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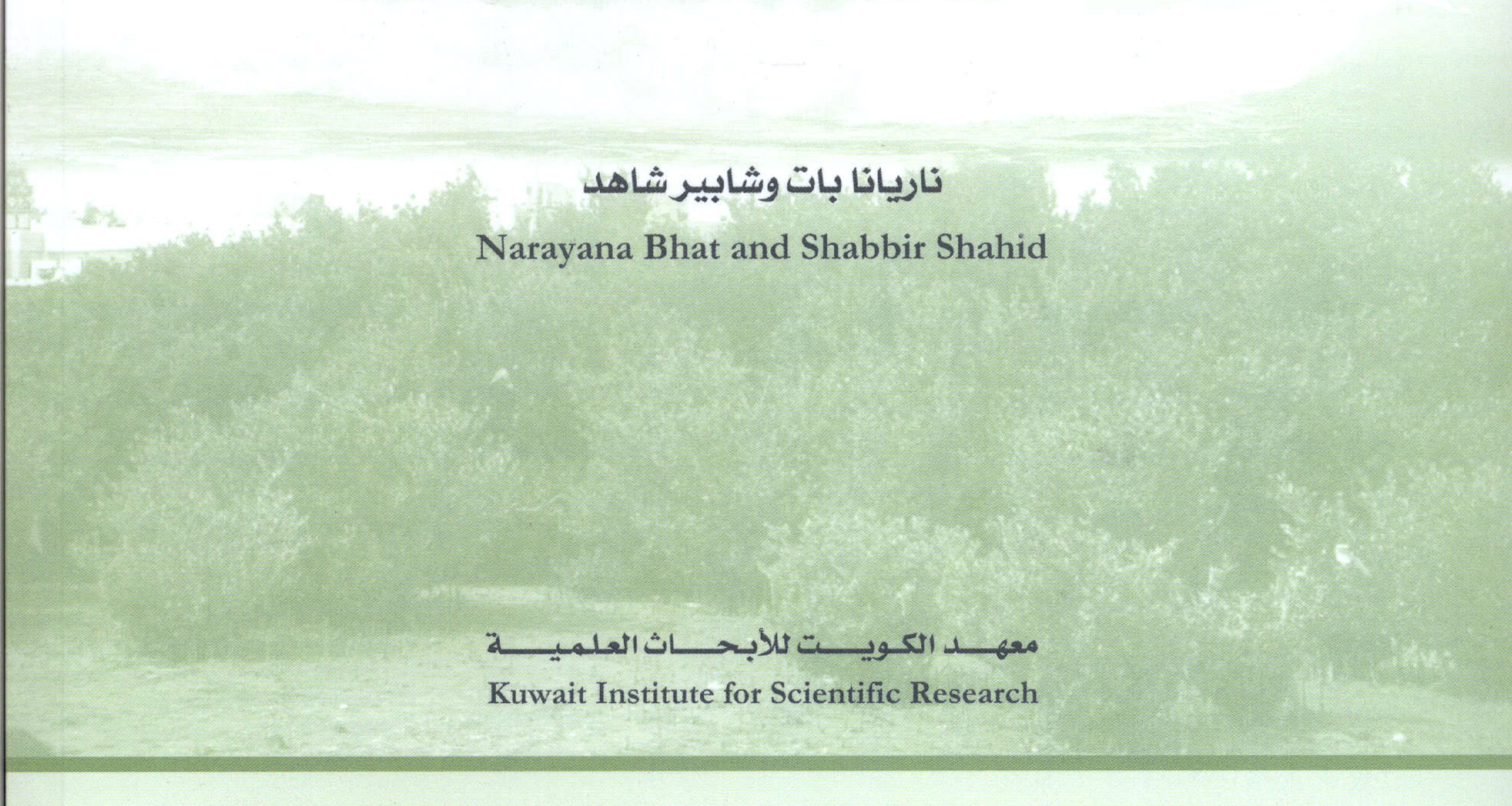
التقرير النهائي

Final Report

استزراع نبات القرم لحماية وإنماء السواحل الكويتية (المرحلة الثانية)

Introduction of Mangroves for Protection and Enrichment of Kuwait Coastlines (Phase II)



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معهد الكويت للأبحاث العلمية

Kuwait Institute for Scientific Research

2002

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Title: Introduction of Mangroves for Protection and Enrichment of Kuwait Coastlines (Phase II)

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Abstract:

The introduction of mangrove along the coastline is believed to play a major role in enhancing greenery and enriching the marine environment in the intertidal areas. Therefore, the present study was conducted to introduce mangrove ecotypes and species, develop suitable nursery and silvicultural practices, identify suitable sites along the coastline for establishing experimental plantations and assess the likely environmental impacts of mangrove introduction.

Results indicated that raising the seedlings in greenhouses and acclimatizing them to seawater salinity prior to field planting was the most appropriate method of propagation. Data on vegetative growth recorded at three-month intervals indicated that seedling growth varied with site and even at different locations within each site. Plants along or near the tidal line showed the maximum survivability and height increase. Doha site had the most ideal site conditions for establishing *Avicennia marina* plantations. At this site, wet sandy loam that is covered by daily tidal water promoted maximum plant survival and promoted seedling growth. Results of the environmental impact assessment showed that mangrove plantations in the study area had and will have more positive impacts to the surrounding ecosystem. Based on the findings of these studies, a strategic approach has been proposed for establishing mangrove plantations in Kuwait.

Keywords: Environmental enhancement, Propagation, Seed germination, Soil characterization, Intertidal mudflats, *Avicennia marina*, Mangrove reintroduction.

عنوان المشروع: استزراع نبات القرم لحماية وإنماء السواحل الكويتية (المرحلة الثانية)

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الملخص

إن استزراع نبات القرم على طول الشريط الساحلى يلعب دوراً مهماً فى تنمية التخضير وإنماء البيئة البحرية فى المنطقة الممتدة بين المد والجزر. ونتيجة لذلك فإن الغرض من الدراسة الحالية هو استزراع الأنواع البيئية المختلفة والأجناس المتنوعة لنبات القرم، تطوير مشتل مناسب ودراسة الممارسات التحريجية الخاصة بنبات القرم، والتعرف على مواقع ساحلية مناسبة للاستزراع على طول الشريط الساحلى. تدل النتائج على أن إنبات البذور فى المحميات وغمرها فى ماء البحر قبل إنباتها فى الحقل، هي الطريقة المثلى للإكثار الخضري لنبات القرم. تم تدوين البيانات حول النمو الخضرى وذلك خلال ثلاثة أشهر والتى دلت على أن نمو الشتلات يختلف باختلاف الموقع الذي تم فيه الزراعة وأيضا باختلاف المواقع داخل كل موقع. لقد سجلت النباتات المستزرعة على امتداد الساحل قرب منطقة المد والجزر زيادةً فى الطول وارتفاعاً في درجة مقاومة الملوحة. يمثل موقع الدوحة الطيني المغطى بمياه المد والجزر بشكل يومى المكان الأمثل لاستزراع *Avicennia marina*. ومن النتائج يتبين أن استزراع نبات القرم فى هذه المنطقة له تأثير بيئى فعال وإيجابي للمحيط البيئى.

أهم المصطلحات: إثراء البيئة، توالد، إنبات البذور، تصنيف التربة، الرواسب الطينية، *Avicennia marina*، إعادة إدخال القرم.

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Executive Summary

Mangrove communities form an important component of renewable natural resources in coastal regions in several tropical and subtropical countries. They offer very good potential for the enhancement of the coastal environment and enrichment of degraded coastal ecosystems. As coastal and marine resources are of great importance to Kuwait, any improvement in the coastal vegetation would significantly enhance the ecological and economic sustainability of these resources. Therefore, this three year project was undertaken with the financial support from the Kuwait Foundation for the Advancement of Sciences (KFAS) with a view to establish experimental mangrove plantations in selected sites along Kuwait's coastline and develop suitable nursery and silvicultural practices to be adopted under Kuwait's environmental conditions. This project was conducted jointly by the Kuwait Institute for Scientific Research (KISR) and the Public Authority for Agricultural Affairs and Fisheries Resources (PAAF). To accomplish the project's objectives, five tasks were delineated, namely, seed obtainment, germination and seedling growth (Task 1); site selection and evaluation (Task 2); transplantation into permanent site (task 3); evaluation of each genetic population (Task 4); and preparation of environmental impact statement (Task 5). The report presents a detailed account of the materials and methodology employed results and discussion of observed effects, and conclusions and recommendations.

A number of experiments were conducted to ascertain the effects of propagule size, duration of soaking, volume and composition of the growing medium and germination conditions and the results indicated a positive influence of propagule size and negative influence of duration of presoaking on propagule germination and initial seedling growth. Large-sized propagules that were soaked for 24 hours before sowing germinated faster than smaller propagules. Extended period of presoaking resulted in the browning of hypocotyls and adversely affected germination. The volume of the medium and the type of container did not influence the germination, but the volume of the medium had positive effect on the seedling growth, particularly at the later stages of their development. In general, sowing the propagules in 500 ml polybags filled with only soil or soil with sphagnum peat moss (1:1 v/v) produced superior quality seedlings. Under Kuwait's climate, propagules should be germinated in benches flooded with fresh water or under intermittent mist in an environment controlled greenhouses in and

acclimatized to prevailing environmental conditions when they reach transplantable stage.

Selection criteria involving site specific characteristics (accessibility; human impact; dimension of the mudflats; topography; presence of contaminants; rubble and construction material; likely environmental impact; and tidal coverage) were developed for selection of potential sites for establishing experimental plantations. Out of the fourteen sites initially assessed, only five sites that best fulfilled these criteria were selected for field description and detailed characterization. Based on the findings of the field survey and physical (particle size distribution, color) and chemical analysis (Eh, pH EC, CaCO3, and SAR), the soils were described for their suitability, limitations and classification.

Experimental mangrove plantations were established on the five sites selected in Task 2. Seedlings establishment was very good (50 to 100%) during the first three months. Plant performance differed greatly between sites and within each site. Seedling establishment was the best in the Doha, followed by the Sulaibikhat Site No. 1. The highest seedling mortalities were observed in the Subiya and Shuwaikh (Subsite B and C) sites. In general, planting of seedlings in the middle silty loam zone promoted seedling establishment and growth. In contrast, planting in the upper sandy or inner clayey muddy zones increased seedling mortality and hence, should be avoided. Plant performance at various locations within each site was compared with site characteristics to identify potential threats to seedling establishment and growth.

A tree improvement program has been initiated by raising progeny of promising individuals from local *Avicennia* plantations near KISR’s main campus. Additionally, seedlings of both introduced and local ecotypes have been established in the field and were evaluated for their performance. A systematic hybridization program will be undertaken when these lines reach the flowering stage.

The integrated impact assessment methodology indicated positive impacts of mangrove plants on all environmental parameters, particularly the physicochemical effects. Hence, it is concluded that mangrove plantation in the study area has and will have a positive impact to the surrounding ecosystem. However, a continuous follow-up and measurements of the water quality and other environmental parameters especially the organic and non-organic pollutants should be continued to obtain additional information for evaluation and detailed assessment.

National staff participating in the project was trained in propagation, site selection implementation of field experiments and growing of mangroves.

Based on the findings of this project, a planting scheme has been developed for the establishment of mangrove plantation.

Introduction

Mangrove communities are the salt-tolerant forest ecosystems of the tropical and subtropical coastal areas, where they play an important role in the economy of people in those coastal areas. Additionally, they support both recreational and commercial fishing, and provide many other direct and indirect benefits. They also constitute a reservoir and refuge for several unusual plants and animals. Mangrove ecosystems are also among the most productive ecosystems in the world, although their productivity varies considerably, both on regional and local scales. In the Arabian Gulf region, mangroves are important not just biologically, but in a historical context (Sheppard et al., 1992). In fact, they were the first mangroves to be reported in the world's literature (Baker and Dicks, 1982).

The number of mangrove species and associated flora and fauna in the Arabian Gulf are low compared with those in other mangrove growing areas. Of the species known in the region, *Avicennia marina* is by far the most common species used for landscape beautification in the region, especially in the United Arab Emirates (UAE), Bahrain, Oman and the Kingdom of Saudi Arabia (KSA), although others like *Rhizophora mucronata*, *Ceriops tagal* and *Bruguiera gymnorrhiza* are planted on a limited scale. The reports on the ecophysiology of the Arabian Gulf region suggest that the temperature, high salinity and the aridity in climate together with its limited range of suitable habitats and niches, are responsible for the low species diversity, low survival, and slow growth and productivity (Clough, 1993). Rapidly and poorly planned coastal development programs have also contributed to the destruction of suitable habitats for mangrove plantation, and led to the disappearance of mangroves from Kuwait and other countries in the region (Abu El-Nil, 1994; Abu El-Nil et al., 2001, Subandar et al., 2001). These communities were unable to regain their natural existence in the northern part of the Gulf (Sheppard et al., 1992). Under such circumstances, artificial reintroduction or revegetation is the most viable option for restoring coastal plant communities, of which the mangrove is an integral part (Field, 1996; Saenger, 1996).

Limited mangrove planting trials have been undertaken in the Gulf, the first one being in Kuwait in the early 1960s. Three species (*Avicennia marina*, *Bruguiera gymnorrhiza* and *Rhizophora mucronata*) were used for replanting, but with very little success (Firmin, 1968). In the 1970s, the governments of Qatar and UAE introduced *Avicennia marina*. Some plantations were successful (Kogo 1988). Attempts were again made to reintroduce *A. marina* in Kuwait (1978-80 and 1992-93), the KSA (1980-91), Oman (1983-88), UAE (1983-88), and Qatar (1987-88) with appreciable success (Kogo 1988; Abu El-Nil 1994).

Geographically, Kuwait occupies approximately 17,800 km^2 of the northwestern part of the Arabian Gulf, between 28^0 30` and 30$^0$ 05` north and 48^0 33` and 48$^0$ 35` east, with nearly 350 km of coastline (Al-Sarawi et al., 1985). Historically, coastal and marine resources have been important assets for Kuwait. The geomorphology of Kuwait's marine environment is characterized by a shallow shelf less than 30 m deep, with depth tending to increase in the southeasterly direction (Subandar et al., 2001). One of the important features of this ecosystem is Kuwait Bay, an elliptical engulfment protruding westward from the Gulf waters, with depths being mostly between 0 and 10 m. As in other parts of the Gulf area, the morphology of the marine environment favors the formation of a highly sedimentary environment, providing suitable habitats for sea grasses and algae. Soft substrate habitats (mudflats), which constitute nearly 57% of the Kuwaiti coast and spread around the northern area (Bubiyan Island) to Kuwait Bay (Fig. 1), are biologically highly productive areas, as large populations of mudskippers, crabs, gastropods and shrimp exist there. Hard substrate habitats, comprising of 9% of the coastline, are mostly situated away from the coast. They consist of coral reef and carbonate platforms with abundant seasonal algal growth. Most of the coral occurrence is between the Kuwait Institute for Scientific Research (KISR) Aquaculture, Fisheries and Marine Environmental Departments (AFMED's) harbor and Umm Al-Maradem Island in the south. Considering the importance of coastal zones for Kuwait, particularly the mudflats, it is important to improve the quality of this habitat by introducing vegetation cover along the coastal areas.

Considering that mangroves once existed in Kuwait and that it is possible to grow mangrove communities under arid growing conditions, their reintroduction appears promising, particularly if the ombrothermic data for Kuwait (Fig. 2) is compared with that of other areas in the region (Subandar et al., 2001). This is further supported by preliminary findings of a study concluded at KISR. Although Sheppard et al. (1992) argued that salinity could be a major constraint in the establishment of mangrove plantations in the Arabian Gulf, the ongoing research at KISR, and in the UAE and KSA have already proved the contrary. It has also been proven in laboratory experiments that *Avicennia marina* seedlings can grow over a wide salinity range (as high as 85 to 90 % in soil), although they grow rapidly under low salinity levels (Clough, 1992; Hutchings and Saenger, 1987). In Kuwait, seawater salinity ranges from 35 to 40%. However, it is not clear whether the optimum salinity ranges for seedling growth are the same as those for more mature shrubs and trees under Kuwait's conditions.

Low temperature was considered another factor that might hamper the success of any replanting of mangroves in Kuwait. The air temperature in winter reaches 80C and seawater temperature can be as low as 11.5^{0}C. However, a number of studies have demonstrated that *Avicennia marina* can tolerate short exposures to low temperatures and its distribution is, in fact, limited only by the occurrence of killing frost (Abu El-Nil, 1994; Hutchings and Saenger, 1987; Clough, 1992). The seawater temperature in the shallow water around Kuwait Bay is not so low as to affect the normal growth of mangroves (Al-Ghadban and Al-Ajmi, 1993).

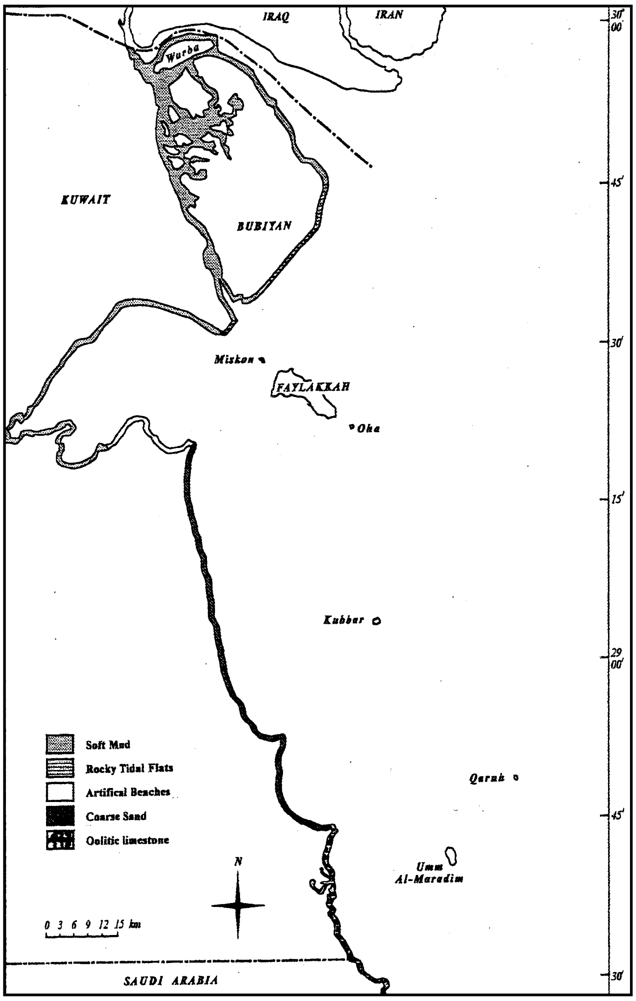


Fig. 1. Distribution of intertidal mudflats along Kuwait's coastline (Subandar et. al., 2001).

