at about 20 meters away on the landward side of the beach when they were 326 days old. The depth of water table was 45 cm observed during the low tide at 20 m distance from the seawater line. In general, most of the plant growth parameters such as shoot height, stem thickness and number of leaves decreased with increasing distances from the seawater line.

The moisture content of the root was higher than that of the shoot or leaf in all experiments conducted. In indoor and outdoor experiments (Experiment No.3 and 4), the percentage moisture content decreased with increasing salinity levels of the medium. While in the field, the moisture content showed a decreasing tendency with further distance from the sea-water line.

The chlorophyll content of mangrove leaves was maximum (total chlorophyll 8.28 mg/l) in plants grown at 0.5 ppt salinity level in the indoor experiment, whereas maximum average total chlorophyll of 12.349 mg/l was found in plants with 20 ppt salinity under outdoor shaded condition. Such salinity levels gave the optimum plant growth as observed in the respective conditions. In the field, the leaf chlorophyll of *A. marina* decreased with further distances from the seawater line in both sloping and flat beach areas. Total chlorophyll of mangrove leaves decreased from 14.856 to 1.074 mg/l from one meter to five meter distance from the seawater line on the sloping beach, while the corresponding values decreased from 2.259 to 0.398 mg/l from low tidal level to a distance of about 19 meters from sea-water line on the flat beach, suggesting a negative correlation between salinity and productivity of *A. marina*.

In general, the soil of the field study areas of the sloping and flat beaches had almost similar physio-chemical characteristics. The texture of the soil was sandy, since the sand fraction was higher than 93% in all samples analyzed. The bulk density of the sediments was between 1.3 and 1.7 g/cm^3. The calcium carbonate content of the soil was high (75.6 - 86.8%), and the pH varied between 8.1 and 9.0. High amount of sodium was observed in the soil which ranged between 40 and 75.4 meq/L.

Since the mangrove growth was observed up to about 5 m distance from the seawater line on the sloping beach, and up to 19 m on the flat beach where soil moisture and the water table depth were almost the same on both beaches, about 10.3% and about 45 cm respectively, a correlation may exist between soil moisture content, depth of water table and mangrove seedling survival and growth.

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APPENDICES

APPENDICES

Appendix I. Water parameters observed in experimental tanks during emergence studies in experiment No.1 located at indoor low temperature condition with average air temperature 19±1°C.

Appendix II. Water parameters observed in experimental tanks during emergence studies in experiment No.2 located at outdoor shaded condition with average air temperature ranging from 19±1 to 28±4°C.

Appendix III. Weekly average values of water parameters in experimental tanks through out growth studies in experiment No.3 located at indoor low temperature condition with average air temperature 19±1°C.

Appendix IV. Weekly average values of water parameters in experimental tanks throughout growth studies in experiment No.4 located at outdoor shaded condition with average air temperature ranging from 19±1°C to 28±4°C.

Appendix V. Water parameters observed in wells at different distances from seawater line on the sloping beach and coastal water in experiment No. 5 and 6.

Appendix VI. Plates 1 to 27.

Appendix I. Water parameters observed in experimental tanks during emergence studies in experiment No.1 located at indoor low temperature condition with average air temperature 19±1°C.

Salinity Level 0.5 ppt (Control)					
Expt Days	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	8.2	18.2	5.0	1.0	20
02	7.8	18.4	5.5	1.0	40
03	7.6	18.4	5.4	1.0	40
04	7.7	18.0	5.0	1.0	38
06	7.8	18.4	4.8	1.2	34
07	7.6	18.2	4.6	1.0	30
08	7.4	18.4	4.6	1.0	22
09	7.6	18.6	4.5	1.7	24
10	7.9	17.8	4.8	1.1	20
11	7.9	17.4	4.8	1.0	20
13	7.8	17.8	4.9	1.0	20
14	7.7	17.6	5.0	1.1	18
15	7.8	17.8	4.8	1.0	20
16	7.6	18.0	5.0	1.0	19
17	7.4	18.1	4.8	1.1	20
18	7.3	18.0	4.4	1.1	18
20	7.1	17.6	4.0	1.0	16
21	7.0	17.6	4.2	1.0	16
22	6.9	17.4	4.0	1.1	14
23	6.8	17.2	4.2	1.2	12
24	6.8	17.2	4.2	1.1	13
25	6.8	17.0	4.4	1.0	14
27	6.7	17.2	4.6	1.0	12
28	6.6	17.2	4.6	1.1	12
29	6.5	17.0	4.8	1.2	11

Salinity Levels 10 ppt

Expt Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	7.8	18.8	5.0	16.6	30
02	7.2	18.2	5.2	18.5	65
03	7.0	18.4	5.0	18.0	60
04	7.6	18.2	4.9	18.2	56
06	7.6	18.4	4.6	19.2	46
07	7.6	18.6	4.4	19.6	30
08	7.4	18.4	4.4	19.2	32
09	7.6	18.6	4.2	19.4	20
10	7.6	18.0	4.6	19.2	18
11	7.8	17.4	4.8	19.4	18
13	7.8	17.8	4.9	19.4	20
14	7.7	17.6	4.8	19.2	18
15	7.6	17.4	4.8	19.3	20
16	7.5	17.6	4.6	19.2	24
17	7.5	17.2	4.8	19.4	26
18	7.4	17.0	4.0	19.0	24
20	7.2	16.8	3.8	19.2	20
21	6.8	17.0	3.6	19.2	22
22	6.5	17.2	3.6	19.0	20
1.0	12				
28	6.6	17.2	4.6	1.1	12
29	6.5	17.0	4.8	1.2	11

Salinity Levels 10 ppt

Expt Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	7.8	18.8	5.0	16.6	30
02	7.2	18.2	5.2	18.5	65
03	7.0	18.4	5.0	18.0	60
04	7.6	18.2	4.9	18.2	56
06	7.6	18.4	4.6	19.2	46
07	7.6	18.6	4.4	19.6	30
08	7.4	18.4	4.4	19.2	32
09	7.6	18.6	4.2	19.4	20
10	7.6	18.0	4.6	19.2	18
11	7.8	17.4	4.8	19.4	18
13	7.8	17.8	4.9	19.4	20
14	7.7	17.6	4.8	19.2	18
15	7.6	17.4	4.8	19.3	20
16	7.5	17.6	4.6	19.2	24
17	7.5	17.2	4.8	19.4	26
18	7.4	17.0	4.0	19.0	24
20	7.2	16.8	3.8	19.2	20
21	6.8	17.0	3.6	19.2	22
22	6.5	17.2	3.6	19.0	20
23	6.4	17.1	3.8	19.4	21
24	6.6	17.2	4.0	19.4	18
25	6.5	17.2	4.2	19.0	20
27	6.5	17.0	4.0	18.6	18
28	6.7	17.0	4.4	18.8	16
29	6.8	16.8	4.6	18.8	16