As coastal and marine resources are important national resources for Kuwait, there is an immediate need to improve the quality of the coastal ecosystem. Studies conducted elsewhere have clearly established that mangrove plantations along the

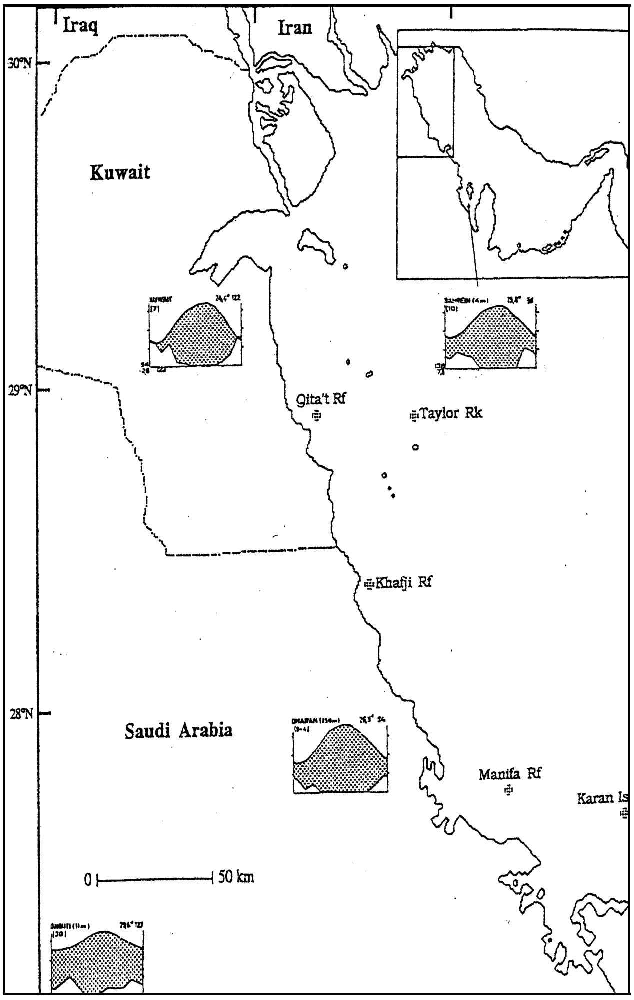


Fig. 2. Comparison of ombrothermic data for Kuwait with that of other Gulf Cooperation Council (GCC) countries (Subandar et al., 2001).

coastlines would significantly improve marine productivity and the coastal environment. Further more, a review of the literature on mangrove ecosystems worldwide, indicated a good potential for growing certain species of mangroves in arid climates. Therefore, it was considered important to make a concerted effort to establish the ecological and environmental feasibilities for artificial afforestation with mangrove species along the coastlines and developing suitable nursery and silvicultural practices to grow them in for the harsh arid climate of Kuwait. Thus, a three-year project was undertaken jointly by the KISR and the Public Authority for Agricultural Affairs and Fisheries Resources (PAAFR) in January 1999. This report presents a detailed account of the work on the research tasks and other activities undertaken during the three-year duration of the project along with the outcome, recommendations and action plan for future research in this area.

Project Objectives

The project was planned with the following objectives:

- Document and evaluate techniques and silvicultural practices leading to large-scale out-planting for the introduction of mangrove into the coastlines of Kuwait;
- Collect information on mangrove growth and development and their relationships to site specifications in selected sites via experimental trials;
- Assess risk levels and long-term environmental impacts on the ecosystem, of reintroduction of mangroves into the intertidal flats, and impacts on fishery activities and issue an environmental impact statement (EIS); and
- Select and propagate biotypes of *A. marina* that are adapted to the environment of Kuwait's coastline, and are suitable for large-scale introduction and afforestation.

Project Tasks and Implementation

The project objectives were accomplished through five research tasks, namely, seed obtainment, germination and seedling growth (Task 1); site selection and evaluation (Task 2), and transplantation into permanent site (Task 3); evaluation of genetic populations for growth in Kuwait (Task 4) and preparation of environment impact statement (Task 5). These tasks were executed using a scientifically sound work plan developed during the beginning of the project implementation (Fig. 3). For this purpose, a technical team comprised of KISR and PAAFR staff was formulated and a time schedule was developed by the project staff during the first six months of project implementation. KISR and PAAFR facilities were utilized for the various project activities.

As in any plant introduction program, locating suitable sites is the first and a vital step in the successful establishment of mangrove plantation. Due to the fact that mangroves exist in dynamic coastal environments, several environmental factors (i.e. temperature, aridity of the environment, occurrence of frost, and strength of tidal waves) and soil characteristics (i.e. slope, soil pH, soil and water salinity, redox pot., and soil texture) affect the success of mangrove introduction programs. Therefore, the available and KISR's experience was reviewed to ascertain ideal sediment qualities and environmental conditions for establishing mangrove plantations. Based on this information, criteria for the selection of potential sites were established. Using these criteria, Kuwait's coastline was surveyed and assessed, and a few potential sites were identified for final, detailed characterization. These selected sites were revisited to study the tidal movements, and flora and fauna of the intertidal mudflats, and to collect soil samples for laboratory analysis. Detailed site characterization was carried out once all of the laboratory analysis was completed.

During the first six months, efforts were made to collect mangrove genotypes from various sources. Propagules of imported genotypes were germinated in the greenhouse. A number of studies were undertaken to standardize and refine the propagation techniques. The growth and development of seedlings in the greenhouse were monitored to develop recommendations for mass multiplication of mangrove plants under Kuwait's climatic conditions. Nursery techniques for mass multiplication of mangroves were continuously refined by repeating experiments. Seedlings were hardened for introduction in the selected sites. Hardened mangrove plants were planted to create dense island plantations to create favorable microclimates for their development. Studies on transplanting techniques and silvicultural practices were undertaken during the planting season (October to March) with a view to improving survival and growth of mangrove seedlings in the field.

In arid regions, where the annual precipitation is far below the total evaporation, the salinity of both coastal soils and seawater are high. Therefore, to improve the success of mangrove planting in arid countries like Kuwait, it was necessary to locate and mass-multiply biotypes with high salinity-tolerance. Unlike other arid countries, winter temperatures in Kuwait are fairly low, particularly in the northern parts. Hence, it was also necessary to select low-temperature-tolerant biotypes. For this reason, various *Avicennia* biotypes were screened for their growth performance under Kuwait's climatic conditions. Side by side, efforts were made to locate and multiply promising individuals within the existing *Avicennia* populations for the future tree improvement program.

It is expected that some problems will arise during the establishment of mangrove plantations. Four kinds of land stability problems, namely, burial of mangrove seedlings, smothering of seedlings by sand, washing of fine sediments and erosion of mangrove stand margins, have been recorded in new mangrove plantation sites. While some of these problems are difficult to avoid completely, others can be overcome if effective control measures are developed. For this reason, the characteristics of mudflats were regularly monitored to define the risk elements involved at each site, and their possible impacts on mangrove growth and development.

Environmental factors such as temperature and aridity of the environment influence establishment, survival and vegetative growth in mangroves. Therefore, survivability, vegetative growth and pest incidence were recorded at three-month intervals.

To increase the resiliency of a mangrove ecosystem, it is advisable to consider multispecies plantation. From an ecological point of view, mono-species mangrove plantations of *Avicennia marina* are vulnerable to disturbances like pest and disease outbreaks. Therefore, *Ceriops tagal* was introduced at selected locations.

Mangroves are widely reported as serving as a nexus between marine and terrestrial ecosystems. For Kuwait, they are clearly vital to the stability and maintenance

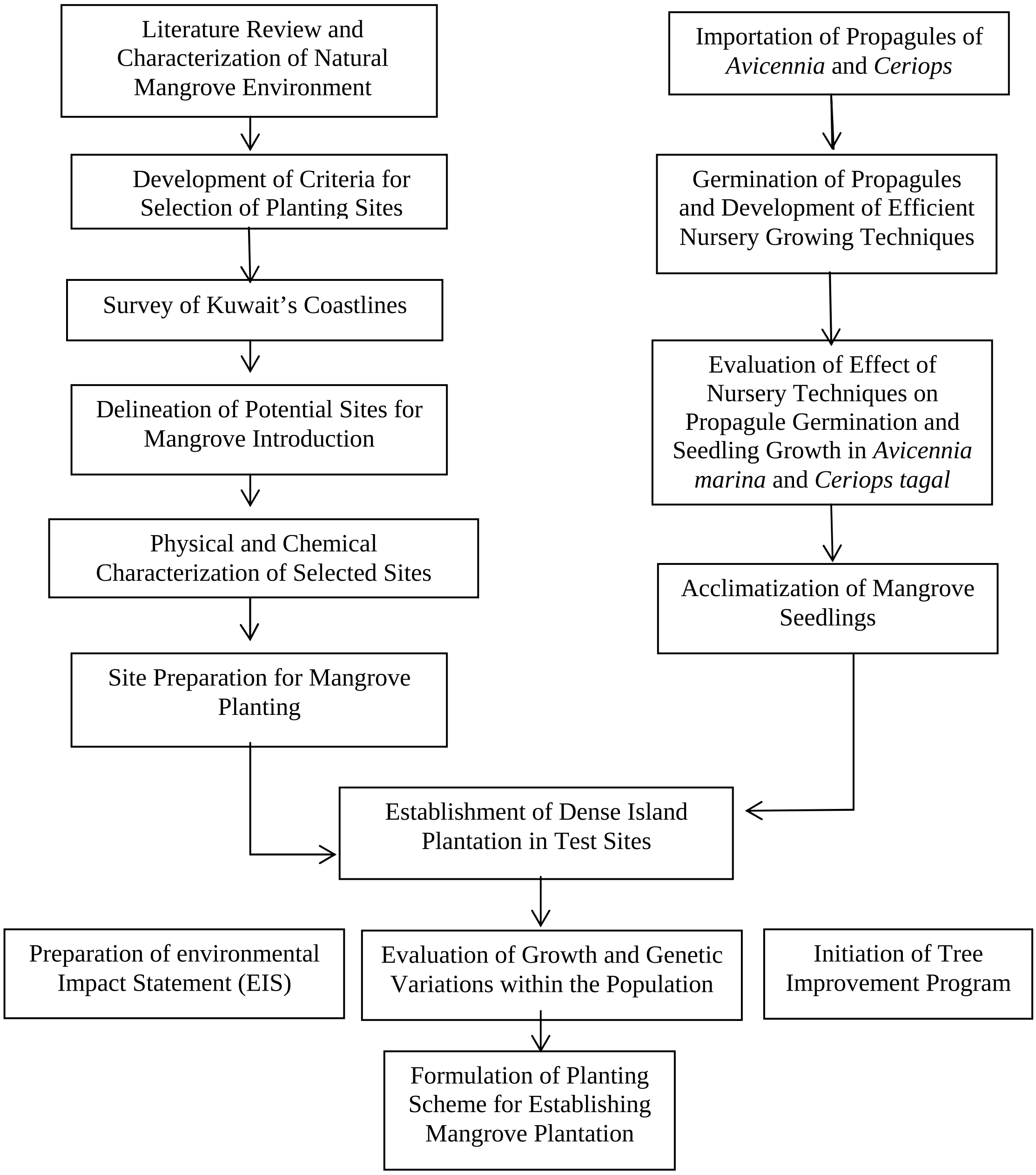


Fig. 3. Work plan for execution of the research tasks during the three-year duration of the project.

of the marine ecosystems, particularly in light of the depleting stock of zobaidy fish (Subandar et al., 2001). Mangrove ecosystems provide a nursery ground for juvenile fish and shrimps, and a refuge and breeding area for birds and other marine and terrestrial wildlife. Therefore, the impact of mangrove plantation on the biological productivity of the mudflats was ascertained.

In the long run, a successful mangrove planting program may lead to a better coastal zone environment. To ascertain the environmental impact of mangrove introduction, parameters such as atmosphere, biosphere, hydrosphere and lithosphere were characterized. Data from the pilot plantation was used to develop valid recommendations for establishment of extensive mangrove plantations. In a matrix analysis of the project and environmental parameters, the negative and positive effects of the introduction were evaluated and an EIS was developed. Suggestions are made to overcome the negative and enhance the positive impacts of mangrove introduction.

The detailed methodology and the discussions of the findings of each task are presented below:

Mobilization of Resources

Necessary arrangements were made to procure laboratory supplies, chemicals, equipment and other materials required for executing the various tasks of the project.

Task 1. Seed Obtainment, Germination and Seedling Growth

Introduction

The first step in any plant introduction program is to raise good-quality planting materials. *Avicennia marina* is commercially propagated from viviparous propagules, although tissue culture and other vegetative methods have been tried with varying degrees of success. As propagules in *Avicennia* remain viable only for a short period (two to four weeks), storage of propagules in plastic bags for periods of more than a few days is not recommended because of the possibility of fungal attack or fermentation of stored food. Therefore, it is important that only fresh, viable propagules be used for propagation. Production of propagules in most mangrove species is strongly seasonal. For example, in the Gulf area, matured propagules in *Avicennia marina* are available during September and October, whereas they are available in May in Australia.

Thus, locating suitable genetic materials and adopting proper nursery techniques are crucial for any large-scale plant introduction program. In view of these facts, this task involved several activities such as identification of alternative propagule sources, procurement of propagules, and initiation of studies to develop appropriate nursery practices for Kuwait's growing conditions.

Materials and Methods

Identification of Propagule Sources. It was envisaged in the project that *Avicennia* biotypes from Gulf Cooperation Council (GCC) countries (the UAE and Bahrain) would be used for establishing experimental plantations in Kuwait. As indicated earlier, in the Arabian Gulf environment, *Avicennia marina* propagules mature in September. The propagule production season was already over when the project was initiated. In order to save time, efforts were made to identify alternate propagule sources. For this purpose, a request was sent to a mangrove research discussion list on the Internet, and besides some of the known sources in the Arabian Gulf and other countries was contacted. Based on the responses received and considering practicality, it was decided to import propagules from Pakistan and the United States of America (USA), as well as from the GCC countries.

Propagule Treatment. As the propagules of *Avicennia* are viviparous in nature, it is important to handle them properly. Therefore, immediately upon arrival, they were unpacked and graded as large or small based on size. The average weights of the large and small lots were recorded before placing them in tap water for either 48 or 72 hours. Propagules after removal from water are shown in Plates 1 to 4.

Plate 1. Large-sized propagules soaked in tap water for 48 hours.

Propagule Sowing. Specially designed galvanized iron trays (Plate 5) or greenhouse benches covered with two layers of polyethylene films to retain water

Plate 2. Small-sized propagules soaked in water for 48 hours.

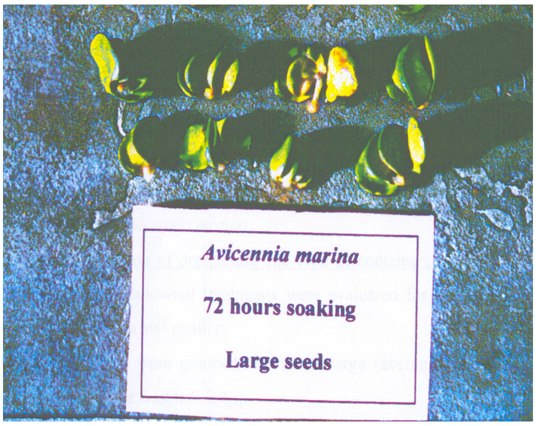


Plate 3. Large-sized propagules soaked in water for 72 hours.

Plate 4. Small-sized propagules soaked in water for 72 hours.

(Plate 6) were used to germinate the propagules. Containers filled with either only soil or soil with sphagnum peat moss was placed on these benches. Presoaked propagules were planted in the containers. A general view of the experimental area after planting is presented in Plate 7. Viable seedlings with healthy roots and shoots were produced 15 days after sowing (Plate 8).

Experimental Details. The following experiments were conducted to evaluate the

Plate 5. A view of the specially designed galvanized iron tray used in the study.

Plate 6. Greenhouse bench covered with polyethylene-sheet used for sowing mangrove propagules.

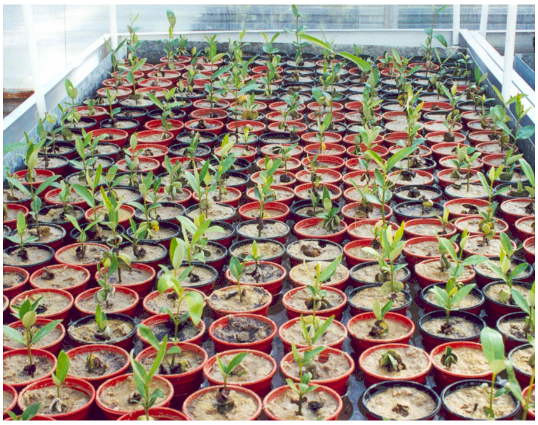


Plate 7. A general view of a greenhouse bench after germination.

effects of various nursery practices for improving propagule germination, seedling growth and quality of seedlings in *Avicennia marina*.