Salinity Level 20 ppt

Expt Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	7.6	19.0	4.9	27.0	27
02	7.1	18.3	4.8	34.4	40
03	7.2	18.4	4.6	33.8	38
04	7.6	18.4	4.9	34.0	30
06	7.6	18.6	4.6	34.2	28
07	7.5	18.8	4.4	34.4	26
08	7.4	18.5	4.2	34.4	26
09	7.5	19.0	4.1	34.6	24
10	7.6	18.2	4.4	34.4	20
11	7.8	17.6	4.8	34.8	22
13	7.6	18.0	4.8	34.2	24
14	7.5	18.2	4.6	34.4	22
15	7.7	18.0	4.8	34.0	20
16	7.7	17.8	5.0	34.4	22
17	7.6	17.6	4.6	34.2	20
18	7.4	17.6	4.2	34.0	18
20	7.0	17.4	4.1	34.4	20
21	6.8	17.0	4.0	34.2	19
22	6.6	17.2	4.2	34.0	18
23	6.2	17.0	4.4	34.2	21
24	6.4	17.2	4.1	34.4	20
25	6.6	17.4	4.0	34.0	22
27	6.4	17.2	4.1	34.2	19
28	6.6	17.2	3.9	34.0	18
29	6.6	17.0	3.8	34.4	18

Salinity Level 40 ppt

Expt Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	7.8	19.8	4.9	50.3	25
02	6.9	19.8	4.6	58.5	45
03	7.1	18.4	4.5	58.0	44
04	7.0	18.4	4.6	58.2	40
06	7.4	19.0	4.3	58.2	36
07	7.2	19.0	4.3	58.0	32
08	7.4	19.2	4.1	58.4	30
09	7.2	19.2	4.0	58.4	30
10	7.4	18.0	4.2	58.2	32
11	7.6	17.4	4.5	58.6	28
13	7.8	17.8	4.4	58.4	28
14	7.6	17.6	4.2	58.6	30
15	7.8	17.5	4.3	58.6	32
16	7.7	17.5	4.4	58.2	28
17	7.4	17.6	4.0	58.2	24
18	7.6	17.4	3.8	58.0	22
20	7.4	17.6	3.9	58.4	20
21	7.3	17.6	3.8	58.2	18
22	7.4	17.4	3.6	58.4	20
23	7.4	17.2	3.4	58.4	21
24	7.6	17.4	3.4	58.6	22
25	7.7	17.4	3.6	58.4	19
27	7.4	17.2	3.4	58.2	18
28	7.3	17.0	3.6	58.4	18
29	7.2	17.2	3.8	58.2	20

Salinity Level 60 ppt

Expt Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	7.3	18.2	4.8	62.7	32
02	6.8	18.3	4.6	62.6	59
03	7.0	18.2	4.6	62.4	50
04	6.8	18.2	4.5	62.0	48
06	6.7	19.8	4.0	62.0	40
07	6.6	19.0	4.2	62.2	38
08	6.5	19.0	4.0	62.4	40
09	6.8	18.8	3.9	62.4	42
10	7.0	18.2	4.0	62.2	40
11	7.4	17.4	4.0	62.6	36
13	7.2	18.2	4.2	62.4	30
14	7.0	18.0	4.0	62.0	28
15	7.1	18.4	3.9	62.2	26
16	7.0	18.2	4.1	62.4	27
17	6.9	18.0	4.0	62.2	25
18	7.0	18.2	3.8	62.0	22
20	6.8	18.0	3.8	62.2	20
21	6.6	17.8	3.4	62.4	24
22	6.6	17.6	3.6	62.2	22
23	6.4	17.6	3.4	62.0	20
24	6.2	17.8	3.4	62.4	18
25	6.2	17.6	3.3	62.6	18
27	6.4	17.4	3.4	62.2	16
28	6.2	17.4	3.2	62.4	18
29	6.5	17.4	3.4	62.2	16

Salinity Level 80 ppt

Expt Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	7.3	18.3	4.8	62.9	25
02	6.8	18.2	4.6	62.8	58
03	7.0	18.4	4.6	62.6	50
04	6.8	18.8	4.5	62.4	44
06	6.4	19.8	4.0	62.6	40
07	6.4	19.6	3.8	62.8	42
08	6.4	19.6	3.8	63.0	43
09	6.3	19.0	3.9	63.0	40
10	7.0	18.2	4.0	62.6	38
11	7.4	17.6	4.2	62.8	38
13	7.0	18.0	4.2	63.0	34
14	6.9	18.2	4.0	62.8	30
15	7.1	18.2	3.9	62.6	28
16	7.0	18.0	4.1	62.8	31
17	7.1	18.2	4.0	63.0	30
18	6.8	18.4	3.6	63.2	26
20	7.0	18.0	3.8	63.0	24
21	6.8	18.2	3.4	62.8	20
22	6.6	18.2	3.4	62.8	24
23	6.4	18.0	3.2	63.0	22
24	6.2	18.4	3.4	63.2	20
25	6.4	18.2	3.4	63.0	21
27	6.5	18.2	3.3	63.0	18
28	6.4	18.0	3.2	62.8	16
29	6.2	17.8	3.2	62.6	20

Salinity Level 100 ppt

Expt Days	pH	Water temp.°C	D.O. ppt	m Cond. moh/cm	Turb. ppm
01	7.2	18.2	4.2	62.9	25
02	6.8	18.5	4.8	63.0	53
03	7.2	18.4	4.4	62.8	50
04	6.6	19.0	4.4	62.6	46
06	6.4	18.6	4.0	62.8	40
07	6.4	18.8	4.0	62.8	34
08	6.4	19.0	3.8	63.0	34
09	6.2	19.4	3.8	63.0	32
10	7.0	18.4	4.0	62.9	30
11	7.2	17.8	4.0	63.0	36
13	7.0	18.2	4.0	63.2	34
14	6.8	18.4	3.8	63.4	30
15	6.7	18.4	3.6	63.4	28
16	7.0	18.2	3.7	63.2	29
17	7.1	18.4	3.5	63.3	30
18	6.9	18.6	3.8	63.0	26
20	6.8	18.4	3.8	63.2	28
21	6.8	18.4	3.6	63.0	28
22	6.7	18.2	3.2	63.0	30
23	6.6	18.4	3.2	62.8	26
24	6.6	18.2	3.4	62.7	24
25	6.4	18.2	3.2	62.9	24
27	6.2	18.0	3.4	63.0	22
28	6.2	18.2	3.4	63.2	22
29	6.3	18.4	3.2	63.2	22

Appendix II. Water parameters observed in experimental tanks during emergence studies in experiment No. 2 located at outdoor shaded condition with average air temperature ranged 19±1°C to 28±4°C.

Salinity Level 0.5 ppt (Control)					
Experiment Days	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	8.0	28.6	4.8	1.0	16
02	8.1	28.4	4.7	1.2	17
03	8.0	28.6	4.5	1.1	18
04	7.9	28.6	4.6	1.0	16
05	7.8	28.8	4.5	1.1	17
06	7.9	29.4	4.6	1.2	18
07	7.8	29.6	3.8	1.2	19
08	7.9	29.8	3.6	1.4	18
09	7.6	30.0	3.4	1.2	20
10	7.8	29.6	3.6	1.4	21
11	7.8	29.4	3.6	1.2	20
12	7.9	29.2	3.6	1.0	20
13	7.8	29.4	3.4	1.2	22
14	7.8	29.2	3.6	1.1	21
15	7.7	29.0	3.6	1.2	20
16	7.8	29.0	3.6	1.2	20
17	7.7	29.0	3.8	1.1	20
18	7.8	28.8	3.8	1.1	21
19	7.8	28.8	3.8	1.2	22
20	7.8	28.6	4.0	1.1	22

Salinity Level 10 ppt

Experiment Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	8.0	28.6	4.6	3.8	18
02	7.8	28.4	4.6	4.0	16
03	8.0	28.6	4.4	3.8	18
04	7.9	28.6	4.5	4.2	18
05	7.8	28.8	4.4	4.0	18
06	8.0	29.4	4.6	4.2	20
07	7.9	29.8	3.8	4.2	20
08	8.0	29.8	3.6	4.0	18
09	7.8	30.0	3.4	3.9	20
10	7.9	29.8	3.4	3.8	22
11	7.8	29.6	3.4	3.8	20
12	7.9	29.4	3.6	3.8	20
13	7.8	29.4	3.4	4.0	20
14	7.9	29.4	3.6	4.1	20
15	7.8	29.2	3.6	3.8	22
16	7.9	29.0	3.6	3.9	22
17	7.8	29.2	3.6	4.0	20
18	7.9	28.9	3.6	3.8	22
19	7.9	29.0	4.0	4.0	20
20	8.0	28.8	3.9	3.9	22

Salinity Level 20 ppt

Experiment Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	7.8	28.6	4.8	39.0	20
02	7.8	28.6	4.6	38.8	18
03	8.0	28.6	4.3	39.0	18
04	7.8	28.8	4.5	39.0	20
05	8.0	29.0	4.4	38.8	18
06	8.0	29.4	4.5	40.0	20
07	8.0	29.8	3.6	39.8	22
08	8.1	29.8	3.6	39.8	20
09	8.0	30.2	3.2	40.0	22
10	8.0	29.8	3.4	40.0	22
11	7.9	29.8	3.4	39.4	20
12	7.9	29.4	3.4	39.6	22
13	8.0	29.4	3.4	39.6	22
14	8.0	29.6	3.4	39.4	20
15	8.1	29.4	3.6	39.0	22
16	7.9	29.0	3.6	38.8	20
17	8.0	29.2	3.8	39.0	22
18	8.1	29.0	3.6	38.8	24
19	8.0	29.0	4.0	38.8	22
20	8.0	28.8	4.0	38.8	22

Salinity Level 40 ppt

Experiment Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	8.1	28.6	4.6	59.7	18
02	8.0	28.8	4.5	59.6	17
03	8.2	28.8	4.3	59.7	18
04	8.1	28.9	4.4	59.8	20
05	8.1	29.2	4.4	59.6	19
06	8.0	29.6	4.5	59.4	20
07	8.1	29.8	3.8	59.2	22
08	8.2	30.0	3.6	59.4	20
09	8.2	30.2	3.4	59.4	24
10	8.1	30.0	3.2	59.6	22
11	8.0	29.8	3.4	59.8	20
12	8.0	29.6	3.4	59.6	21
13	8.1	29.4	3.4	59.6	20
14	8.1	29.6	3.4	59.4	20
15	8.2	29.4	3.6	59.6	22
16	8.0	29.0	3.8	59.4	20
17	8.1	29.2	3.8	59.6	22
18	8.1	29.0	4.0	59.4	22
19	8.0	29.0	4.1	59.6	21
20	8.0	28.8	4.2	59.4	20

Salinity Level 60 ppt

Experiment Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	8.1	28.6	4.4	61.0	20
02	8.0	28.8	4.4	61.2	20
03	8.1	28.8	4.2	61.2	18
04	8.1	29.0	4.2	61.4	20
05	8.2	29.2	4.2	61.2	20
06	8.0	29.6	4.4	61.4	20
07	8.1	29.8	4.0	61.4	22
08	8.2	30.0	3.6	61.6	22
09	8.2	30.4	3.6	61.8	24
10	8.2	29.8	3.4	61.4	22
11	8.0	30.0	3.4	61.6	22
12	8.1	29.6	3.2	61.6	22
13	8.1	29.6	3.4	61.4	24
14	8.2	29.6	3.4	61.6	22
15	8.1	29.2	3.4	61.4	24
16	8.1	29.0	3.8	61.2	28
17	8.2	29.1	3.6	61.4	26
18	8.1	29.0	3.8	61.2	27
19	8.1	29.0	4.0	61.4	28
20	8.1	28.8	4.0	61.2	30

Salinity Level 80 ppt

Experiment Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	8.1	28.8	4.4	62.0	20
02	8.0	28.8	4.2	62.0	22
03	8.2	29.0	4.0	62.2	20
04	8.1	29.0	4.2	62.0	22
05	8.2	29.4	4.0	62.2	20
06	8.1	29.6	4.4	62.4	22
07	8.2	29.8	4.1	62.2	24
08	8.2	30.0	3.8	62.8	22
09	8.3	30.4	3.4	62.6	24
10	8.2	29.8	3.4	62.4	24
11	8.1	30.0	3.4	62.4	24
12	8.1	29.8	3.4	62.2	24
13	8.2	29.6	3.6	62.2	24
14	8.2	29.6	3.4	62.4	24
15	8.1	29.2	3.2	62.2	24
16	8.1	29.1	3.6	61.8	30
17	8.2	29.2	3.6	62.0	32
18	8.2	29.0	3.6	62.0	36
19	8.1	29.1	3.8	62.2	34
20	8.2	29.0	3.9	62.0	36

Salinity Level 100 ppt

Experiment Days	pH	Water temp.°C	D.O. ppt	Cond. m moh/cm	Turb. ppm
01	8.2	28.6	4.3	62.9	20
02	8.1	28.8	4.2	62.8	22
03	8.1	29.0	4.0	62.7	21
04	8.2	29.2	4.1	62.9	22
05	8.3	29.6	4.0	62.8	20
06	8.2	29.8	4.2	62.8	22
07	8.3	30.0	4.1	62.6	24
08	8.3	30.2	4.0	62.8	24
09	8.4	30.4	3.8	62.6	26
10	8.2	29.8	3.6	62.8	24
11	8.2	30.0	3.4	63.0	26
12	8.1	29.8	3.6	62.8	24
13	8.2	29.6	3.6	62.8	26
14	8.2	29.6	3.4	62.7	24
15	8.1	29.2	3.2	62.8	24
16	8.1	29.2	3.4	62.6	22
17	8.2	29.2	3.4	62.8	24
18	8.1	29.0	3.6	62.6	24
19	8.1	28.8	3.8	62.4	26
20	8.2	29.0	3.8	62.2	25

Appendix III. Weekly average values of water parameters in experimental tanks during growth studies in experiment No.3 located at indoor low temperature condition with average air temperature ranged 19±1°C to 28±4°C.