Experiment 1. Effects of Propagule Size, Duration of Presoaking and Type of Container on Germination and Seedling Growth. The following treatments were evaluated for improving propagule germination, seedling growth and quality:

Plate 8. Viable seedlings with healthy roots and shoots.

- Propagule Size: Propagule lots were grouped as either large (with an average propagule weight of 5.1 g) or small (with an average propagule weight of 2.4 g).
- Duration of presoaking: Propagules were soaked in tap water for either 48 or 72 hours prior to sowing. The water was changed daily.
- Type of containers: Polybags (500 ml), plastic containers (400 or 200 ml) or Jiffy pots (400 or 100 ml) were used for sowing.

In all, there were 20 treatment combinations, each with 100 propagules, arranged in a completely randomized design. This experiment was conducted using propagules received from Pakistan in May 1999.

Experiment 2. Effect of Growing Medium on Germination and Seedling Growth. Two types of growing medium (100% sphagnum peat moss or 1:1 soil: sphagnum peat moss) were used. Propagules that were presoaked for 48 hours were used for sowing. Each treatment had 25 propagules arranged in a completely randomized design.

Based on the results of the above studies, treatments were modified and the following experiments were conducted during September 2000.

Experiment 3. Effects of Propagule Size, Duration of Presoaking and Type of Containers on Germination and Seedling Growth. Based on the results of the earlier

- Propagule Size: Propagule lots were grouped as either large (with an average propagule weight of 4.7 g) or small (with an average propagule weight of 2.8g).
- Duration of presoaking: Propagules were soaked in tap water for either 0, 24 or 48 hours prior to sowing. The water was changed daily.
- Type of containers: Polybags (500 ml), plastic containers (400 or 200 ml) or Jiffy pots (400 or 100 ml) were used for sowing.

In all, there were 30 treatment combinations, each with 50 propagules, arranged in a completely randomized block design with two replications.

Experiment 4. Effect of Time of Sowing on Germination and Seedlings Growth. Total germination and seedling heights from various sowings (May 6, May 26, September 15 and October 26, 1999, and June and July 2000) were compared to ascertain the effects of planting season on the success of nursery operations.

Experiment 5. Effect of Growing Conditions on Germination and Seedlings Growth. Propagules were sown in an evaporatively cooled greenhouse or in the open to assess the need for controlled conditions for germination of *Avicennia* propagules during winter months.

Experiment 6. Effect of Water Quality on Germination and Seedling Growth. This experiment was conducted to ascertain if high-salinity water could be used for germinating *Avicennia marina* seedlings. Treatments included holding water salinities of 1.6, 23.5, and 69.5 dS/m. However, the salinity fluctuated slightly depending on the prevailing climatic conditions.

Experiment 7. Use of Intermittent Misting for Germination of Propagules. Propagules were sown in polyethylene-lined greenhouse benches using the procedure described above and were maintained either under intermittent misting or in stagnant water (Plates 9 and 10).

Plate 9. Germinating *Avicennia marina* propagules in a controlled environment greenhouse with intermittent misting.

Data Collection and Analysis. Periodic data on germination and seedling growth were recorded. The data on seedling height were subjected to analysis of variance using a mixed-model least-squares and maximum-likelihood computer program. Significant treatment means were identified using Duncan's multiple range test (DMRT) at a 5% level of probability.

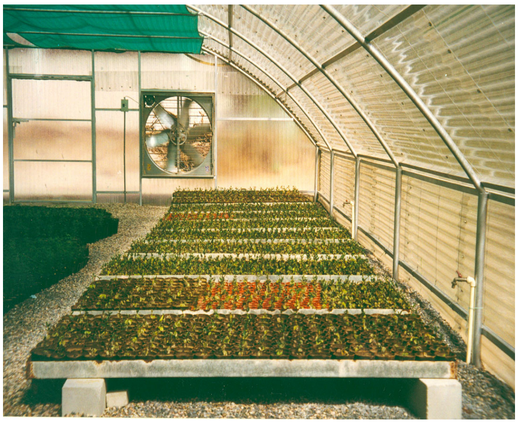


Plate 10. Germinating *Avicennia marina* propagules in a flooded bench in a controlled environment greenhouse.

Results

Data on propagule germination and periodic seedling height were recorded in these experiments to ascertain their applicability and also to standardize the most suitable package of propagation techniques for mass multiplication of *Avicennia marina*.

Experiment 1. Effects of Propagule Size, Duration of Presoaking and Type of Container on Germination and Seedling Growth. The data on the effects of propagule size, duration of soaking and container type on germination and seedling growth are presented in Tables 1 and 2.

Table 1. Germination of *Avicennia marina* Propagules as Influenced by Size, Duration of Soaking and Container Type

Treatment	Germination/Survival (%)			
	15 days	30 days	60 days	90 days
Propagule Size				
5.1 g	34.5*	57.5	62.5	62.9
2.4 g	21.0	32.5	32.4	33.0
Duration of Soaking				
48 h	40.2	61.0	64.7	66.4
72 h	15.7	29.0	30.2	29.5
Container Type and Volume				
Plastic, 400 ml	34.0	58.0	57.3	58.8
Plastic, 200 ml	34.8	42.3	52.0	54.5
Jiffy, 400 ml	22.8	39.3	39.0	46.0
Jiffy, 100 ml	24.8	46.3	49.3	43.0
Polybag, 500 ml	24.0	36.3	39.8	37.5

*Only seedlings with normal shoots and roots were considered as viable or healthy, and were counted for determining germination and survival percentages.

<u>Effects of Propagule Size, Duration of Presoaking and Type of Container on Germination</u>. As the data indicate, both the speed of germination and the total

Table 2. Seedling Height in *Avicennia marina* as Influenced by Propagule Size, Duration of Soaking and Container Type

Treatment	Seedling Height, Days after Sowing (cm)		
	30	**60**	**90**
Propagule Size			
5.1 g	16.43a*	23.90a	27.00a
2.4 g	14.35b	21.11b	21.32b
Duration of Soaking			
48 h	17.55a	26.30a	29.42a
72 h	13.25b	18.69b	21.90b
Container Type and Volume			
Plastic, 400 ml	17.28a	27.15a	31.69a
Plastic, 200 ml	14.14a	19.68b	20.60b
Jiffy, 400 ml	11.85b	20.86b	27.56c
Jiffy, 100 ml	13.48b	18.43b	15.26d
Polybag, 500 ml	17.17b	26.67a	33.17a

*Analysis of variance was conducted using a mixed-model least-squares and maximum-likelihood computer program. Significant means were separated using the Duncan multiple range test (DMRT) at 5% probability level. Figures followed by the same letter (a or b) are not significantly different at the 5% probability level.

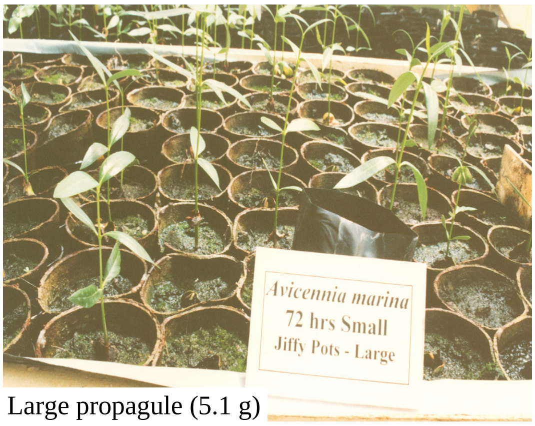
germination percentage were influenced both by propagule size and duration of presoaking (Table 1). Larger propagules (5.1 g) germinated faster and produced the highest number of viable seedlings (with roots and shoots), as compared to smaller propagules (Plates 11 and 12). During the first 15 d, 34.5% of the larger propagules germinated, as opposed to 21.0% in the case of small propagules. Thirty days after sowing, the germination percents were increased to 57.5 and 32.5% for large and small propagules, respectively. The final germination percentage in the case of the large propagules was nearly double (62.5%) that of the small propagules (33%).

Large propagule (5.1g)

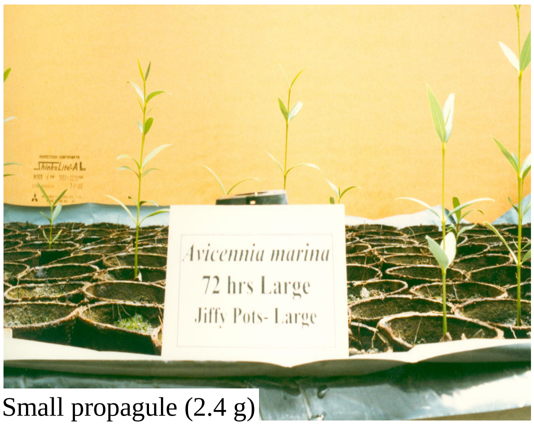
Small Propagule (2.4g)

Plate 11.Germination of *Avicennia marina* propagules soaked in water for 48 hours prior to sowing.

The duration of soaking also affected propagule germination with 48 hours soaking resulting in a higher number of viable seedlings than 72 hours soaking. At the time of their removal from water, propagules soaked for 48 hours appeared healthier



Large propagule (5.1 g)



Small propagule (2.4 g)

Plate 12. Drastic reduction in germination of *Avicennia marina* propagules caused by extended duration of soaking in water (72 hours) prior to sowing.

and greener than those soaked for 72 hours. Extended periods of soaking resulted in browning of hypocotyls (Plate 13). Propagules soaked for 48 hours developed healthy, vigorous roots (Plate 14).

Plate 13. Browning of *Avicennia* propagules caused by extended soaking (72 hours).

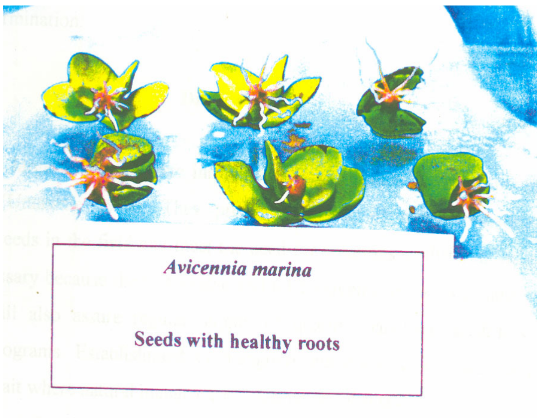


Plate 14. Soaking of propagules for 48 hours promoted the development of healthy roots.

Container type or the volume of growing medium did not influence propagule germination in *Avicennia marina*.

Effects of Propagule Size, Duration of Presoaking and Type of Container on Seedling Growth**.** Seedling height in *Avicennia marina* was significantly influenced by propagule size, duration of presoaking and container type (Table 2). In general, the large propagules produced taller plants than the small propagules (Plate 15). Similarly, presoaking for a shorter period (48 hours) resulted in taller seedlings than the extended period soaking (72 hours). For example, the average seedling heights were 23.9 and 21.1 cm for large and small propagules, respectively. The average seedling height for the 48 hours presoaking treatment was 26.3 cm, as compared to 18.9 for the 72 hours soaking treatment.

Plate 15. Tall seedlings are produced by large propagules.

Although container type did not affect seedling height, the volume of growing medium influenced seedling growth produced larger seedlings.

Experiment 2. Effect of Growing Medium on Germination and Seedling Growth. The composition of the growing medium had a major influence on the germination and seedling growth. Either soil alone or a mixture of soil and sphagnum peat moss resulted in higher germination and better quality seedlings than sphagnum peat moss alone. Propagules sown in 100% sphagnum peat moss, although remaining green, did not produce viable seedlings, thereby suggesting that *Avicennia marina* needs firm media for germination.

Experiment 3. Effects of Propagule Size, Duration of Presoaking and Type of Container on Germination and Seedlings Growth. The effect of propagule size, duration of soaking and container type on germination and seedling growth are presented in Plates 16 and 17, and Tables 3 and 4. As the data in Table 3 indicate, both

Plate 16. Seedlings of *Avicennia marina* from large propagules (5.1 g) that were not soaked in water prior to sowing.

Plate 17. Seedlings of *Avicennia marina* from large propagules (5.1 g) that were soaked in water for 24 hours.

the speed (as indicated by germination percentages in the initial 30 days period) and the total germination percentage were significantly influenced by the duration of presoaking. Large propagules (4.7 g) germinated faster and produced a higher number of viable seedlings (with both roots and shoots) than small propagules. During the first 30 days, 62.3% of the large propagules germinated compared to 57.3% of the small propagules. Sixty days after sowing, the germination percentages increased to 67.7 and 57.0% for large and small propagules, respectively. The final germination and survival percentage 120 days after sowing was about six percent higher the large propagules than for the small propagules.

The data presented in Table 3 also indicated that the duration of soaking affected both the germination time and total germination. Unsoaked propagules took longer to initiate germination. In contrast, presoaking in water for 24 hours accelerated the germination process slightly (manifested as nearly six percent higher germination percentages) in the initial 60 days period, but the final germination in this treatment was same as in the case of the control (no soaking) treatment. The extended soaking (48 hours) decreased the total germination percentage from 78.6 to 39.5%. However, propagules soaked for 48 hours appeared healthy and green at the time of their removal from water.

Table 3. Germination of *Avicennia marina* Propagules as Influenced by Propagule Size, Duration of Soaking and Container Type

Treatment	Germination/Survival (%)			
	30 days	60 days	90 days	120 days
Propagule Size				
4.7 g	62.3	67.7	69.4	68.4a
2.8 g	57.3	57.0	62.5	62.9b
Duration of Soaking				
No Soaking	71.2	75.7	76.7	78.6a
24 h	77.4	81.1	79.7	77.6ab
48 h	35.3	38.0	42.1	39.50
Container Type and Volume				
Plastic, 400ml	59.2	64.5	64.8	63.8a
Plastic, 200ml	63.5	64.2	69.0	68.5a
Jiffy, 400 ml	59.0	60.2	64.7	63.8a
Jiffy, 100 ml	65.3	71.7	66.3	66.7a
Polybag, 500 ml	59.5	64.2	64.8	65.8a

NB: Only seedlings with normal shoots and roots were considered as viable or healthy, and were counted for determining germination and survival percentages.

Analysis of variance was conducted using a mixed-model least-squares and maximum-likelihood computer program. Significant means were separated using the Duncan multiple range test (DMRT) at a 5% probability level. Figures followed by the same letter(s) are not significantly different at the 5% probability level.

Container type or the volume of growing medium did not influence germination time or the total germination in *Avicennia marina*.

Propagule size, duration of presoaking and container type did not appear to have any influence on seedling height in *Avicennia marina* (Table 4, Plates 18 and 19).

Experiment 4. Effect of Time of Sowing on Germination and Seedlings Growth. Time of sowing greatly influenced both germination and seedling growth in *Avicennia* (Table 5). Sowing during September and October produced 10 to 30% more seedlings than May sowings. However, the speed of germination as indicated by germination percentage during the initial 15 days period was the highest in the May sowings (Table 5). In contrast, the differences were negligible for sowing between May 6 and May 26 and between September and October. Seedlings from May sowings were taller and more vigorous than those from September and October sowings (Plate 20).

Seedlings from May 6 sowing attained an average height of 29.4 cm in 90 days as compared to those from May 26 (28.9 cm), September 15 (14.8 cm) and October 26 sowings (13.88 cm).

Plate 18. Seedlings of *Avicennia marina* from large propagules that were soaked for 48 hours.

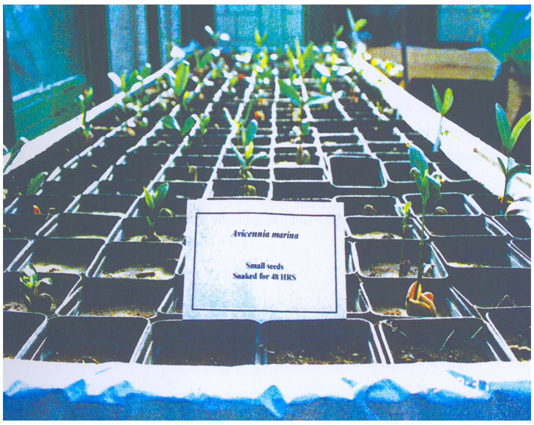


Plate 19. Seedlings of *Avicennia marina* from small propagules that were soaked for 72 hours.

Table 4. Seedling Height in *Avicennia marina* as Influenced by Propagule Size, Duration of Soaking and Container Type

Treatment	Seedling Height (cm)			
	30 days	**60 days**	**90 days**	**120 days**
Propagule Size				
4.7 g	9.05	11.46	13.67	12.32
2.9 g	7.58	9.65	11.16	10.77
Duration of Soaking				
No soaking	8.33	10.03	12.77	10.77
24 h	8.13	10.70	12.04	11.10
48 h	7.88	9.86	11.20	10.91
Container Type and Volume				
Plastic, 400 ml	8.96	10.74	12.58	11.96
Plastic, 200 ml	7.89	10.46	12.49	11.93
Jiffy, 400 ml	6.48	9.08	10.48	11.08
Jiffy, 100 ml	6.76	9.72	11.36	11.08
Polybag, 500 ml	9.79	11.64	13.13	12.53

NB: Analysis of variance was conducted using a mixed-model least-squares and maximum-likelihood computer program. Significant means were separated using the Duncan multiple range test (DMRT) at a 5% probability level.

Table 5. Germination and Seedling Height in *Avicennia marina* Propagules Sown on Various Dates

Time of Sowing	Germination/Survival (%)		Seedling Height (cm)
	15 days	90 days	
May 6, 1999	40.2	66.4	29.4
May 26, 1999	43.0	68.0	28.9
September 1999	20.0	77.6	14.8
October 1999	18.0	95.0	13.8
June 2000	59.8	63.6	12.8
July 2000	75.4	82.6	13.6
September 2000	4.5	78.0	5.0

NB: Propagules were soaked in water for 24 hours or 48 hours and sown in specially designed benches in evaporatively cooled greenhouses.