Salinity Level 0.5 ppt (Control)					
Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	6.9	17.0	5.0	3.6	10
02	7.0	17.2	5.2	3.4	12
03	7.0	16.6	5.0	3.2	10
04	7.1	16.8	4.8	3.2	8
05	7.1	16.4	4.8	3.0	9
06	7.2	16.4	4.8	3.2	11
07	7.1	16.8	4.6	3.0	10
08	7.0	17.0	4.8	3.2	12
09	7.0	16.8	4.6	3.0	12
10	6.9	16.8	4.6	3.0	11
11	7.0	16.6	4.8	3.2	12
12	7.1	16.8	4.8	3.2	14
13	7.1	16.0	5.0	3.2	14
14	7.0	16.2	5.2	3.4	14
15	7.1	16.0	5.2	3.2	12
16	7.2	16.0	5.0	3.0	13
17	7.2	16.2	4.8	3.0	14

Salinity Level 10 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	6.9	17.2	4.8	18.0	16
02	7.0	17.2	5.0	17.8	14
03	7.1	16.6	4.8	17.6	16
04	7.1	16.8	4.8	17.6	14
05	7.1	16.6	4.6	17.8	16
06	7.1	16.4	4.8	17.8	15
07	7.2	16.8	4.8	17.8	15
08	7.1	17.0	4.6	18.0	16
09	7.2	17.0	4.4	18.0	17
10	7.0	16.8	4.5	17.8	18
11	7.1	16.8	4.6	17.6	18
12	7.2	17.0	4.6	17.8	18
13	7.1	16.2	4.8	18.0	19
14	7.1	16.4	5.0	18.2	20
15	7.2	16.2	4.8	18.0	18
16	7.3	16.0	4.8	18.0	20
17	7.3	16.2	4.8	18.4	21

Salinity Level 20 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.0	17.2	4.9	28.2	20
02	7.1	17.0	4.8	28.0	21
03	7.2	16.8	4.6	28.4	20
04	7.2	16.8	4.6	28.4	22
05	7.1	16.6	4.6	28.2	20
06	7.2	16.6	4.6	28.0	21
07	7.2	16.8	4.4	28.6	20
08	7.1	17.0	4.6	28.8	18
09	7.3	16.8	4.5	29.0	20
10	7.1	17.0	4.5	29.0	19
11	7.2	17.0	4.4	32.0	20
12	7.2	17.2	4.6	32.0	20
13	7.2	16.2	4.8	30.6	22
14	7.1	16.6	5.0	31.2	22
15	7.2	16.4	4.6	31.2	21
16	7.4	16.2	4.6	31.4	23
17	7.3	16.2	4.6	31.2	22

Salinity Level 40 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.2	17.2	4.7	58.3	22
02	7.2	17.0	4.5	58.2	23
03	7.4	16.8	4.6	58.1	21
04	7.2	16.6	4.5	58.2	20
05	7.2	16.6	4.5	58.1	21
06	7.2	16.6	4.6	58.2	20
07	7.2	17.0	4.4	58.2	22
08	7.2	17.2	4.5	58.0	24
09	7.4	16.8	4.6	58.1	24
10	7.2	17.0	4.5	58.0	20
11	7.2	17.0	4.6	58.2	18
12	7.4	17.2	4.6	58.1	20
13	7.2	16.4	4.8	58.2	22
14	7.2	16.8	4.6	58.1	20
15	7.2	16.6	4.4	58.2	21
16	7.4	16.4	4.5	58.4	20
17	7.4	16.2	4.6	58.2	22

Salinity Level 60 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.2	17.4	4.6	60.6	34
02	7.2	17.2	4.4	60.8	33
03	7.6	17.0	4.4	61.0	31
04	7.4	16.8	4.4	61.2	30
05	7.2	16.8	4.4	61.0	31
06	7.4	16.6	4.5	61.2	30
07	7.2	17.2	4.2	60.8	32
08	7.2	17.4	4.4	61.0	34
09	7.4	16.8	4.5	60.8	34
10	7.2	17.2	4.4	61.0	30
11	7.4	17.2	4.4	60.8	28
12	7.6	17.4	4.6	61.6	26
13	7.4	16.6	4.8	60.6	28
14	7.4	17.0	4.6	60.0	30
15	7.2	16.8	4.4	60.6	32
16	7.6	16.6	4.4	60.8	32
17	7.4	16.4	4.6	60.6	30

Salinity Level 80 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.2	17.4	4.6	61.4	38
02	7.3	17.4	4.5	62.0	35
03	7.4	17.2	4.2	62.2	34
04	7.4	16.8	4.0	62.4	32
05	7.4	16.8	4.4	62.2	34
06	7.6	16.8	4.4	62.4	34
07	7.4	17.2	4.2	62.0	36
08	7.2	17.4	4.4	62.4	36
09	7.6	17.0	4.4	63.2	38
10	7.4	17.2	4.2	63.4	33
11	7.4	17.4	4.2	63.2	36
12	7.8	17.6	4.4	63.0	32
13	7.6	16.6	4.6	61.4	36
14	7.6	17.2	4.6	61.4	36
15	7.4	16.8	4.4	61.2	34
16	7.8	16.8	4.4	61.6	36
17	7.6	16.4	4.6	61.4	38

Salinity Level 100 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.4	17.6	4.5	62.6	42
02	7.4	17.4	4.2	63.0	46
03	7.6	17.2	4.0	63.2	44
04	7.6	17.0	4.2	63.4	43
05	7.4	17.2	4.4	63.2	42
06	7.6	17.0	4.2	63.4	44
07	7.4	17.4	4.2	63.2	46
08	7.4	17.6	4.0	63.6	48
09	7.8	17.2	4.2	64.2	49
10	7.6	17.4	4.0	64.4	48
11	7.8	17.6	4.0	64.0	46
12	7.9	17.6	4.2	64.2	40
13	7.8	16.8	4.4	62.6	38
14	7.8	17.2	4.4	62.2	42
15	8.0	17.0	4.2	62.4	44
16	8.2	16.8	4.2	62.6	46
17	8.1	16.6	4.4	62.4	46

Appendix IV. Weekly average values of water parameters in experimental tanks during growth studies in experiment No.4 located at outdoor shaded condition with average air temperature ranging from 19±1°C to 28±4°C.