Final germination count and seedling heights were measured 90 days after sowing.


a. May

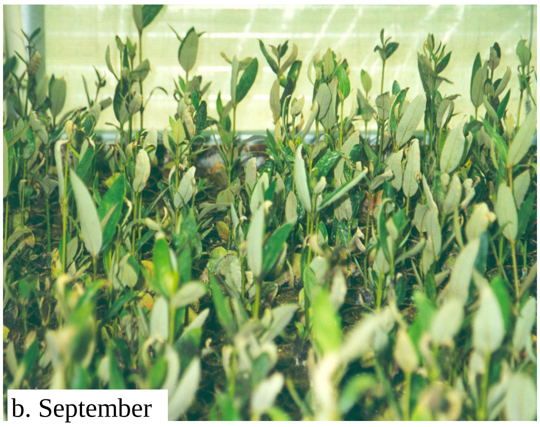

b. September

Plate 20. Comparison of *Avicennia* seedlings from May and September sowings.

Experiment 5. Effect of Growing Conditions on Germination and Seedling Growth. Growing conditions had no effect on propagule germination but had a significant effect on seedling growth. Seedlings were more vigorous and attained an average height of 16.0 cm in 120 days when the propagules were sown in environment-controlled greenhouses, as compared to sowing in open field conditions (Plate 21). The seedling mortality due to low temperatures was also high under open field conditions.

Experiment 6. Effects of Water Quality on Germination and Seedling Growth. As the data presented in Table 6 indicate, propagule germination, total germination percentage, and seedling height were influenced by the water quality. Flooding the germination benches with freshwater resulted in 63.6% germination 30 days after sowing (Plate 22). In contrast, only 2 to 4% of the propagules germinated in moderately saline (23.5 dS/m) and highly saline (69.5 dS/m) water (Plate 23). While the germination percentage in the freshwater treatment increased to 87.4% by the 60th day, there was no change in the moderately and highly saline water treatments.

Plate 21. Comparison of germination of *Avicennia marina* propagules in an environment-controlled greenhouse and open field conditions.

Plate 22. Germination of *Avicennia* propagules in fresh water.

Table 6. Germination and Seedling Height in *Avicennia marina* as Influenced by Water Quality

Salinity Level	Propagule Germination (%) on Day		Seedling Height (cm) on Day	
	30	60	30	60
Freshwater	63.6a	87.4a	8.60a	12.92a
Moderately saline	4.0b	4.0b	3.00a	5.00b
Highly saline	2.0b	2.0b	3.00a	4.00b

NB: Propagules were soaked in water for 24 hours and sown in specially designed benches in evaporatively cooled greenhouses.

Final germination count and seedling heights were measured 60 days after sowing. Only seedlings with normal roots and shoots were counted.

Analysis of variance was conducted using a mixed-model least-squares and maximum-likelihood computer program. Significant means were separated using the Duncan multiple range test (DMRT) at a 5% probability level. Figures followed by the same letter are not significantly different at the 5% probability level.

Seedling growth was also adversely affected by water quality. This was evident from the fact that 60 days after sowing, seedlings in the freshwater treatment attained an average height of 12.92 cm compared with 5.00 cm and 4.00 cm heights in the moderately and highly saline water treatments respectively (Table 6).

Plate 23. Germination of *Avicennia* propagules in highly saline water.

Experiment 7. Use of intermittent misting for germination of *Avicennia marina* propagules. The data recorded in the initial 30 days period suggested that sowing propagules in benches flooded with fresh water seemed to slightly increase the germination by 7%; however, the final germination were the same in both treatments (Table 7, Plates 24 and 25). The average seedling heights after 30 days of sowing were also the same in both treatments.

Table 7. Propagule Germination and Seedling Height of *Avicennia marina* as Influenced by Intermittent Misting

Treatment	Germination (%) on Day		Seedling Height (cm) on Day 30
	15	30	
Intermittent Misting	68.1	85.7	13.66
Flooding	75.5	92.6	15.64

NB: Propagules were soaked in water for 24 hours and sown in specially designed Benches in evaporatively cooled greenhouses.
Final germination count and seedling heights were measured 30 days after sowing. Only seedlings with normal shoots/roots were counted.

Insect Pests and Diseases. *Avicennia marina* seedlings from September and October sowings were severely infested by thrips and sooty mold (Plate 26). It is interesting to note that *Avicennia germinans* seedlings were free from thrip infestation, although they were grown in the same greenhouse (Plate 27). Complete control of the pest was achieved by alternating sprayings of Hostathion (0.01%), Fenethrothion (0.01%) and Carbandezene (0.01%).

Discussion

For any large-scale mangrove introduction or restoration program, nurseries are essential (Untawale, 1993). They prevent the risk of non-germination of propagules and meet the need for seedlings of different heights, which are necessary because the water table and tidal movements vary in inter-tidal mudflats. It also ensures regular supply of quality mangrove seedlings for afforestation programs. Establishment of mangrove nurseries is also necessary in places like Kuwait where natural mangrove plantations do not exist.

Plate 24. Germination and seedling growth under intermittent misting.

Plate 25. Germination and seedling growth in flooded benches.

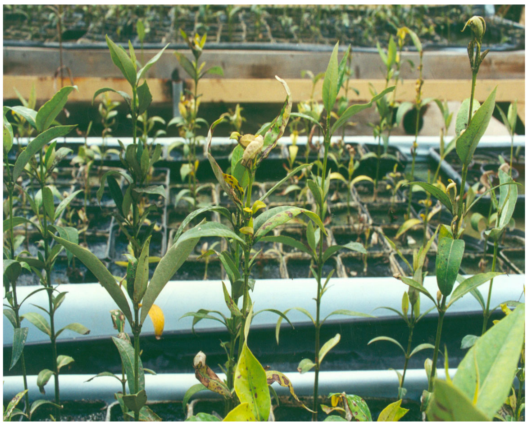


Plate 26. *Avicennia marina* seedlings infested with Thrips.

Plate 27. *Avicennia germinans* seedlings free from Thrips infestation.

Adoption of scientifically sound nursery practices is essential for a commercial nursery operation. These include selection of suitable biotypes and reliable propagule sources, grading of propagules, presoaking, selection of proper germination media and conditions, and seedling growth and hardening techniques. In the present series of experiments, efforts were made to evaluate the effects of propagule size, duration of presoaking, type of container, time of sowing and composition of germination medium on germination and seedling growth.

The results from these studies clearly demonstrated the positive influence of propagule size and duration of presoaking on propagule germination. In the present set of experiments, propagules weighing 4.7 g (as in the third experiment) to 5.1 g (as per the first experiment) had the bigger hypocotyls with larger pools of stored foods. They were able to initiate and sustain rapid growth of the embryonic axis and establishment of seedlings in the growing medium. Low germination of small propagules (2.4 g) during the first 15 days suggests that their embryonic axis needed longer time to initiate growth and development. In *Avicennia marina*, Ghowail et al. (1993) and Abu El-Nil et al. (1992) also demonstrated that propagules weighing more than 3.21 g germinated better than smaller propagules.

Duration of presoaking is another critical factor in the germination and early growth of *Avicennia* seedlings. In the present experiment, soaking of propagules for 48 hours was found to be ideal for both small and large propagules. Research in Australia have suggested that extended soaking or storage causes fermentation of stored foods and/or fungal infection leading to disruption in physiological activity in the embryonic axis (Clough, 1993). This will lead to a loss in propagule vigor, which is later manifested in terms of slower and poor germination, and a reduced seedling growth rate. Browning of the hypocotyl (Plate 13) observed in the 72 hours soaking treatment is an indication of the initiation of the fermentation process. Earlier research also suggests that propagules of *Avicennia marina* are highly susceptible to fermentation (Clough, 1993).

It is known that the majority of plant species grow larger in thin stands than in thick ones. This effect has often been attributed to plant competition in terms of water, nutrients and aeration (Baker and Woodruff, 1962). However, plant competition may also arise from other sources such as higher root density where individual roots compete with each other for available space and aeration. All these conditions eventually restrict top and root growth, and affect the quality of seedlings. However, the crucial problem is whether similar explanations can be extended to mangrove plants as they are grown with excess water. Although several studies have been conducted to elucidate the relationship between the available soil volume and plant growth in terms of water availability and nutrient dynamics in glycophytes, similar investigations in mangrove ecosystems are scarce. According to these reports, for optimal seedling growth, the volume of the soil per plant in the container should approach the volume of soil in their natural habitat (Jayasekar and Leith, 1993). They also suggested that root volume is a significant index of plant growth even under flooded saline conditions.

In our experiments, seedling growth was improved when the volume of the available growing medium was increased. In *Rhizophora mangle*, Jayasekara and Leith (1993) observed larger and consistently less dense root systems as the available soil volume increased.

The initial findings suggested that in a commercial nursery operation, it is more efficient to germinate *Avicennia marina* propagules in freshwater and then gradually acclimatize the seedlings to seawater salinity. However, in nature, mangrove propagules, after being separated from the mother plant, establish and germinate under highly saline conditions, although the speed of and the total germination are much lower than in a commercial nursery. Therefore, for mass multiplication of mangroves, it is important to germinate them in freshwater and then acclimatize them to salinity levels prevailing in a particular location.

In the present study, low temperatures affected seedlings of the Pakistan ecotype, but not those of Bahrain and local ecotypes. Low-temperature damage was evidenced by yellowing, wilting or necrosis of the foliage or the death of seedlings. Although low-temperature tolerance is a genetic trait in plants, they tend to adapt themselves to prevailing weather conditions. Therefore, *Avicennia marina* can tolerate low temperatures. It is possible that mangrove plantations in Pakistan are not exposed to low winter temperatures in their natural habitat and, hence, become vulnerable to sudden drops in temperature. However, they can adapt themselves if the drops are gradual. Thus, it is important to consider the propagule source when establishing large-scale nursery facilities in places where winters are severe.

Acclimatization of *Avicennia* Seedlings

Soil salinity in potential sites selected for mangrove introduction ranged from 11.05 to 55.5 dSm^{-1}. Similarly, the seawater salinity along the northern coastline of Kuwait is around 35,000 to 40,000 ppm. To improve survival and growth in the field, it is necessary to acclimatize the seedlings to prevailing salinity levels.

Acclimatization of seedlings to salinity was accomplished by gradually raising the salinity levels of the water in the nursery benches to around 50,000 ppm (Plate 28). The seedlings were maintained at this salinity level until they were transferred to the field.

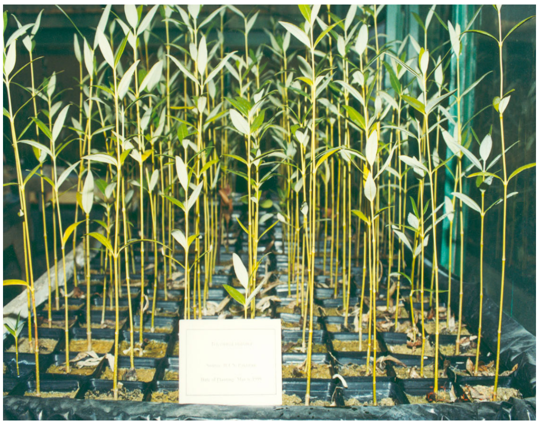


Plate 28. Hardened *Avicennia marina* seedlings ready for transplanting.

Propagation of *Avicennia marina* by Cuttings

Because of the difficulty in obtaining freshly harvested propagules in sufficient quantities, it is desirable to investigate alternative methods of propagation. Also, under Kuwait's growing conditions, the propagule set for *Avicennia* is very low. Studies in Thailand, Japan and Australia have shown that the hypocotyls of a number of *Rhizophoraceae* can be cut into transverse segments and used for propagation (Clough, 1993). Similarly, researchers in India have successfully demonstrated the possibility of using shoot cuttings and air layering for propagating *Rhizophora* sp., *Excoecaria* *agallocha, Acanthus ilicifolius, Intsia bijuga, Cerbera manghas,* and *Heritiera fomes* (Srinivasarao et al., 2001). Also, scientists have succeeded in inducing callus from leaf, stem and propagule materials (Srinivasrao et al., 2001). However, there have been no reports of development of a commercially viable tissue culture technique for mangrove.

In view of the above facts, attempts were made to propagate *Avicennia marina* using shoot cuttings. Ten centimeter long shoot cuttings were prepared from the current season's growth in the second fortnight of July and were planted in 400 ml plastic containers using garden soil as the rooting medium (Plate 29). Cuttings were treated with commercial rooting hormone at the time of planting. Initiation of roots is being closely monitored to ascertain the feasibility of adopting this technique for mass multiplication of promising local biotypes. Preliminary observations indicated that terminal cuttings with soft stems rooted faster than those with hardened stems (Plate 30).

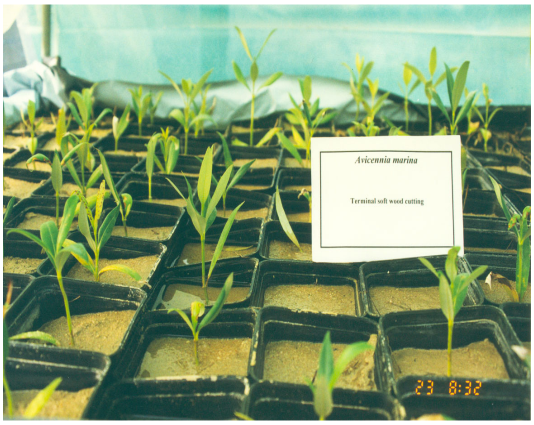


Plate 29. Propagation of *Avicennia marina* by terminal cuttings.

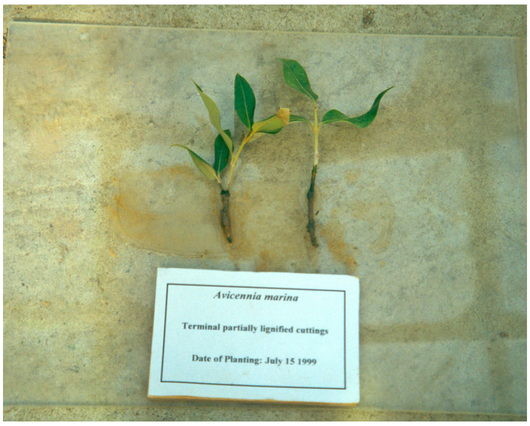
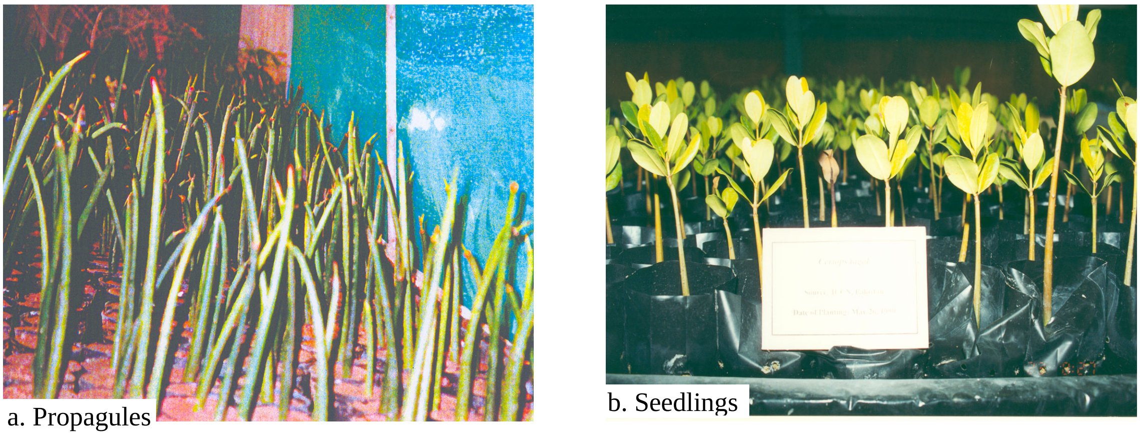


Plate 30. Absence of rooting in hard-wood cuttings.

Raising of *Ceriops tagal* Seedlings

In areas where mangroves occur naturally, one can select any species growing in the surrounding area with to establish new mangrove plantations. However, in Kuwait, there are no natural mangrove plantations. Under these circumstances, it is desirable to undertake a species trial to identify suitable species for establishing mixed mangrove plantations.

Although *Avicennia marina* is the most common and widely distributed species in the Gulf region, other species from arid climates, such as *Rhizophora mucronata* and *Ceriops tagal* can be successfully grown in the region (Kogo and Tsuruda, 1995). In view of this, it was decided to evaluate the growth performance of *Ceriops tagal* and *Rhizophora mucronata* under Kuwait's climatic conditions. For this purpose, 1,500 *Ceriops tagal* propagules were imported from Pakistan. Propagules were sown in 500 ml polybags filled with garden soil (Plate 31). These seedlings were hardened and transferred to the field in October 2000 and 2001.



a. Propagules

b. Seedlings

Plate 31. A general view of *Ceriops tagal* propagules and seedlings

Summary

Standardization of nursery techniques is essential for raising the planting materials required for establishment of large-scale mangrove plantations, especially when natural mangrove strands are not present. During the first two years of the project, efforts were made to evaluate a number of parameters, such as propagule size, duration of presoaking, type of container, time of sowing, composition of germination medium, water quality and germinating conditions for *Avicennia marina*.

The results indicated a positive influence of propagule size and negative influence of duration of presoaking on propagule germination and initial seedling growth. Large-sized propagules that were soaked for 24 hours before sowing germinated faster than smaller propagules. Extended presoaking resulted in the browning of hypocotyls and adversely affected germination. September and October sowings produced more viable seedlings than May sowings. However, seedlings from the May sowings grew faster than those from the September and October sowings.