Salinity Level 0.5 ppt					
Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.0	29.4	4.8	3.4	15
02	7.1	29.2	4.6	3.2	14
03	7.1	29.2	4.4	3.4	16
04	7.2	29.0	4.4	3.2	18
05	7.2	28.6	4.2	3.4	19
06	7.1	26.8	4.0	3.3	18
07	7.2	24.6	4.2	3.2	16
08	7.2	23.0	4.2	3.4	16
09	7.1	22.4	4.2	3.2	18
10	7.2	21.8	4.0	3.4	19
11	7.2	20.2	3.8	3.6	18
12	7.2	20.0	3.9	4.0	20
13	7.2	19.6	4.2	3.8	18
14	7.2	19.4	4.2	3.6	20
15	7.1	19.2	4.4	3.6	20
16	7.2	19.0	4.4	3.4	18
17	7.2	19.0	4.4	3.4	19

Salinity Level 10 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.1	29.4	4.8	18.2	18
02	7.2	29.2	4.4	18.0	19
03	7.1	29.2	4.4	17.8	18
04	7.2	29.2	4.2	17.8	20
05	7.2	28.2	4.2	18.0	20
06	7.1	26.4	4.1	18.0	19
07	7.2	24.2	4.2	18.0	18
08	7.2	23.0	4.3	18.2	19
09	7.1	22.2	4.4	18.0	20
10	7.2	21.8	4.6	18.4	18
11	7.3	20.2	4.0	18.8	20
12	7.4	20.2	3.9	19.0	20
13	7.2	19.8	4.0	19.2	20
14	7.2	19.6	4.2	19.2	22
15	7.1	19.4	4.2	19.0	21
16	7.2	19.2	4.4	19.0	20
17	7.4	19.2	4.2	19.2	20

Salinity Level 20 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.2	29.6	4.6	34.0	24
02	7.2	29.4	4.4	33.8	26
03	7.4	29.2	4.4	34.0	25
04	7.4	29.0	4.2	34.0	26
05	7.2	28.4	4.2	34.2	24
06	7.2	26.0	4.0	34.0	22
07	7.1	23.8	4.2	35.0	24
08	7.4	22.8	4.4	36.0	22
09	7.2	22.0	4.4	36.2	20
10	7.4	22.0	4.2	36.8	18
11	7.4	20.0	3.9	37.2	20
12	7.4	20.2	4.0	38.0	22
13	7.2	19.6	4.0	38.0	24
14	7.4	19.8	4.0	38.2	26
15	7.2	19.4	4.2	38.2	24
16	7.4	19.4	4.2	38.4	22
17	7.4	19.2	4.2	38.2	24

Salinity Level 40 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.4	29.6	4.5	62.2	44
02	7.4	29.4	4.6	62.2	42
03	7.6	29.0	4.6	62.4	44
04	7.4	28.8	4.4	62.6	46
05	7.5	28.4	4.2	62.4	42
06	7.4	25.0	4.0	62.4	40
07	7.2	23.4	4.2	62.2	38
08	7.5	22.2	4.4	62.4	40
09	7.2	22.0	4.0	62.2	40
10	7.4	21.6	3.8	62.4	38
11	7.2	20.0	4.0	62.0	40
12	7.4	20.0	3.9	61.8	38
13	7.2	19.8	3.8	62.2	39
14	7.4	19.8	4.0	61.6	39
15	7.2	19.6	4.2	62.0	38
16	7.4	19.6	3.8	62.2	40
17	7.4	19.2	4.0	62.2	42

Salinity Level 60 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.4	29.6	4.5	62.6	42
02	7.5	29.6	4.5	62.8	46
03	7.6	29.2	4.4	63.0	44
04	7.5	29.0	4.2	63.2	48
05	7.5	28.8	4.0	63.0	44
06	7.4	25.4	4.0	63.2	42
07	7.3	23.4	4.2	62.8	46
08	7.5	22.4	4.2	63.0	48
09	7.4	22.0	3.8	62.8	44
10	7.5	22.0	3.9	63.0	42
11	7.4	20.2	3.8	62.8	44
12	7.6	20.0	3.8	62.6	46
13	7.4	19.8	3.6	62.6	42
14	7.5	20.0	3.8	61.2	44
15	7.4	19.8	4.0	62.6	44
16	7.6	19.6	3.8	62.8	42
17	7.8	19.8	3.8	62.8	44

Salinity Level 80 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.4	29.6	4.2	63.4	48
02	7.6	29.8	4.4	64.0	50
03	7.6	29.2	4.2	64.2	52
04	7.5	29.2	4.2	64.4	50
05	7.6	29.0	3.8	64.2	48
06	7.5	25.6	3.9	64.4	46
07	7.4	23.6	4.0	64.0	48
08	7.6	22.6	4.2	64.4	48
09	7.5	22.2	3.8	65.2	46
10	7.5	22.2	3.6	65.4	46
11	7.6	20.2	3.6	65.2	48
12	7.8	20.2	3.8	65.0	50
13	7.6	19.8	3.4	63.4	44
14	7.6	20.2	3.8	63.0	46
15	7.8	19.8	4.1	63.2	48
16	7.9	19.6	3.8	63.6	46
17	7.8	19.8	3.6	63.4	48

Salinity Level 100 ppt

Number of weeks	pH	Water temp.°C	D.O. ppt	Cond. m mohs/cm	Turb. ppm
01	7.8	29.8	4.2	64.6	54
02	7.8	29.8	4.2	65.0	56
03	7.9	29.4	4.0	65.2	56
04	7.6	29.2	4.0	65.4	50
05	7.8	29.0	3.8	65.2	49
06	7.6	25.8	3.8	65.4	50
07	7.8	23.6	4.0	65.2	50
08	8.1	22.4	4.2	65.6	52
09	7.6	22.0	3.9	66.2	50
10	7.8	22.2	3.6	66.4	52
11	7.8	20.4	3.4	66.0	52
12	8.0	20.2	3.6	66.0	52
13	7.8	19.8	3.4	64.8	52
14	7.8	20.2	3.6	64.2	50
15	7.8	20.0	4.0	64.4	52
16	8.1	19.8	3.9	64.6	46
17	8.2	20.0	3.6	64.4	54

Appendix V. Water parameters observed in wells at different distances (m) from sea water line on the sloping beach and coastal water in experiment No. 5 and 6 , A = water temperature (°C), B = salinity (ppt), C = dissolved oxygen (ppm), D = pH, E= conductivity (Ms/cm), F = turbidity (ppm).

Date of of observation		Well No.1 0m	No.2 1.5m	No.3 3m	No.4 4.5m	No.5 6m	No.6 7.5m	No.7 9m	Coastal water
10-10-1992	A	28.7	29.2	29.8	30.5	31.1	31.4	31.4	28.5
	B	42.0	50.0	55.0	65.0	75.0	78.0	80.0	40.8
	C	3.8	3.0	3.4	3.7	3.0	3.2	3.2	4.0
	D	7.5	7.6	7.4	7.5	7.5	7.4	7.5	7.4
	E	59.1	60.2	60.7	62.3	63.7	63.8	64.0	59.0
	F	14.0	10.0	16.0	24.0	19.0	20.0	21.0	18.0
28-10-1992	A	27.0	27.7	28.5	29.3	30.1	31.0	31.3	28.0
	B	42.0	45.0	48.0	55.0	62.0	70.0	70.0	40.0
	C	3.0	3.2	3.5	4.0	3.8	4.0	4.0	3.8
	D	7.2	7.1	7.2	7.2	7.2	7.2	7.2	7.4
	E	58.0	59.6	59.6	62.9	63.2	63.7	64.0	58.4
	F	2.0	1.0	4.0	2.0	3.0	4.0	4.0	4.0
19-11-1992	A	23.9	24.3	24.9	26.0	26.9	27.8	27.9	24.5
	B	40.0	42.0	42.0	48.0	54.0	63.0	68.0	40.0
	C	4.2	4.1	4.0	3.8	3.6	3.8	3.8	4.4
	D	7.6	7.6	7.6	7.6	7.5	7.5	7.5	7.6
	E	56.8	57.8	58.3	59.8	63.0	63.7	64.0	57.0
	F	5.0	4.0	4.0	1.0	1.0	2.0	4.0	2.0
20-12-1992	A	20.2	20.7	20.9	22.2	23.5	24.7	25.0	21.7
	B	39.0	39.0	40.0	50.0	58.0	60.0	65.0	40.0
	C	4.2	4.2	4.1	4.0	4.1	4.1	4.2	4.5
	D	7.6	7.6	7.7	7.7	7.7	7.7	7.7	7.6
	E	53.9	54.6	55.9	58.7	61.2	63.5	64.0	56.3
	F	9.0	4.0	4.0	1.0	1.0	2.0	4.0	2.0

Appendix V cont.

Date of observation		Well No.1 0m	No.2 1.5m	No.3 3m	No.4 4.5m	No.5 6m	No.6 7.5m	No.7 9m	Coastal water
	A	16.9	17.0	17.4	18.3	19.0	19.5	20.6	17.0
	B	41.0	41.0	42.0	51.0	60.0	68.0	80.0	40.0
	C	4.5	4.4	4.5	4.2	4.0	4.3	4.4	4.5
25-01-1993	D	7.8	7.8	7.9	7.9	8.0	7.9	7.7	7.9
	E	51.4	51.5	51.5	51.8	56.4	59.6	63.2	51.6
	F	5.0	5.0	5.0	4.0	5.0	5.0	5.0	3.0
	A	20.2	20.2	20.1	19.8	20.0	20.7	21.8	21.8
	B	40.0	38.0	35.0	48.0	58.0	78.0	84.0	40.0
	C	4.4	4.5	3.8	3.7	3.5	3.5	3.8	4.0
20-02-1993	D	7.8	7.8	7.6	7.9	8.0	7.9	7.8	7.9
	E	53.6	52.2	49.7	50.0	51.0	51.8	58.4	54.7
	F	28.0	28.0	25.0	24.0	21.0	18.0	20.0	24.0
	A	24.0	23.6	22.2	22.2	22.2	22.4	22.8	24.0
	B	40.0	40.0	42.0	48.0	52.0	60.0	70.0	40.0
	C	4.2	4.1	4.1	4.0	3.9	3.9	3.8	4.2
29-03-1993	D	7.9	7.9	7.9	7.9	7.9	8.0	8.0	7.9
	E	55.8	55.5	55.5	55.5	56.5	55.4	54.8	56.0
	F	10.0	20.0	20.0	18.0	16.0	17.0	17.0	17.0
	A	29.5	30.5	30.7	31.2	31.3	31.1	31.6	30.7
	B	43.0	44.0	45.0	49.0	59.0	59.0	62.0	40.0
	C	4.0	3.8	3.2	3.0	3.1	3.2	3.5	4.0
13-06-1993	D	7.0	6.9	7.0	7.2	7.3	7.4	7.4	7.1
	E	59.7	60.0	60.9	62.0	62.1	62.0	62.1	59.1
	F	15.0	14.0	15.0	11.0	6.0	4.0	15.0	15.0
	A	32.8	32.8	33.0	33.6	34.4	34.4	34.2	32.9
	B	44.0	45.0	46.0	50.0	62.0	62.0	70.0	41.0
	C	4.0	3.8	3.6	3.4	3.4	3.0	2.8	4.0
21-08-1993	D	7.2	7.2	7.1	7.1	7.2	7.6	7.7	7.9
	E	60.1	60.8	61.3	61.2	62.2	62.2	62.9	59.9
	F	14.0	12.0	14.0	12.0	17.0	16.0	13.0	13.0
	A	30.4	31.4	31.8	32.4	33.4	33.8	33.8	30.4
	B	38.0	38.0	38.0	43.0	50.0	55.0	73.0	38.0
	C	3.8	3.8	3.6	3.4	3.2	3.0	3.0	3.8
26-09-1993	D	7.2	7.0	7.1	7.2	7.4	7.4	7.4	7.2
	E	60.0	60.2	60.2	61.0	61.8	62.0	62.6	51.8
	F	12.0	10.0	11.0	10.0	10.0	8.0	6.0	12.0

Appendix VI : Plates 1 to 27.

Plate 1. Gray mangrove (A. marina) trees flower in June in United Arab Emirates.

Plate 2. Seeds of mangrove are available during September and October in United Arab Emirates.

Plate 3. Mangrove seeds from Umm Al Qaiwain having an average length of 3.2 cm, average width 2.7 cm and average weight 7.2 g.

Plate 4. Mangrove seeds infested with pest fail to emerge.

Plate 5. Mangrove seeds which were soaked in salinities greater than 40 ppt turned their colour to black and failed to shed their seed coat.

Plate 6. Different stages of mangrove seed emergence.

Plate 7. Mangrove growth studies under outdoor shaded conditions ($19 \pm 1°C$ to 28 ± 4 °C) were conducted using four replicates for each salinity level and five seedlings in each replicate and supplied with aeration in experiment No. 4.