The volume of medium and the type of container did not influence germination, but the volume of medium had a positive effect on seedling growth, particularly at the later stages of development. In general, sowing of the propagules in 500 ml polybags filled with soil produced quality seedlings.

One hundred percent soil or soil mixed with sphagnum peat moss (1:1 v/v) was found to be ideal for propagule germination.

Propagules can be germinated either in flooded benches or under intermittent mist. Under Kuwait's climate, propagules should be germinated in environment-controlled greenhouses and acclimatized to prevailing environmental conditions when they reach the transplantable stage.

Although seedlings appeared to be healthy, they grew slowly during the winter months. Seedling growth of the Pakistan ecotype was greatly affected by low temperatures and severe Thrips infestations. In contrast, *Avicennia germinans* seedlings were completely free from pest infestations and also withstood low temperatures better than *Avicennia marina*.

Germinating the propagules and growing the seedlings in freshwater in greenhouses followed by acclimatization to seawater salinity was found to be a more efficient approach than germinating them directly in saline water.

Task 2. Site Selection and Evaluation

Introduction

Mangrove ecosystems are very varied, and their structure and function depend heavily on the prevailing environment; but they all possess tolerance to high soil and water salinities. The boundaries of this littoral ecosystem are fairly well defined by the terrestrial and oceanic ecosystems that border it. In fact, mangroves are located in the region between the sea and dry land. The dynamic nature of mangrove ecosystems is due to continuously changing environmental and site conditions, and the ability of plants and animals in coastal areas to adapt to such changing chemical, physical and ecological parameters in their immediate surroundings. Hence, the poor performance of mangrove ecosystems in a particular location is related to several environmental (unfavorable light, temperature and relative humidity, precipitation, wind velocity, occurrence of frost, etc.), site (topography), soil (excess or deficient water around the root systems, physical and chemical characteristics, presence of pollutants in the soil and nutritional status) and physiological (reduced photosynthetic production and disturbance in the water relationship in plant tissues) factors. Therefore, a number of factors will have to be considered while selecting sites for establishing mangrove plantations. To provide a better perspective of the need, a brief review of coastal environmental conditions in Kuwait is presented below.

Because of its critical effect on both photosynthetic and respiratory processes, temperature regulates a large number of internal physiological processes including salt regulation and excretion, and root respiration (Saenger, 1996). Almost all mangrove species are susceptible to frost (Markley et al., 1982). Optimum temperatures for photosynthesis in mangroves appear to be around 35^{o}C with little or no photosynthesis occurring at or above 40^{o}C (Chapman, 1976; Clough et al., 1982). According to Siddiqi and Khan (1996), extensive mangrove development occurs when the average air temperature of the coldest month is higher than 20^{o}C, and where the seasonal range does not exceed 10^{o}C (Chapman, 1976)

Kuwait's climate is characterized by a desert-type environment with scanty rainfall. Summer is very hot, especially July and August, with a mean temperature of 37.4^{o}C and a maximum mean temperature of 45^{o}C (Al-Kulaib, 1995). Winter is moderate with maximum temperatures usually around 15^{o} to 20^{o}C. Only during the months of June to September is the daily maximum temperature above 40^{o}C, when photosynthesis is affected. During the rest of the year, the temperature has little effect on photosynthesis, thereby suggesting a good possibility for establishing new mangrove plantations along Kuwait's coastline.

Wind affects the physiological performance of mangroves by regulating evapotranspiration from leaves. Excessive rates of evaporation can also cause salinity levels to build up, which in turn, may prevent the regeneration of mangroves (Spenceley, 1976). Such an effect may be overcome by planting the mangroves in regular, active, tidal areas, avoiding the margin of the inland area that tides do not reach. In Kuwait, winds usually blow from the northwest and, to a lesser extent, from the southeast. Dust and duststorms are common throughout the year, but are more frequent during the spring and summer months, March to August. As stated above, the wind's effect on salinity buildup can be minimized if the marginal areas in the inlands are avoided in establishing new mangrove plantations.

The nature of the soil where mangroves are planted should be silty or clayey-muddy in nature. During tidal movement, coarser sediments carried in suspension are generally settled prior to reaching the coastal fringe; while the coarser material reaching the coast is from other sources, such as erosion from adjoining areas. Moreover, the height and frequency of tides determine the textural composition of soils in coastal sites. In areas where high tides occur less frequently, high prevailing temperature causes excessive water loss from the soil resulting in shrinkage of the soil, thereby changing its consistency from semifluid to firm and ultimately to hard. As the sites that are prone to such changes are not suitable, only those where tides regularly cover the entire area should be selected for establishing new mangrove plantations.

Intertidal areas also experience frequent fluctuations in water table depending on the tidal movement and the level of seawater. Such fluctuations do not occur in landward areas along the seashore. Clarke and Hanon (1969) concluded that water table influences are less important in determining plant distribution and performance of mangroves than such factors as the frequency of inundation and exposure, the mechanical action of tidal water and soil salinity.

Salinity has long been recognized as a critical factor in regulating survival growth, regeneration and zonation in mangrove species (Semeniuk, 1983). Limited data are available on the tolerance of mangrove species to high salinities (Hutchings and Saenger, 1987). However, the response to salinity is more variable in the field than that in culture experiments. Mangroves have been found in soil salinities considerably higher than those suggested by laboratory experimentation. According to Hutchings and Saenger (1987), the response of different mangrove species to salinity ranges varies considerably. Therefore, mangrove species that have tolerances to the prevailing soil and seawater salinity levels in coastal areas (such as *Avicennia marina*) should be selected.

Drainage is another important feature of the sites, as it regulates oxygen supply to the mangrove root system. Mangrove species vary in their sensitivity to poor drainage and anaerobic conditions in coastal soils. Tidal inundation combined with poor drainage conditions generally leads to high water content, low oxygen levels, high salinity levels, free hydrogen sulfide, Eh values between -200 and 400 mV, and pH values ranging from 4.9 to 7.2. Such soils often are semifluid and poorly consolidated during wet periods, and hard and cracked during dry periods.

Deposition and/or stranding of fresh oil and toxic substances in intertidal mudflats have a significant, adverse effect on seedling establishment and growth for most mangrove species, especially in new areas. While volatile petroleum pollutants have phytotoxic effects, weathered fractions promote growth in some mangrove species (Snedaker et al., 2001).

Materials and Methods

Intensive survey of the areas has to be undertaken prior to the selection of sites for establishing mangrove plantations. Mangrove plantation cannot be established in every available site or vacant mudflat, as site and environmental conditions largely determine the successful establishment, productivity and sustainability of mangrove ecosystems. Therefore, a very detailed site survey and selection are prerequisites for establishing successful mangrove plantations. As the mudflats used for mangrove plantation are flushed continuously by seawater, which offsets soil-plant-water relations, unless the site conditions are appropriate, seedlings will have difficulties in developing proper root systems. Several factors have to be considered very carefully while selecting sites. Keeping in mind all possible interactions taking place in mangrove ecosystems, the project staff carefully developed selection criteria for selecting suitable sites for establishing new mangrove plantations in Kuwait (Shahid et al., 2000). The salient features of the selection criteria are given below.

Accessibility: The site was to be easily accessible, to facilitate movement of materials and people during planting and maintenance operations. Sites with poor accessibility pose problem in such operations.

No grazing: The site was to be protected from grazing as this would improve the chances of successful establishment of plantations.

Silty/clayey mudflat: The soil of the mudflat site was to be silty/clayey in texture. Sandy-textured sites were to be avoided as they tend to be eroded easily. It was to be kept in mind that loose mudflats do not provide stable substrate for mangrove roots, especially when they are planted as propagules or seeds. Potted seedlings with well developed root systems could be used in sandy substrate, if no better site was located.

Suitable topography: The site was not to be either too low to covered with tidal water for too long; or too high, so as to be covered by tidal water for only a brief period or only a few days in a month. The best site exists between the mean sea level and the mean high tide level (Qureshi, 1996). Mangroves thrive best on a slightly sloping ground, for which tidal water drains back to the sea, rather than flat surfaces where water stagnates for longer periods. Siddiqi and Khan (1996) suggested areas that are inundated during normal high tides but exposed during low tides to be ideal for mangrove plantations.

Regular tidal coverage: The site was to be covered by high tides for regular flushing of salts as well as to offset the water requirement with seawater.

Uncontaminated by household and construction wastes and rubbles: The site was not to be free from human influence, i.e., household wastes, leftover construction materials and rubble. These materials normally pose problems in planting and maintenance operations by causing physical damage to the seedlings.

Uncontaminated by oil spills: The site was to be free of petroleum oil pollution. Oily soil is hydrophobic in nature and may contain heavy metals (Pb, V, Cu etc.) at levels that impair mangrove seedling establishment and growth. Additionally, such sites have toxic levels of total petroleum hydrocarbons (TPH) and polycyclic aromatic hydrocarbons (PAHs).

Uncontaminated by drainage influence: The site was not to be contaminated with drainage effluents or harmful industrial discharges.

Nonsaline and not shelly: Sites that are compacted with higher proportions of sand or shells pose difficulties in planting of propagules and seedlings. Hence, these sites were to be avoided.

Based on the above-mentioned criteria, 14 sites were initially identified for surveying along the coastline of Kuwait from Subiya to Khiran. Aerial photographs and Sensitivity of Costal Environments and Wildlife to Spilled Oil, Kuwait: *An Atlas of Shoreline types and Resources* (Al-Sarawi et al., 1985) were used to identify sites along the coastlineof Kuwait. The objectives were to investigate Kuwait’s coastlines and to select five sites having maximum potential for mangrove plantation. The focus was to bring together all of the available information on the potential sites and their properties, with special emphasis on those aspects that would help to determine the suitability of the sites for mangrove plantation. The suitability of these sites was cross-examined against the selection criteria, as shown in Table 8. Of these 14 sites, only five sites fulfilled all of the requirements.

The selected sites were subjected to further sampling and analyses. These sites were described as per the Soil Survey Division Staff’s (1993) and the USDA’s (1996b) specifications, and classified according to the procedures recommended by the Soil Survey Staff, Soil Conservation Service (1998).

Table 8. Criteria Used for Selection of Sites for Introduction of Mangroves

Site	A	B	C	D	E	F	G	H	I	Remarks
1	☒	✓	☒	☒	☒	☒	✓	✓	☒	
2	✓	✓	☒	☒	☒	✓	✓	✓	☒	
3	✓	✓	✓	✓	✓	☒	✓	✓	✓	
4	✓	✓	✓	✓	✓	✓	✓	✓	✓	Selected
5	✓	✓	✓	✓	✓	☒	☒	☒	✓	
6	✓	✓	✓	✓	✓	☒	☒	☒	✓	
7	✓	✓	✓	✓	✓	✓	✓	✓	✓	Selected
8	✓	✓	✓	✓	✓	☒	✓	☒	✓	
9	✓	✓	✓	✓	✓	✓	✓	✓	✓	Selected
10	☒	✓	✓	☒	☒	☒	✓	☒	☒	
11	✓	✓	✓	✓	✓	✓	✓	✓	✓	Selected
12	☒	☒	✓	☒	☒	✓	✓	✓	☒	
13	✓	✓	✓	☒	☒	✓	✓	✓	✓	
14	✓	✓	✓	✓	✓	✓	✓	✓	✓	Selected

A – Easy accessibility; B – No grazing; C – Silty/clayey mudflats; D – Suitable topography; E – Regular tidal coverage; F – Uncontaminated by household wastes, construction materials and rubble; G – Uncontaminated by oil spills; H – Uncontaminated by drainage effluents; I – Nonsaline and notshelly.

At each site, at least three transects were prepared covering all distinct zones on the entire coast (saline/sandy mud flat, silty/sandy flat and silty/clayey mudflat). Soil pedons were dug at each transect, to just below the depth of standing water in the pits. The soil profile (termed ‘pedon’ when a volume of soil is examined) is the sequence of natural layers, or horizons in a soil. It was generally observed that the water table at all sites fluctuated within one meter of the soil surface. It ranged from 10 to 25 cm in the silty/clayey mudflat near the seawater, to about 40 to 60 cm in the silty/sandy mudflat, and around 60 to 80 cm in the saline/sandy flat area. As the water always collected in the soil pits, it was not possible to describe the visually horizons visually below the water table; however, soil samples were collected by hand below the water level for laboratory investigation. The samples were collected at various depths based on the distinct soil layers in the pedon, using the United States Department of Agriculture (USDA’s 1975) guidelines. Representative soil samples of approximately 2.5 kg were pooled from each layer (USDA, 1988). The soil taxonomy system (Soil Survey Staff, Soil Conservation Service, 1998) was used to classify each profile based mainly on the kinds and characteristics of the soil properties, and the arrangement of horizons within the profile. The horizons in the pits were described, where appropriate, for color (dry and moist), apparent texture, structure, excavation difficulty, effervescence, consistence, stickiness, presence of coarse fragments, salinity and soil reaction.

The samples collected from all the soil pits were processed by air drying and sieving to separate the different fractions based on particle size. Soil fractions of less than 2 mm were analyzed at the Soil Laboratory of the Aridland Agriculture and Greenery Department, KISR for a range of physical and chemical characteristics using the USDA's (1995, 1996c) and Page et al.'s (1982) procedures. The laboratory measurement of Eh, pH (soil reaction), electrical conductivity (EC), $CaCO_3$, and sodium adsorption ratio (SAR) generally assist in describing soils suitability, limitations and classification. The soil investigation in the laboratory was continued throughout the course of the project to ascertain the relationship between soil properties and mangrove plant development.

Soil Properties

Estimates of soil properties are based on field examinations and on laboratory tests of soil samples. Laboratory tests usually verify the field observations, determine properties that cannot be estimated accurately by field observations, and help characterize key soils. The soil properties estimated through laboratory analysis are indicated in profile descriptions.

The laboratory determinations were made on soil material that was less than 2 mm in diameter; however, rock fragments (> 2 mm in diameter), when found were reported separately. Measurements were reported as the percent or quantity of unit weight calculated on an oven-dried basis. The primary methods used in obtaining the data were those described in the USDA (1995, 1996c). Rock fragments (2 to 5, 5 to 20, and 20 to 75 mm in diameter) were reported as weight of all of the materials between 2 and 75 mm in diameter (Soil Survey Division Staff, 1993).

Soil texture was determined by the modified hydrometer method supplemented with wet sieving (Shahid, 1992). Soils were dispersed with 4% sodium hexametaphosphate solution, and particle size distribution analysis was by the modified Day's method. The data (on sand, silt and clay) were presented as a percentage by weight of the soil material that was < 2 mm in diameter. The USDA textural class (Soil Survey Division Staff, 1993) was used to define soil texture in diameter by plotting the sand (2 to 0.05 mm in diameter), silt (0.05 to 0.002 mm in diameter) and clay (< 0.002 mm in diameter) values on the textural triangle.

Saturation percentage (SP) was measured from the volume of water added to a known weight of soil to prepare a saturated soil paste. Soil pH was measured in 1:2.5 soil-to-water suspensions, and salinity was determined using an EC meter in filtered 1:1 soil-to-water extract, as required by *Keys to Soil Taxonomy* (Soil Survey Staff, Soil Conservation Service, 1998).

The soil saturation extract collected from soil saturated paste was analyzed for EC, soluble Na and K using flame emission spectroscopy (FES), Ca plus Mg measured by titration with ethylene diamine tetra acetic acid (EDTA) in the presence of ammonium chloride, ammonium hydroxide buffer solution and Eriochrome black T indicator or atomic absorption spectrophotometer (AAS as needed). CO_3 and HCO_3 were measured by titration with sulfuric acid using phenolphthalein and methyl orange indicator, respectively. The chlorides were analyzed by chloride analyzer or titration with silver nitrate solution using potassium chromate as indicator. SO_4 was estimated by the difference between the total measured cations and CO_3 + HCO_3 + Cl, as suggested by Bresler et al., (1982). Calcium carbonate was measured by a standard calcimeter and through an effervescence test. The color of both dry and moist soil samples was determined using the *Munsell Soil Color Charts* (Munsell, 1998). SAR was calculated for saturated soil paste extract, using ionic concentrations expressed in milliequivalents per liter, for each horizon as follows:

$$SAR = Na/[(Ca+Mg)/2]^{1/2} \text{ in } (mmol/l)^{1/2}$$

Results and Discussion

This section describes various sites surveyed along the coastline of Kuwait. Important aspects of the sites are presented using a number of plates, as well as the pedon description made to ascertain the suitability of potential sites for mangrove plantation. Sites in Khiran, Shuwaikh, Sulaibikhat, Doha, the National Park and Subiya (near the Bubiyan Bridge) were surveyed.

Sites at Khiran. Khiran is one of the main areas of public interest for entertainment and weekend camping, with people visiting throughout the year. Initially it was thought that a trial on mangroves could be made in the Khiran area. During the field visits made to the site, it was found that the coastal areas at this location were significantly influenced by human activities, such as construction of chalets along the coast. The coastal areas were mostly covered with sandy beach contaminated with rubble and other floating materials, both of which are known to affect the establishment and growth of mangrove plants. Hence, the sites at this location were not considered for further investigation.

KISR Site at Khiran (Coastal Sites with Ponds). KISR's Aquaculture, Fisheries and Marine Environmental Department have an experimental farm at Khiran, where research on fish farming is being undertaken. Arrangements were made with the department for access to the farm to assess the suitability of the site for mangrove plantation. At this site, KISR has established a number of small, interlinked ponds, where water with low currents enters during high tides. Investigation of these ponds showed that their outer fringes were sandy in texture and contain appreciable quantities of shells. The water enters quietly into these ponds from a narrow opening (formed due to an infilling of the sea through human activity) from the sea. The water has not brought silty material to these ponds to create mudflats around the water ponds. Based on the selection criteria, the site was rejected for mangrove plantation. An overall view of these ponds is presented in Plate 32.

Plate 32. A general view of the ponds at the KISR's Experimental Station at Khiran showing evidence of the shelly and loose sandy nature of the site.

Shuwaikh (KISR East) Site1. KISR has already completed a preliminary study on mangrove plantation, in which two sites at the KISR main campus in Shuwaikh and one in Sulaibikhat were planted with *Avicennia marina*. The first site exists to the east of KISR's new buildings near the KISR Sports Club (Plate 33). The site has a lot of rubbles and construction materials. Although mangroves are growing successfully at this site, the heavy deposition of waste materials, nonavailability of suitable intertidal area and high intensity of water currents offer little scope for further expansion of mangrove plantation. Based on the selection criteria, this site was rejected.

Shuwaikh (KISR West) Site 2. The second site at KISR is located near the Tissue Culture Laboratories of the Biotechnology Department. A general view of the site is presented in Plate 34. The site was not contaminated, as the KISR 1 site, and fulfilled the selection criteria for mangrove plantation. The visual assessment of the site showed

a. Nature of the intertidal mudflat

b. View of the existing mangrove plantation

Plate 33. A view of the Shuwaikh (KISR East) Site 1 near the KISR Sports Club.

a gap in the mangrove plantation at this site (Plate 34a). It was decided to extend the mangrove plantation at this site. Establishing mangroves at this site would enhance the quality of the site for public entertainment, wildlife and marine life.

a. Nature of the mudflat

b. View of existing plantation

Plate 34. A view of the Shuwaikh (KISR West) Site 2 site near KISR's Tissue Culture Laboratories

KISR Site on Sulaibikhat Bay. The third site of the old mangrove project is located in Sulaibikhat Bay. Field investigation showed that only a few plants were surviving at this site (Plate 35). The site was visited both at high and low tide. At low tide periods, it appeared that the site was contaminated with rubble, household wastes and construction materials, and bordered the drainage outlet. The drain regularly collects wastewater from houses and commercial establishments in the nearby areas, and in all probability, it contains toxic chemical contaminants that might affect mangrove growth. At high tide periods, the currents are quite strong and might affect the plant survival after transplantation. This site, therefore, did not meet all the selection criteria, and hence, was rejected. Existing mangrove plantation and an outlet of the drain at the site are shown in Plate 35.


Plate 35. A view of the mangrove site on Sulaibikhat Bay showing the presence of a few *Avicennia marina* plants.

Sulaibikhat Site 1. The entire coastline between Sulaibikhat Bay (starting from the Maternity Hospital) and Doha's Entertainment City was visited for a preliminary assessment of potential sites and to select suitable sites for establishing mangrove plantation. A number of features were noted, viz., the presence of rubble, construction materials and household wastes, discharge of drainage effluents, accessibility of mudflats, oil contamination, and deposition of salts on the surface of mudflats. Five sites on Sulaibikhat Bay were found to have some potential and, hence, were initially selected. These were assessed using the selection criteria indicated in Table 8 for selecting sites for further investigation.

The general view of the first site at Sulaibikhat is shown in Plate 36. Distinct features of this site are fresh oil (Plate 36a), contamination from a drainage outlet, rubble, and household and construction wastes (Plate 36b). The site was rejected for further investigation.

a. Deposition of oil

b. Drainage outlet

Plate 36. A view of the coastal site on Sulaibikhat Bay

Sulaibikhat Site 2. The site is located in the northern corner of the children's entertainment park on Sulaibikhat Bay, facing Doha town. The field investigation indicated the productive nature of the mudflat, which is not contaminated with fresh oil and is free from salt depositions and drainage discharges. The site is also easily accessible. A view of the site during the low tide period is shown in Plate 37. The luxuriant growth of *Zygophyllum* plants in the mudflat is an indication of the high productivity of the site; however, these plants might very well compete with mangrove seedlings for nutrients and other resources. It is possible to overcome this nutritional deficiency problem by applying chemical fertilizers. As the site fulfilled the selection criteria very well, it was selected for establishing mangrove plantation. Around 1.5 to 2 ha at this site was found suitable for mangrove plantation. Some rubble and household waste materials were noticed on the outskirts of the site that was not covered during high tide.

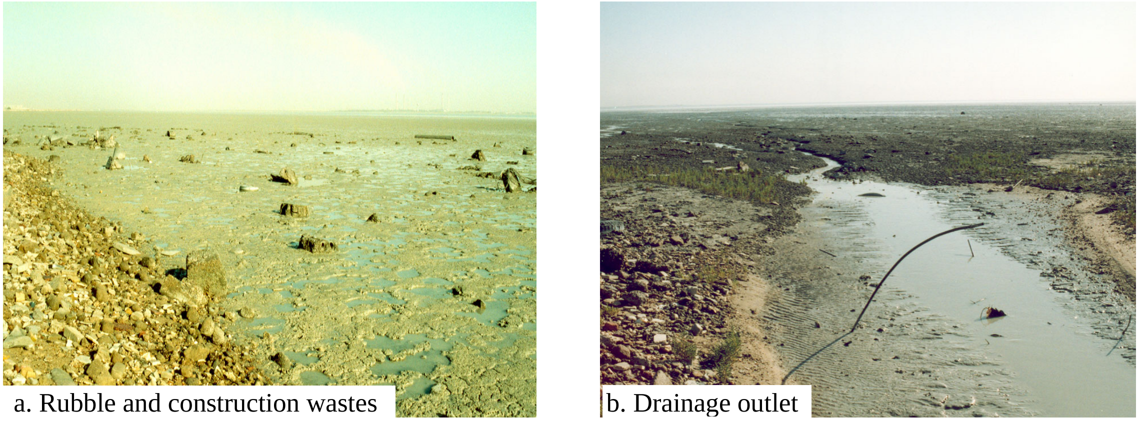

a. Silty/clayey mudflat


b. Native *Zygophyllum* vegetation

Plate 37. A view of the silty/clayey mudflat on Sulaibikhat Bay and native *Zygophyllum* vegetation.

Sulaibikhat Site 3. The site has large quantities of rubble, construction wastes and other materials. It also has a drainage outlet that discharges large quantities of effluents. The mudflats were dug into with a shovel to investigate their depths. The entire mudflat was contaminated at the surface and at depth. A general view of the site is shown in Plate 38. The site was, therefore, rejected.

Sulaibikhat Site 4. The site had features similar to that of Sulaibikhat Site 2. The site has a few *Zygophyllum* plants, an indication of the high productivity, low contamination and easy accessibility and cleanliness of the mudflat. The fringe of the site was sandy, while further up, it contained relatively high surface salt depositions (visible white crystals). The site was selected for further investigation. A birds-eye view of the site is shown in Plate 39.



a. Rubble and construction wastes

b. Drainage outlet

Plate 38. A view of another site along the Sulaibikhat Bay showing large quantities of rubble and construction wastes, and excessive discharge by a drainage outlet.

Plate 39. A view of a site along the Sulaibikhat Bay showing luxuriant growth of native *Zygophyllum* vegetation.

Sulaibikhat Site 5. This was the last site along Sulaibikhat Bay, located on the right side of the road, just before turning towards Doha’s Entertainment City. The dominant features of this site were a drainage outlet letting the effluent into the sea (Plate 40a), a large saline mudflat (Plate 40b) not covered by daily high tides, and an inaccessible clayey mudflat that is not suitable for mangrove plantation. The site also contained high salt accumulations near the shoreline, and large quantities of household and construction wastes. The site was rejected for further investigation.

Site near Doha’s Entertainment City. The site is located behind Entertainment City. The site was approached through the Sheikh Zayed Park. The main features of the site are a saline mudflat not covered by daily high tides, reeds growing in swamps (Plate 41a), dead halophytic plants near the seashore due to high salinity levels, extensive saline area along the shoreline (Plate 41b), and a silty/clay mudflat covered by regular daily high tides (Plate 42a) where a lonely healthy mangrove plant was growing (Plate

42b). The presence of the mangrove plant indicates that the site has good potential for successful mangrove plantation. Contamination by spilled oil (Plate 43a) and a rocky coastline (Plate 43b) was also observed.


a. Drainage outlet


b. Highly saline mudflat

Plate 40. A view of another site surveyed along Sulaibikhat Bay showing drainage outlet and highly saline mudflat.

Site at the National Park on Kuwait Bay. The site is located on Kuwait Bay bordering the coastal area of the National Park. The site is approximately 2.5 km away from the Jahra-Subiya road. The site has a long slippery salty flat area, not covered by the daily high tide. This area borders a silty/clayey mudflat, which is covered by the daily high tide, but has poor accessibility. The site was, therefore, rejected for further investigation.

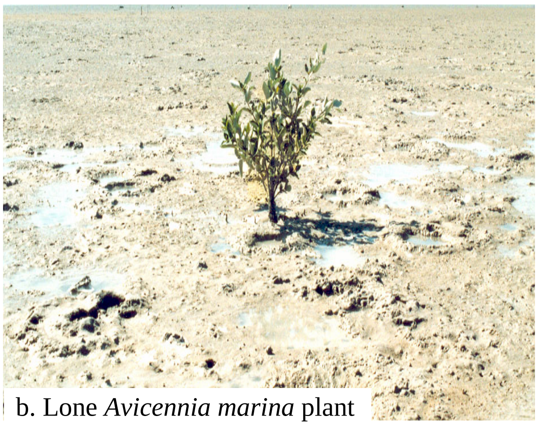

a.*Tamarix* plantation on the shore


b. Mudflat covered with salt

Plate 41. Another site along Sulaibikhat Bay showing *Tamarix* plantation on the shore and a mudflat covered with salt.

Site at Subiya near the Bubiyan Bridge (Left Corner). The site is situated on the left corner of the bridge leading to Bubiyan Island. The site presents three dominant features: a saline sandy flat area (Plate 44a) without any vegetation, and no uniform coverage by the daily high tide. This saline flat area borders a sandy flat area covered by

a. Vast intertidal mudflat



b. Lone *Avicennia marina* plant

Plate 42. A view of a site near Doha's Entertainment City.

Plate 43. Presence of highly weathered oil on the soil surface on the shoreline at the Doha site.

the daily high tide, that has *Zygophyllum* vegetation scattered in the area (Plate 44b).The sandy flat area adjoins a silty/clayey mudflat covered by the daily high tide. Also the site did not have a uniform topography and had a few scattered sand ridges, which diverted high tides in other directions. As a result, a portion of the mudflat was not covered uniformly by seawater during the high tide periods. Although from the site observation, the site seemed to have good prospects for establishing mangrove plantation, it was decided to select only one site at this location (Bubiyan Bridge). The site on the other side of the bridge was also investigated for comparative advantages before making a final selection. The site on the right side of the bridge met the selection criteria better than this site, and hence, this site was not selected for further investigation.

Site at Subiya near Bubiyan Bridge (Right corner). The site is situated on the right side of the bridge leading to Bubiyan Island. The site was investigated for its suitability for mangrove plantation. The site has three important features: 1) the saline

a.Saline, sandy area

b. Native *Zygophyllum* on the intertidal mudflat

Plate 44. A general view of the site on left side of the Bubiyan Bridge.

sandy flat area bordering the shoreline (Plate 45a) with no vegetation and a high salt content. It is not covered by daily high tide; 2) the silty/sandy flat area with *Zygophyllum* vegetation at some spots (Plate 45b). Thus area is flushed daily by the

a. Highly saline area near the shoreline

b. Clean, intertidal mudflat with scattered native vegetation

Plate 45. A view of site on the right side of the Bubiyan Bridge in Subiya.

tidal water; 3) the silty/clayey mudflat (Plate 46a). The silty/clayey mudflat is triangular in shape and highly accessible. This area has high crab activity as indicated by a large number of crab mounds rising to a few centimeters above ground level in the intertidal mudflat (Plate 46b). The site was the cleanliest of all the sites surveyed, appeared productive and fulfilled all of the selection criteria. Therefore, this site was selected for further investigation and establishment of an experimental mangrove plantation.

Soil Taxonomy and Pedon Description at the Five Sites Selected for Establishing Experimental Mangrove Plantations

Soil classification is a comprehensive multicategory system based on hierarchical, differentiating criteria. Classification is based on soil properties observed in the field or

a. Intertidal mudflat

b. Other areas

Plate 46. Close-up view of the intertidal mudflat and other areas at the Subiya site.

inferred from laboratory measurements. The system has six categories. Thus, at the broadest level, there are soil orders, based on key or diagnostic soil horizons. The system used in this survey is the one recommended by the USDA in *Keys to Soil Taxonomy* (Soil Survey Staff, Soil Conservation Service, 1998). Beginning with the broadest, these categories are order, suborder, great group, subgroup, family and series.

To assess the sites suitability for establishing experimental mangrove plantations, the site was divided into a number of transects namely silty/clayey mudflat, silty sandy flat area, and saline sandy area. Representative pits from each area were described for various features in the field, and a taxonomic name was allocated.

Shuwaikh (KISR) Site. This site is situated near the Tissue Culture Laboratories of the division of Food Resources and Marine Sciences, at KISR main campus. In 1993, this site was used for ascertaining the technical feasibility of introducing mangrove plants in Kuwait. Preliminary assessment of the site showed a good possibility for further expansion of plantation. Hence, it was decided to investigate further the suitability of the site.

The site was divided into two distinct zones: a silty/clayey muddy flat zone near the seawater and sandy beach at the outer border. The water table fluctuated with seawater level. A total of four pits were made: three in the silty/clayey muddy flat covered by the daily high tide (having a uniform texture) and one in the sandy beach area (with non-uniform texture) that was not covered by a regular high tide. Oil contamination was observed at a depth of 30 cm in the sandy area. A representative pedon description of the selected location is presented below:

- Taxonomic name: Typic aquisalid,
- Diagnostic horizon: Salic,

- Type of observation: Oil pit,
- Surface condition: Muddy,
- Slope: < 1%,
- Slope class: Nearly level,
- Slope morphological type: Simple,
- Moisture status: Wet,
- Land use: None or mudflat,
- Biological activity: Low,
- Parent material: Alluvium, and
- Water table: Fluctuated with seawater level.

The pit was dug to a 30 cm depth. As the water table appeared at 30 cm, it was not possible to study visually in the field the horizons below 30 cm depths and samples were collected by hand through the water level.

The Akzg from 0 to 5 cm, was light grey (2.5Y 7/1) when dry, dark grey (5Y 4/1) when moist, clay to clay loam with a massive structure, and moderate to high excavation difficulty when wet, but very high excavation difficulty when dry. It was violently effervescent with a rigid, dry consistency. It was very sticky and had no gravel.

Bkzg from 5 to 30 cm + was light grey (5Y 7/1) when dry, dark grey (5Y 4/1) when moist, clay loam with a massive structure and moderate to high excavation difficulty when wet, but a very high excavation difficulty when dry. It was strongly effervescent with a rigid dry consistence. It was very sticky and had no gravels. Some selected physical and chemical characteristics are indicated in Table 9.

Table 9. Physical and Chemical Characteristics of a Typical Soil Pedon (Inner Zone)

Horizon	**Depth (cm)**	**pHs**	**ECe dS/m**	**SAR $(mmoles/l)^{1/2}$**	**$CaCO_3$ % eq**	**Sand**	**Silt**	**clay**	**Text Class**
						%			
Akzg	0-3	8.02	74	104	31.4	26	39	35	CL
Bkzg	3-30+	7.75	32	66	24.1	41	25	34	CL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; CL = Clayey loam; SiC= Silty clay

The Akzg had hues of 2.5Y or 5Y (both dry and moist), values of 7 (dry) and 4 (moist) and chromas of 1 (dry) and 1 or 2 (moist). The Bkzg had a hue of 5Y (dry and moist), values 7 (dry) and 4 (moist) and a chroma of 1 (both dry and moist). The effervescence was violent. The texture in the Akzg and Bkzg varied between clay loam and clay. The ECe ranged from 74 to 78 dS/m (Akzg) and from 32 to 51 dS/m (Bkzg). The SAR fluctuated from 104 to 118 $(mmoles/l)^{1/2}$ (Akzg) and from 66 to 87 $(mmoles/l)^{1/2}$ (Bkzg). The $CaCO_3$ content in the soil ranged from 25.6 to 31.4% eq (Akzg) and from 24.1 to 27.3 % eq. (Bkzg). The saturated soil pH values were 7.9 to 8.02 (Akzg) and 7.75 to 7.97 (Bkzg). The mud contents were between 65 and 74% and between 59 and 76% in Akzg and Bkzg layers, respectively.

The characteristics of the outer sandy zone are presented in Table 10. Two pits were dug; but samples were collected only from above pit. Both the pits presented oil contamination below 30 cm depth. The texture of the Akzg layer was sandy. Oil deposits were observed at 30 cm below the surface. The mud content in the top 30 cm was only 2%.

Table 10.Physical and Chemical Characteristics of a Typical Soil Pedon (Outer Sandy Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Texture Class
						%			
Ak	0-30	8.47	16	50	14.1	98	1	1	S
30+	……..………..………..oil contaminated zone…...……….……...……								

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; CL = Clayey loam; SiC = Silty clay.

The characteristics of the mudflat near the existing mangrove plantation are given in Table 11.

Table 11. Physical and Chemical Characteristics of a Typical Soil Pedon (Mudflat Nearer to the Existing Mangrove Plantation)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Texture Class
						%			
Akzg	0-5	7.68	109	128	17.3	74	13	13	SL
Bkzg	5-30	7.94	55	89	17.2	71	14	15	SL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; CL = Clayey loam; SiC = Silty clay.
NB: Only one pit was dug at the above site.

The texture in both the Akzg and Bkzg was sandy loam, and the mud contents were 26% and 29% in the Akzg and the Bkzg, respectively.

The characteristics of the inner zone and the mudflat with existing mangroves showed better promise for additional plantation (inner zone) to the north. The sandy zone did not show suitable mudflat texture. Additionally, this zone was affected by oil contamination below 30 cm depth. Therefore, this zone should be avoided for mangrove plantation.