Plate 8. The growth of mangrove seedlings was better in lower salinity levels (equal or less than 40 ppt) while in higher salinity levels the growth was poor in experiment No. 4 .

Plate 9. Mangrove seedlings grown in lower salinity levels had longer roots and better growth.

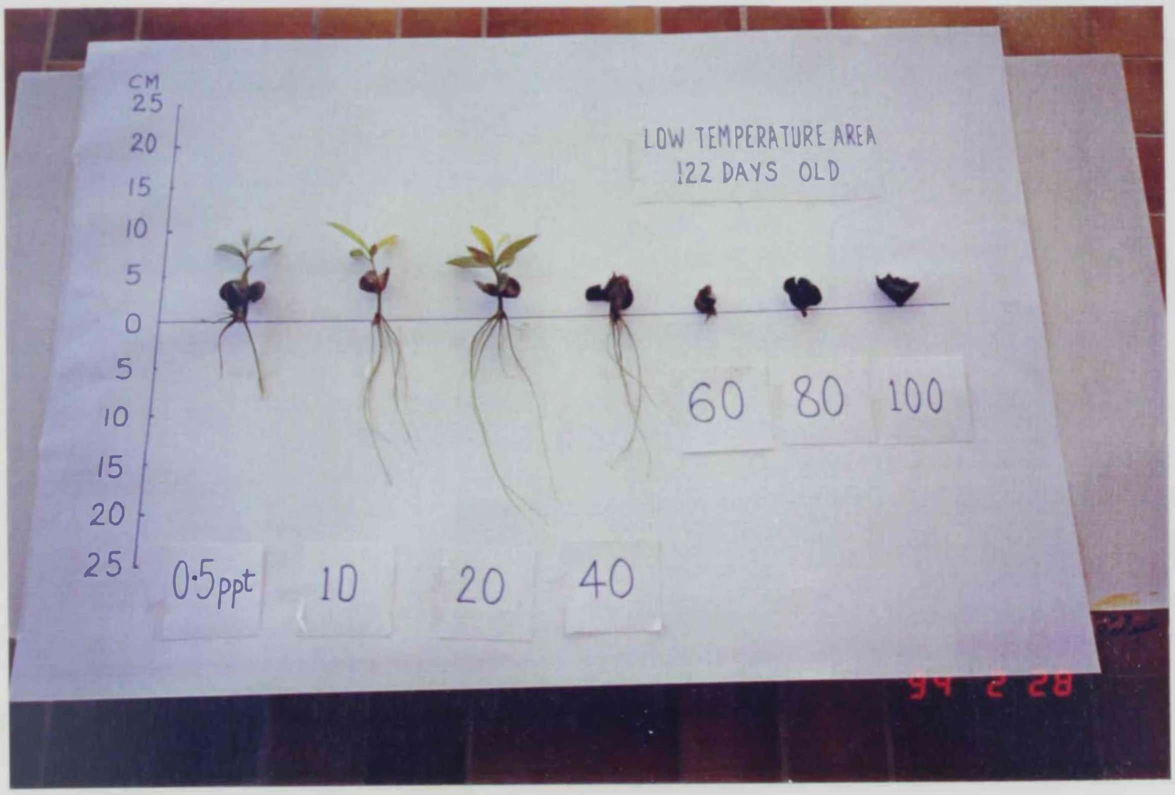

Plate 10. Mangrove seedling growth was low at different salinity levels under low temperature conditions (19 $\pm$ 1 °C) in experiment No. 3.

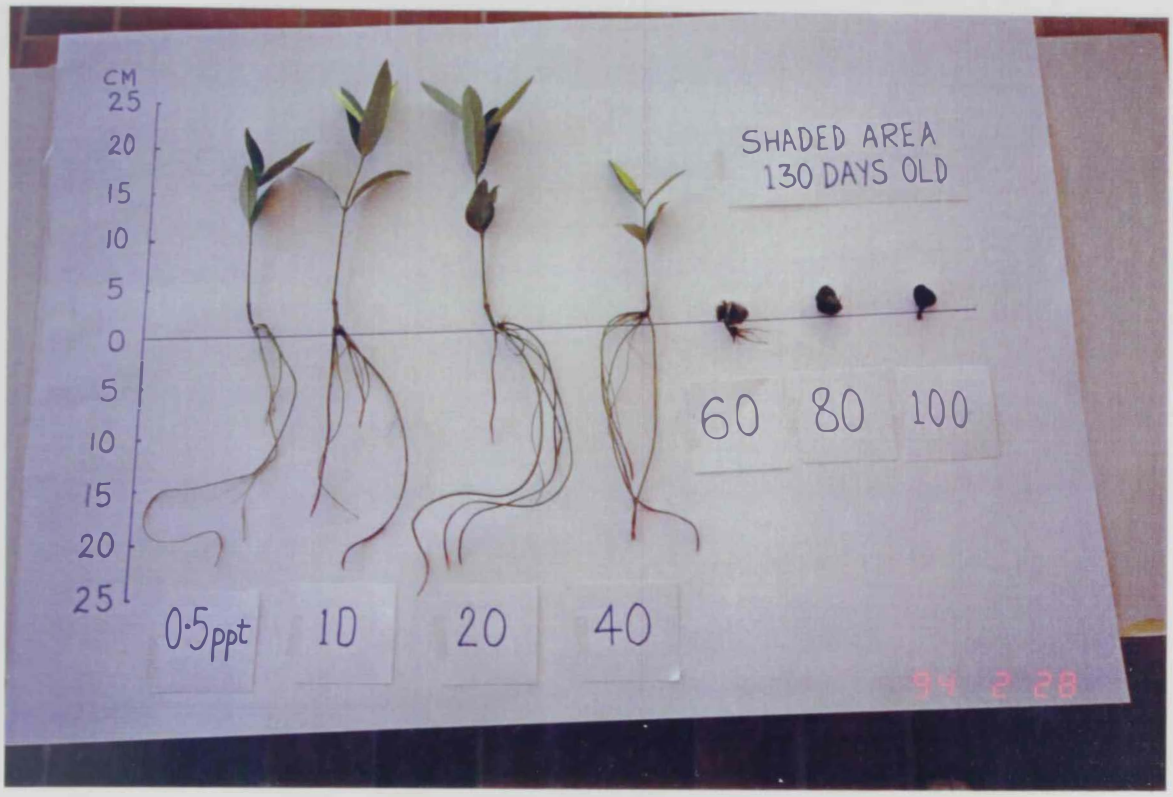

Plate 11. High growth in mangrove seedling was observed under outdoor shaded conditions in experiment No. 4.

Plate 12. Sowing the mangrove seeds on 23 transects starting from the seawater line upwards on the flat beach near the Marine Resources Research Centre, Umm Al Qaiwain in experiment No. 7.