Sulaibikhat Site 1. It is located in the northern corner of the children amusement park on Sulaibikhat Bay. The field investigation revealed that the mudflat at this site is productive, and is not contaminated with oil, household wastes, excess salts and drainage, etc. The site is also easily accessible. The presence of *Zygophyllum* plants in the site also indicates that the site is productive; however, they might compete for nutrition with the planted mangroves. As the site met the selection criteria, it was proposed for establishment of an experimental mangrove plantation.

The Sulaibikhat site was divided into three distinct zones: silty/clayey muddy near the seawater, silty sand in the middle, and sand towards the shoreline. The water table fluctuated with seawater level. A total of seven pits were made, three in the inner zone that was covered daily by the high tide, three in the middle silty sandy zone which was covered uniformly by the high tides and where *Zygophyllum* plants were observed, and one in the sandy dry beach which was not covered by high tides. In the sandy dry beach, sand is only accumulated in the top 20 cm. Below this depth silty/sandy mud (grey in color) was found. The silty/clayey muddy area was selected for mangrove plantation. The outer sandy area was not recommended for mangrove plantation. The representative pedon description of the selected site is given below:

- Taxonomic Name: Typic aquisalid,
- Diagnostic horizon: Salic,
- Type of observation: Soil pit,
- Surface condition: Muddy,
- Slope: $< 1\%$,
- Slope class: Nearly level,
- Slope morphological type: Simple,
- Moisture status: Wet,
- Land use: None,
- Biological activity: High fish activity,
- Parent material: Alluvium, and
- Water table: Fluctuated with seawater level.

The Akzg from 0 to 5 cm, was light grey (2.5Y 7/1) when dry, grey (2.5Y 5/1) when moist, clay loam with a massive structure, and moderate to high excavation difficulty when wet, but very high excavation difficulty when dry. It was violently effervescent with a rigid dry consistency. It was very sticky and had no gravel.

The Bkzg from 5 to 30-plus cm, was grey (2.5Y 6/1) when dry, grey (5Y 6/1) when moist, but silty clay loam with a massive structure, and moderate to high excavation difficulty when wet, but very high excavation difficulty when dry. It was strongly effervescent with a rigid, dry consistency. It was very sticky and had no gravel. Selected characteristics of the inner zone, where mangrove plantation is proposed, are presented in Table 12.

Table 12. Physical and Chemical Characteristics of a Typical Soil Pedon (Inner Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR (mmoles/l)$^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-5	8.11	64	93	40.0	30	34	36	CL
Bkzg	5-30	8.13	43	111	34.2	14	47	39	SiCL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio CL= Clayey loam; SiCL= Silty clayey loam.

The Akzg had hues of 2.5Y or 5Y (dry and moist respectively), values of 7 (dry) and 5 (moist), and a chroma of 1 (both dry and moist). The Bkzg had hues of 2.5Y or 5Y (dry) and 5Y (moist), values of 6 or 7 (dry) and 6 (moist), and a chroma of 1 (both dry and moist). The effervescence was violent. While the soil texture was silty clay loam, clay loam or clay in the Akzg, it was silty clay, silty clay loam or clay in the Bkzg. The ECe ranged from 51 to 66 dS/m (Akzg) and from 40 to 59 dS/m (Bkzg). The SAR ranged from 89 to 98 (mmol/l)$^{1/2}$ (Akzg) and from 80 to 111 (mmol/l)$^{1/2}$ (Bkzg). The $CaCO_3$ levels were from 32.7 to 40.0% eq (Akzg) and from 32.9 to 34.2% eq (Bkzg). The pH ranged from 8.11 to 8.25 (Akzg) and from 8.13 to 8.26 (Bkzg). The mud content in the Akzg ranged between 70 and 86%, whereas it was between 86 and 91% in the Bkzg indicating a silty/clayey nature in the mudflat. Selected characteristics of the middle inner zone, where mangrove plantation may have potential are given in Table 13.

Table 13. Physical and Chemical Characteristics of a Typical Soil Pedon (Middle Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR (mmoles/l)$^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-5	8.40	85	120	29.8	32	33	35	CL
Bkzg	5-30	8.13	54	54	32.2	9	42	49	SiC

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; CL = Clayey loam; SiC = Silty clay.

The Akzg had hues of 2.5Yor 5Y (both dry and moist), values of 6 or 7 (dry) and

4 or 5 (moist), and chromas of 1 or 2 (dry) and 2 (moist). The Bkzg had a hue of 2.5Y or 5Y (both dry and moist), values 6 or 7 (dry) and 4 or 5 (moist) and chromas of 1 or 2 (dry) and 1 or 3 (moist). The effervescence was violent. The texture of the Akzg was sand, sandy loam or clay loam, whereas the texture of Bkzg the layer (3 to 30 cm below the surface) was sand, clay loam or silty clay. However, clay soil was found below 30 cm depths from the surface in one pedon. The ECe ranged from 65 to 94 dS/m (Akzg) and from 26 to 72 dS/m (Bkzg). The SAR ranged from 97-163 $(mmol/l)^{1/2}$ (Akzg) and from 54 to 102 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ content ranged from 10.5 to 29.8% eq (Akzg) and from 15.2 to 32.22% eq (Bkzg). The pH varied from 7.79 to 8.4 (Akzg) and from 7.95 to 8.4 (Bkzg). The mud content of the Akzg ranged between 28 and 68%, whereas in the Bkzg, it varied between 63 and 91%. Selected characteristics of the outer zone are given in Table 14.

Table 14. Physical and Chemical Characteristics of a Typical Soil Pedon (Outer Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-10	8.35	24	69	9.2	97	2	1	S
Bkzg	10-30	7.89	25	99	29.7	32	40	28	CL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; S = Sandy; CL = Clayey loam.

The Akzg had hues of 5Y (dry) and 2.5Y (moist), values of 6 (dry) and 4 (moist) and chromas of 2 (dry) and 3 (moist). The Bkzg had a hue of 5Y (both dry and moist), values of 7 (dry) and 5 (moist), and a chroma of 1 (both dry and moist). The effervescence was strong in the Akzg and violent in the Bkzg. The texture of the Akzg was sand, but it was clay loam below 10 cm (Bkzg). The ECe was 24 dS/m (Akzg) and 25 dS/m (Bkzg), and the SAR was between 69 $(mmol/l)^{1/2}$ (Akzg) and 99 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ contents varied between 9.2% eq (Akzg) and 29.7% eq (Bkzg). The pH was 8.35 in the Akzg and 7.89 in the Bkzg. The mud content in the Akzg was 3%. However, the Bkzg layer contained up to 68% mud.

Comparatively, the inner and the middle zones showed better promise for mangrove plantation the outer zone. Therefore, both the inner and middle zones should be exploited for mangrove plantation. However, out of these two zones, the inner zone offers better potential and meets the selection criteria better. The outer zone showed reasonable mud content below 10 cm, but this zone is not covered by the daily high tide. Hence, it was decided not to carry out mangrove plantation in this zone.

Sulaibikhat Site 2. This site is also situated on Sulaibikhat Bay. A general view of the site is shown in Plate 40. The salient features of the site are described in previous sections. This site was divided into three distinct zones: a silty/clayey muddy flat zone near the seawater, a silty sand zone in the middle, and a sandy zone along the shoreline bordering the dry land. The water table in this site also fluctuated with the level of water in the sea.

This site had features similar to those of Sulaibikhat Site 1.The site appeared productive and less contaminated, and had an easily accessible mudflat. At the fringe of the site, it was sandy in texture, while at further up it had high salt contents (visible as white crystals).

A total of six pits were made: three in the inner zone (covered daily by high tide), two in the middle zone (covered uniformly by high tide, with *Zygophyllum* plants observed) and one in the outer zone comprised of dry sandy, beach. In the outer zone of dry sandy, beach, the sand was observed only in the first 30 cm from the surface. Oil contamination was noticed below 30 cm depths. A representative pedon description of the selected site is given below:

- Taxonomic name: Typic aquisalid,
- Diagnostic horizon: Salic,
- Type of observation: Soil pit,
- Surface condition: Muddy,
- Slope: < 1%,
- Slope class: Nearly level,
- Slope morphological type: Simple,
- Moisture status: Wet,
- Land use: None,
- Biological activity: High fish activity,
- Parent material: Alluvium, and
- Water table: Fluctuated with seawater level.

The Akzg from 0 to 5 cm, was light grey (5Y 7/1) when dry, dark grey (5Y 4/1) when moist, loam with a massive structure and moderate to high excavation difficulty when wet, but very high excavation difficulty when dry. It was violently effervescent with a rigid, dry consistency. It was very sticky and had no gravel.

The Bkzg from 5 to 30-plus cm was light grey (5Y 7/1) when dry, grey (5Y 5/1) when moist, clay loam with a massive structure, and moderate to high excavation difficulty when wet, but very high excavation difficulty when dry. It was strongly effervescent with a rigid, dry consistency. It was very sticky and had no gravel. Selected characteristics of the inner zone, where mangrove plantation is proposed are given in Table 15.

Table 15. Physical and Chemical Characteristics of a Typical Soil Pedon (Inner Clayey/Silt Muddy Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-5	8.43	60	86	28.0	48	29	23	L
Bkzg	5-30	8.48	47	92	30.1	42	19	39	CL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio L = Loamy; CL = Clayey loam.

The Akzg had hues of 2.5Y or 5Y (dry) and 5 (moist), values of 6 or 7 (dry) and 4 (moist), and chromas of 1 (dry) and 1 or 2 (moist). The Bkzg had hues of 2.5Y or 5Y (dry) and 5Y (moist), values of 7 (dry) and 5 (moist) and a chroma of 1 (both dry and moist). The effervescence was violent. The texture of the Akzg was loam or clay loam, and that of the Bkzg was sandy clay loam, clay loam or clay. The ECe ranged from 60 to 73 dS/m (Akzg) and from 31 to 69 dS/m (Bkzg). The SAR ranged from 86 to 108 $(mmol/l)^{1/2}$ (Akzg) and from 92 to 157 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ contents ranged from 28.0 to 37.5% eq (Akzg) and from 30.1 to 33.8% eq (Bkzg). The pH ranged from 8.12 to 8.53 (Akzg) and from 8.42 to 8.52 (Bkzg). The Akzg and Bkzg had mud contents ranging between 52 and 70% and 43 and 84%, respectively. Selected characteristics of the middle zone are given in Table 16.

Table 16. Physical and Chemical Characteristics of a Typical Soil Pedon (Middle Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-20	8.56	99	135	33.8	38	34	28	CL
Bkzg	20+	8.71	86	184	33.1	14	42	44	SiC

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; CL = Clayey loam; SiC = Silty clay.

The Akzg had hues of 2.5Y or 5Y (dry) and 5 (moist), values of 7 (dry) and 5 (moist) and a chroma of 2 (both dry and moist). The Bkzg had a hue of 5Y (both dry and moist), values of 7 (dry) and 4 or 5 (moist), and a chroma of 1 (both dry and moist). The effervescence was violent. The texture of the Akzg layer ranged between loam and clay loam. In contrast, the Bkzg layer had a silty clay or clay texture. The ECe ranged from 75 to 99 dS/m (Akzg) and from 64 to 86 dS/m (Bkzg). The SAR ranged from 135 to 204 $(mmol/l)^{1/2}$ (Akzg) and from 110 to 184 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ levels in the Akzg and Bkzg layers were from 33.8 to 38.8% eq and from 33.1 to 37.4% eq, respectively. The pH ranged from 8.56 to 8.63 (Akzg) and from 8.58 to 8.71 (Bkzg). The mud contents in Akzg and Bkzg layers ranged between 62 and 64% and between 82 and 86%, respectively. Selected characteristics of the outer zone, where mangrove plantation is not proposed, are given in Table 17.

Table 17. Physical and Chemical Characteristics of a Typical Soil Pedon (Outer Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Texture Class
						%			
Ak	0-20	7.85	74	111	39.2	98	1.5	0.5	S
30+	20+	…………………..oil contaminated zone……………………							

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; S = Sandy.

The outer zone was almost homogeneous in nature and was exposed at 5 places. Therefore, only one representative pedon was sampled for further investigation. In all five sites, the lower zone was contaminated with oil. The texture in the upper 20 cm was predominantly sand throughout the outer zone. The profile was contaminated with oil at 20 cm and below.

The characteristics of both the inner and the middle zones showed good promise for introducing mangrove plants. However, the inner zone was found superior to the middle zone. Both of these zones met the selection criteria more closely than the outer zone. The outer has sand-textured soil material, which was contaminated with oil below 30 cm. Hence, the outer zone was not considered for plantation.

Doha Site behind Entertainment City. The salient features of the site are described in previous sections (Plates 42-43). Similar to the Subiya site, the entire flat area also presented three textural demarcations. As observed at low tides, the three features were silty/clayey mudflat near the seawater, silty/sandy flat in the middle and a saline/sandy dry area along the shoreline. The water table in these zones fluctuated with seawater level.

At this site, a total of nine pits were made: four in the inner zone (mudflat covered daily by high tide), three in the middle zone (not uniformly covered by high tides) and two in the saline sandy dry beach zone (not covered by daily high tides). The saline sandy dry beach consists of a 2 to 10 mm thick salt crust at the surface, which at a 1:1 ratio gave EC values of more than 150 dS/m. The silty/clayey muddy area (inner zone) was selected for mangrove plantation. It was decided to avoid the other two zones (silty/sandy and saline sandy) for mangrove plantation. The representative pedon description of the selected site is given below:

- Taxonomic Name: Typic aquisalid,
- Diagnostic horizon: Salic,
- Type of observation: Soil pit,
- Surface condition: Muddy,
- Slope: < 1%,
- Slope class: Nearly level,
- Slope morphological type: Simple,
- Moisture status: Wet,
- Land use: None,
- Biological activity: High crab activity,
- Parent material: Alluvium, and
- Water table: Fluctuated with seawater level.

The Akzg, from 0 to 5 cm, was light grey (2.5Y 7/1) when dry, grey (2.5Y 6/1) when moist, loam, massive structure, and low excavation difficulty when wet, but very high excavation difficulty when dry. It was violently effervescent with a rigid dry consistency. It was very sticky and had no gravel. The Bkzg from 5 to 30-plus cm was light grey (2.5Y 7/1) when dry and light olive grey (5Y 6/2) when moist, clay loam, with a massive structure, and low excavation difficulty when wet, but very high excavation difficulty when dry. It was violent effervescent with a rigid dry consistency. It was very sticky and had no gravel. Selected characteristics of the inner zone, where mangrove plantation is proposed are given in Table 18.

Table 18. Physical and Chemical Characteristics of a Typical Soil Pedon (Inner Clayey/Silt Muddy Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-10	8.19	124	190	35.1	44	31	25	L
Bkzg	10-30+	8.23	115	135	34.1	34	31	35	CL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio, L = Loamy; CL = Clayey loam.

The Akzg had hues of 2.5 Y (dry) and 2.5 or 5Y (moist), values of 7 (dry) and 5 or 6 (moist), and chromas of 1 (dry) and 1 or 2 (moist). The Bkzg had hues of 2.5Y (dry) and 2.5 or 5Y (moist), values of 6 or 7 (dry) and 6 (moist), and chromas of 1 (dry) and 1 or 2 (moist). The effervescence was violent. The texture ranged from sandy loam to loam (Akzg) and from sandy loam to clay loam (Bkzg). The ECe ranged from 89 to 140 dS/m (Akzg) and from 62 to 115 dS/m (Bkzg). The SAR ranged from 137 to 220 $(mmol/l)^{1/2}$ (Akzg) and from 111 to 226 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ levels ranged from 35 to 40% eq (Akzg) and from 34 to 44% eq (Bkzg). The pH ranged from 8.10 to 8.35 (Akzg) and 7.93-8.23 (Bkzg). The mud content ranged from 39-57 (Akzg) and 43-66% (Bkzg). Selected characteristics of the middle zone are given in Table 19.

Table 19. Physical and Chemical Characteristics of a Typical Soil Pedon (Middle Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-5	8.39	152	221	40.0	49	26	25	L
Bkzg1	5-20	8.37	83	211	39.2	64	15	21	SCL
Bkzg2	20-30	8.33	113	139	39.6	62	18	20	SL-SCL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio, L = Loamy; SCL = Silty Clayey Loamy; SL = Sandy loamy.

The Akzg had hues of 2.5 Y (dry) and 2.5Y or 5Y (moist), values of 7 (dry) and 5 or 6 (moist), and chromas of 1 (dry) and 1 or 2 (moist). The Bkzg had hues of 2.5Y (dry) and 2.5Y or 5Y (moist), values of 7 (dry) and 5 or 6 (moist), and chromas of 1 (dry) and 1 or 2 (moist). The effervescence was violent. The texture ranged from sandy loam to loam in the Akzg and from sandy loam to clay loam in the Bkzg. In one pedon, the Bkzg was sandy clay loam. The ECe ranged from 113 to 152 dS/m (Akzg) and from 61 to 153 dS/m (Bkzg). The SAR ranged from 213 to 226 $(mmol/l)^{1/2}$ (Akzg) and from 137 to 286 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ levels ranged from 31 to 40 % eq (Akzg) and from 36 to 40% eq (Bkzg). The pH ranged from 8.07 to 8.39 (Akzg) and from 8.00 to 8.46 (Bkzg). The mud content ranged from 33 to 53% (Akzg) and from 36 to 68% (Bkzg). Selected characteristics of the outer zone, where mangrove plantation is not proposed are given in Table 20.