Plate 13. Mangrove seedling growth studies on a sloping beach in experiment No. 5 & 6. Wells were dug at 1.5 meter interval along the slope of the beach to measure the water table depth and the ground water parameters.

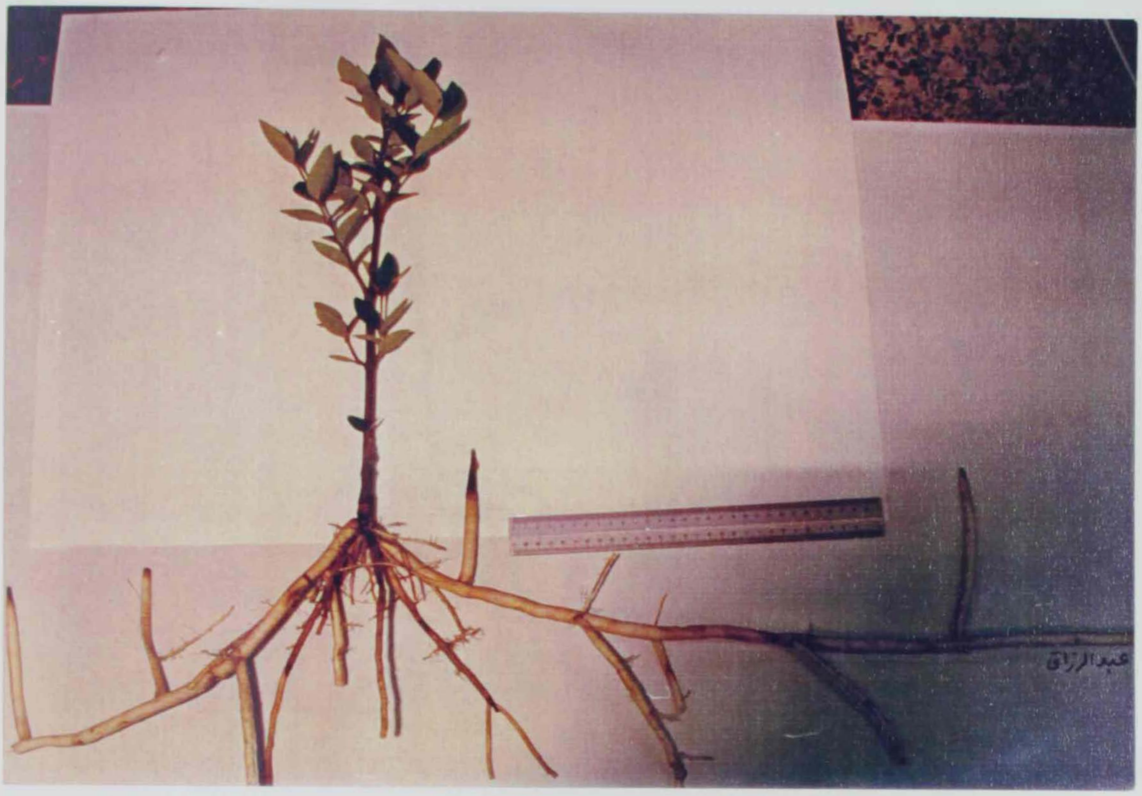

Plate 14. About two year old mangrove seedling grown in the field showing the growth of pneumatophores and the roots.

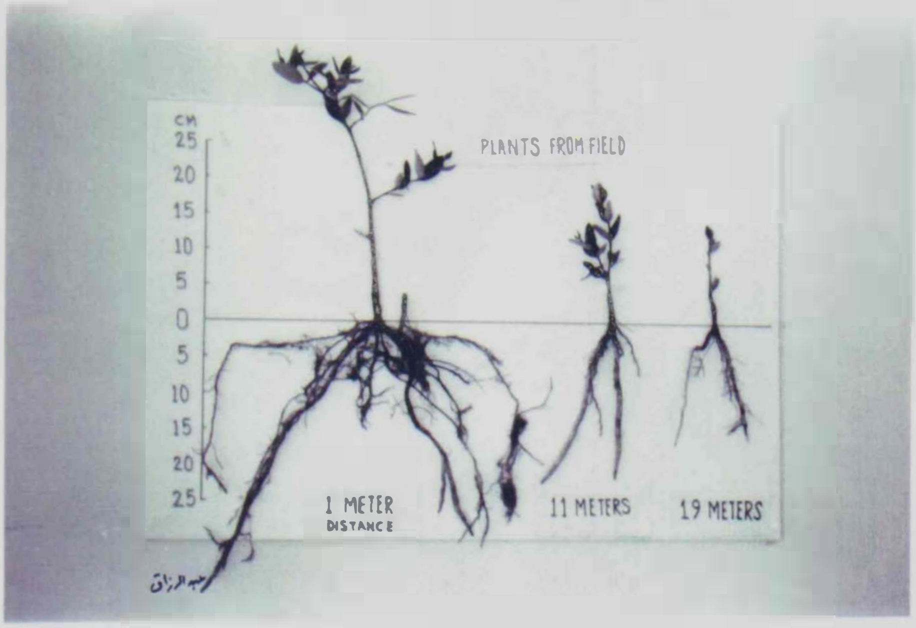

Plate 15. One year old mangrove seedlings showed decreased growth with the increase of the distance from the seawater line in experiment No. 7 .

Plate 16. Measurements of mangrove seedlings were done at different stages of the experiments.

Plate 17. Pneumatophores emerge from the roots of the mangrove tree.

Plate 18. Mangrove areas are good nursery grounds for many fish species. One such location is near the aquaculture effluent of Marine Resources Research Centre in Umm Al Qaiwain.

Plate 19. Mangrove forests in Khor Kalba. About 150 hectares of mangrove exist there (Rabanal et al 1978).

Plate 20. Mangrove forests in Al Rams (Ras Al Khaimah). About 20 hectares of mangrove was reported in this area (Rabanal et al 1978).

Plate 21. Mangrove forest in Ras Al Khaimah. About 40 hectares of mangrove was reported (Rabanal et al 1978).

Plate 22. A Mangrove tree in Umm Al Qaiwain lagoon area showing pneumatophores at low tide. About 200 hectares of mangrove area was reported in Umm Al Qaiwain (Rabanal et al 1978).

Plate 23. Mangrove trees cultivated in 1985 by seeds near the effluent of aquaculture ponds in Umm Al Qaiwain from which some of the seeds were collected for experiments.

Plate 24. Mangrove forests in Al Heel island (Abu Dhabi).

Plate 25. Mangroves of Sadiyat island in Abu Dhabi. About 2500 hectares of mangrove area was reported in Abu Dhabi region (Rabanal et al 1978).

Plate 26. Mangroves in Ad Dabiyyah south west of Abu Dhabi.

Plate 27. Mangroves in Abu Al Abyad island (Abu Dhabi).