The Akzg had hues of 2.5 Y (dry) and 2.5Y or 5Y (moist), a value of 6 (both dry and moist) and chromas of 1 or 2 (dry) and 1 or 3 (moist). The Bkzg had hues of 2.5Y (dry) and 2.5Y or 5Y (moist), a value of 6 (both dry & moist) and chromas of 1 or 2 (dry) and 1, 2 or 3 (moist). The effervescence was violent. The texture in the Akzg ranged between sand and sandy loam, and in the Bkzg, it was sand, sandy loam, silt-loam or clay-loam in different pedons. The SAR ranged from 143 to 208 $(mmol/l)^{1/2}$ (Akzg) and from 120 to 134 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ contents ranged from 19.5-33.7% eq (Akzg) and from 26.9 to 32.8% eq (Bkzg). The pH ranged from 7.53 to 8.28 (Akzg) and from 7.67 to 8.04 (Bkzg). The mud contents in the Akzg and the Bkzg ranged from 6.5 to 36% and from 11 to 70%, respectively.

Table 20. Physical and Chemical Characteristics of a Typical Soil Pedon (Outer Silty/Sandy Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-5	7.53	338	208	19.5	64	31	5	SL
Bkzg1	5-15	7.74	94	133	32.8	89	6	5	S
Bkzg2	15-30	8.04	99	134	29.4	30	30	40	CL-C

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; SL = Sandy loam; S = Sandy; CL = Clayey loam; C = Clayey.

The outer zone was heterogeneous with a loose sand texture at the surface (Akzg), and was not covered by the daily high tide. Hence, this zone should not be used for establishing mangrove plantation. Additionally, the sandy texture might also pose problems in root development.

Comparison of the soil characteristics of three zones at the Doha site suggested relatively low salinity and SAR levels in the inner zone (near the seawater) compared to the other two zones, but the inner zone had slightly higher pHs than the outer zone. The inner zone also presented a relatively finer soil texture than the other two zones. A similar situation was observed in the Bubiyan site also. The outer zone had a maximum clay content (40%) only at 15 to 30 cm depths (fine-textured soil), but this zone was not covered by the daily high tides. Therefore, the inner zone was found more suitable for establishing mangrove plantation at the Doha site.

Subiya Site near the Bubiyan Bridge. As mentioned earlier, this site is situated on the right side of the bridge leading to Bubiyan Island. The salient features of the site were an inner silty/clayey mudflat (covered daily by high tides), a middle saline sandy flat area characterized by the absence of vegetation and hyper-saline conditions (not covered uniformly by high tides daily) and a sandy saline flat area with some *Zygophyllum* vegetation (not covered daily by high tides). A total of eight pedons was investigated: three in the inner zone, two in the middle zone and three in the outer zone. Significant crab activities were evident in the in the inner zone, as indicated by numerous sandy mounds in the mudflat rising to a few centimeters above the ground. The site also appeared productive. The description of the representative pedon of the inner zone is as follows:

- Taxonomic name: Typic aquisalid,
- Diagnostic horizon: Salic,
- Type of observation: Soil pit,
- Surface condition: Muddy,
- Slope: < 1%,
- Slope class: Nearly level,
- Slope morphological type: Simple,
- Moisture status: Wet,
- Land use: None,
- Vegetation: None,
- Parent material: Alluvium, and
- Water table: Fluctuate with seawater level.

A pit was dug to a 30 cm depth. As the water table appeared at 30 cm, it was not possible to visually study in the field the horizons below 30 cm depths, and soil samples were collected manually.

The Akzg from 0 to 10 cm was light grey (5Y 7/1) when dry, olive grey (5Y 5/2) when moist, sandy loam, with a massive structure and low excavation difficulty when wet, but very high excavation difficulty when dry. It was violently effervescent with a rigid dry consistency. It was very sticky and had no gravel.

The Bkzg from 10 to 30 plus cm, was light grey (5Y 7/1) and dry, or olive grey (5Y 5/2) and moist, sandy loam, with a massive structure and low excavation difficulty when wet, but very high excavation difficulty when dry. It was violently effervescent with a rigid, dry consistency. It was very sticky and had no gravel. Some selected characteristics of the inner zone, where mangrove plantation was proposed are given in Table 21.

The Akzg and Bkzg had a hue of 5Y (both dry and moist), values of 7 (dry) and 5 (moist), and chromas of 1 (dry) and 2 (moist). The effervescence was strong to violent. The texture was sandy loam (both Akzg and Bkzg). The EC ranged from 39 to 51 dS/m (Akzg) and from 28 to 39 dS/m (Bkzg). The SAR ranged from 174 to 186 $(mmol/l)^{1/2}$ (Akzg) and from 170 to 174 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ ranged from 13.2 to 22.1%

eq (Akzg) and from 10.6 to 19.8% eq (Bkzg). The pHs ranged from 7.84 to 8.9 (Akzg) and from 7.92 to 8.08 (Bkzg). The texture of both the Akzg and the Bkzg was sandy loam in all three of the pedons investigated. The mud (silt + clay) content ranged between 27 and 44% in the Akzg and between 21 and 31% in the Bkzg.

Table 21. Physical and Chemical Characteristics of a Typical Soil Pedon (Inner Clayey/Silt Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-10	8.01	51	186	15.3	72	16	12	SL
Bkzg	10-30+	8.08	28	170	19.8	69	18	13	SL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; SL = Silty loam.

Some selected characteristics of the middle zone, where mangrove plantation may have potential are given in Table 22.

Table 22. Physical and Chemical Characteristics of a Typical Soil Pedon (Middle Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-10	8.31	92	589	12.7	95	4	1	S
Bkzg	10-30+	8.15	93	361	16.7	78	13	9	SL

EC = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; SL = Silty loam.

The Akzg had hues of 2.5Y or 5Y (both dry and moist), values of 6 or 7 (dry) and 4 or 5 (moist), and chromas of 2 (dry) and 2 or 3 (moist). The effervescence was strong to violent. The Bkzg had a hue of 2.5Y (both dry and moist), values of 7 (dry) and 5 (moist), and chromas of 2 (dry) and 3 (moist). The textures were sand to sandy loam (Akzg) and sandy loam (Bkzg). The ECe ranged from 92 to 104 dS/m (Akzg) and from 42 to 93 dS/m (Bkzg). The SAR ranged from 408 to 589 $(mmol/l)^{1/2}$ (Akzg) and from 152 to 361 $(mmol/l)^{1/2}$ (Bkzg). The $CaCO_3$ ranged from 7.6 to 12.7% eq (Akzg) and from 16.7 to 19.2% eq (Bkzg). The pH ranged from 8.18 to 8.31 (Akzg) and from 8.15 to 8.16 (Bkzg). The texture ranged between sand and sandy loam in the Akzg and was sandy loam in the Bkzg. The mud (silt + clay) content ranged from 5 to 32% in the Akzg and from 22 to 31% in the Bkzg. Some selected characteristics of the outer zone, where mangrove plantation is not advocated are given in Table 23.

The Akzg had hue of 2.5 Y (dry) and 2.5Y or 5Y (moist), values of 6 or 7 (dry) and 3 or 4 (moist), and a chroma of 2 (both dry and moist). The Bkzg had hue of 2.5Y (both dry and moist), values of 6 or 7 (dry) and 4 or 5 (moist), and chromas of 2 (dry) and 2 or 3 (moist). The effervescence was strong to violent. The ECe ranged from 128 to 172 dS/m (Akzg) and from 74 to 92 dS/m (Bkzg). The SAR ranged from 114 to 430 $(mmol/l)^{1/2}$ (Akzg) and from 123 to265 $(mmoles/l)^{1/2}$ (Bkzg). The pH ranged from 7.58 to 8.25 (Akzg) and from 7.89 to 8.48 (Bkzg). The texture ranged from sand to sandy loam in the Akzg and was sandy in the Bkzg; however, the Bkzg in one pedon was sandy loam. The mud content at 2 to 15 cm depths was 4%; however, at 15 cm and below, it ranged from 4% (in one pedon) to 23%.

Table 23. Physical and Chemical Characteristics of a Typical Soil Pedon (Outer Silty/Sandy Zone)

Horizon	Depth (cm)	pHs	ECe dS/m	SAR $(mmoles/l)^{1/2}$	$CaCO_3$ % eq	Sand	Silt	clay	Textural Class
						%			
Akzg	0-5	8.25	172	114	16.8	90	6	4	S
Bkzg1	5-20	8.48	92	129	9.4	96	2	2	S
Bkzg2	20+	7.89	82	183	18.9	77	13	10	SL

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; SAR = Sodium adsorption ratio; SL = Silty loam.

Comparison of the soil characteristics of three zones at Bubiyan Island clearly showed that the inner zone (near the seawater) had a low ECe and pH compared to those in the other zones; however, it had a slightly higher SAR than the middle zone. The outer zone presented the highest SAR values. Limited data are currently available on the tolerance of various mangrove species to high salinities under different climatic conditions (Hutchings and Saenger, 1987); however, it has been found that their response to salinity is more variable in the field than in culture experiments. Certain mangrove species have been found to grow satisfactorily at soil salinities considerably higher than those suggested by laboratory experiments.

The inner zone was also comprised of finer textured soil than the other two zones. Therefore, the inner zone seemed suitable for introducing mangrove plants at this location. The water table as a factor of daily tidal coverage was also shallower in the inner zone than in the outer zones. As a result, the soil in the inner zone remained wet all the time. The influences of water table are, however, less important in determining the plant distribution and performance of mangroves than such factors as the frequency of inundation and exposure, the mechanical action of tidal water, and soil salinity (Clarke and Hanon, 1969). This zone offered poor accessibility compared to the other two zones. In contrast, the middle zone had satisfactory soil texture and was free from surface deposition of salt crystals. The soil retained adequate moisture to support plant growth as well as to regulate salinity levels in the soil. Therefore, it was decided to establish mangrove plantation in this middle zone.

On-site observations

Soil Color. Soil color is a reliable indicator of regular high-tide flushing in the silty/clayey muddy area. The grayish color indicates reduced conditions in the soil. The soils in the silty mudflat had a matrix hue of 2.5 or 5 Y, which indicated strong anaerobic conditions: no significant change occurred in soil hue between the surface and the lower depths. Mottling was not observed in any of the pits, possibly due to insignificant oxidation conditions, as the sites are regularly covered during the high tides.

The apparent texture of the sites varied from loose sandy beach along the shoreline to clayey intertidal mudflat towards the sea. Field investigation of the texture was sufficient to identify areas with high silt/clay contents. The pits were described when they were wet (with varying water tables relative to seawater level); therefore, the consistency was smooth; however, soils samples became very hard, only crushable with a hammer or strong force, when they were air-dried. This indicates the presence of significant quantities of silt and clay in the intertidal mudflats. It was concluded from the texture determination that the regular tidal flow of water mixed the soil profiles to some extent at shallower depths. Upstream, it had less effect.

$CaCO_3$ Levels. A large proportion of calcium carbonates increases soil pH and reduces the availability of certain plant nutrients like phosphorus and molybdenum because of the high levels of calcium and magnesium associated with the carbonates. Iron, boron, zinc and manganese deficiencies are also common in soils high in calcium carbonates. Calcium carbonate is also one of the soil components. It increases the soil buffering capacity and ammonium volatilization. Calcium accentuates PO_4 precipitation in soil, thus increasing phosphorus unavailability to plants.

The field effervescence test at the site confirmed the presence of $CaCO_3$ to varying degrees (slight to violent effervescence); its actual quantity was measured by calcimeter. This confirmed that the alluvium brought to the coastline, in general, contains calcium carbonates, which could influence the availability of plant nutrients.

Salinity. The Soil Survey Staff of the USDA regularly changes the definitions and criteria for soil classification . In *Keys to Soil Taxonomy* (Soil Survey Staff , Soil Conservation Service, 1998), the definition of a Salic horizon was as below.

A salic (L. *sal*, salt) horizon is a horizon of accumulation of salts, which are more soluble in cold water than gypsum. A salic horizon is 15 cm or more thick and has, for 90 consecutive days or more in a year, in 6 or more years out of 10, an electrical conductivity (EC) equal to or greater than 30 dS/m in a 1:1 soil water extract and the product of the EC in dS/m and thickness in cm equals 900 or more.

The above definition of salic horizon was changed by the Soil Survey Staff, Soil Conservation Service in 1998. The new definition includes an EC of equal to or greater than 30 dS/m measured on a saturated paste, and a product of the EC and thickness (in centimeter) equal to 900 or more.

The complete definition is mentioned here as it is important for classifying the soils in the selected sites. EC values measured on saturated soil pastes were used (instead of 1:1 soil-water ratios) to classify the soil types (Soil Survey Staff, Soil Conservation Service, 1998). According to the criteria described above, all the silty/muddy sites had salic horizons, and, therefore, belong to the salid (suborder). The salids that are saturated with water in one or more layers within 100 cm of the mineral soil surface for one month or more in normal years are known as aquisalids (Soil Survey Staff, Soil Conservation Service, 1998). As these aquisalids do not show significant quantities of gypsum or $CaCO_3$ segregations to qualify the horizons as gypsic or calcic, they are classed as typic aquisalids (subgroup). The soil taxonomy of the selected site is as follows:

- Order: Aridisols,
- Suborder: Salids,
- Great Group: Aquisalids,
- Subgroup: Typic aquisalids,
- Family Texture: Fine silty,
- Temperature Regime: Hyperthermic,
- Family mineralogy: Mixed,
- Taxonomic Name: Fine silty, mixed, hyperthermic.

Soil Characteristics in Plots under Vegetation. Boreholes were made in plot 1 (29^0-35^0-05^0 north and 47^0-47^0-20^0 east), where a vegetation assessment was made. The auguring showed that the soil is typic haplocalcid. Gatch in two boreholes occurred at

140 and 175 cm depths. The soil above the gatch had good characteristics. Plot 2 (290-35^0-05 north and 47^0-47^0-16^0 east) had a similar type of soil, but a gatch layer was observed at 125 cm depth. The soils in both plots contained up to about 10% coarse factions comprised of quartz gravel and $CaCO_3$ concretions. The ECe at the surface (0 to 10 cm) was 0.8 dS/m, increased to 1.6 dS/m at 10 to30 cm and recorded a maximum of 5.3 dS/m at 30 cm depths. The pHs ranged between 7.53 and 7.64 (slightly alkaline). The available water content at the surface (0 to10 cm) was around 6%, increasing to 8% at 10 to125 cm depths. The $CaCO_3$ levels ranged between 12.7 and 14.1%, with the minimum being at the surface and the maximum at 30 to125 cm depths.

Borehole observations in Plots 3 (29^0-35^0-05^0 north and 47^0-47^0-100 east) and 4 (29^0-34^0-95^0 north and 47^0-47^0-20 east) showed the soil types to be calcic petrocalcid and petrocalcic petrogypsid, respectively. Plots 3 and 4 were located at relatively higher elevations than Plots 1 and 2. The soils were shallow, and gatch occurred between 20 and 80 cm below the soil surface.

Summary

The available literature on site selection for mangrove plantation was reviewed, and a set of criteria was developed for selecting potential sites. Specific site characteristics (accessibility, human impact, dimension of the mudflats, topography, presence of contaminants, rubble and construction material, likely environmental impact, and tidal coverage) were considered while developing the criteria. A total of 14 sites were assessed against the criteria, and the five sites that best fulfilled these criteria were selected for field description and characterization. Based on the field survey, the sites were divided into different transacts for pedon description and sample collection. The samples collected from the soil pit profiles were processed by air-drying and sieving to separate different fractions based on particle size. The < 2 mm soil fractions were analyzed at the Soil Laboratory of KISR’s Aridland Agriculture and Greenery Department, for a range of physical and chemical characteristics using the USDA’s (1988) and Page et al.’s, (1982) procedures. The Eh, pH, EC, $CaCO_3$, and SAR were estimated in the laboratory to assist in describing the soils for their suitability, limitations and classification. The Taxonomy System (Soil Survey Staff, Soil Conservation Service, 1998) was used to classify each profile. The system is based mainly on various soil properties and the arrangement of horizons within the profile.

Task 3. Transplantation into Permanent Site

Introduction

Considering the fact that mangroves previously existed in Kuwait and the prevailing climatic and soil conditions in the northern part of Kuwait are comparable with those in the mangrove growing areas in Bahrain and Dhahran, it seemed possible to grow mangroves here (Subandar et al., 2001). For example, the mean annual temperature in Kuwait City is 24.4°C, and the mean annual precipitation is 110 mm. In Bahrain, the mean annual temperature is slightly higher (25.8°C), and the mean annual precipitation is lower (94 mm); whereas the mean annual temperature in Dhahran is even higher (26.9°C), and less mean annual precipitation is lower (56 mm). Furthermore, the possibility of mangrove reestablishment in the northern part of Kuwait appeared even more promising when the ombrothermic data for Kuwait City were compared with those of other areas in the region (Fig. 2). Previous KISR research efforts also indicated good potential for growing *Avicennia marina* successfully in Kuwait (Abu El-Nil, 1994; Abu El-Nil et al., 2001). Also, considering the importance of its coastal zone for Kuwait, particularly the intertidal mudflats, there is a need to improve the quality of this habitat. This might also trigger an improvement in environmental quality, which is important for the existing organisms to survive and grow, and eventually would lead to better productivity. In view of these points, a need was felt to establish experimental mangrove plantations in selected locations along the coastline. For this purpose, five sites, identified as suitable through the field survey and laboratory analysis in Task 2, were utilized. The primary goals of the establishment of experimental mangrove plantations at these sites were the following:

- To evaluate various mangrove planting strategies in Kuwait,
- To document the advantages of establishing mangrove plantations along the coastline (Task 5); and
- To identify problems that might be encountered in the establishment of mangrove plantations in the five selected sites along Kuwait's northern coastline and suggest appropriate solutions to overcome these problems.

Materials and Methods

Mangrove species

Avicennia marina. Hardened one-year-old seedlings with heights ranging from 25 to 50 cm were used for planting (Plate 47). A few seedlings (around 10%) had one branch. The seedlings were raised from propagules received from Pakistan and the UAE.

Plate 47. Acclimatized *Avicennia marina* seedlings used for establishing the experimental plantations.

<u>*Ceriops tagal*</u>. Although *Ceriops tagal* was not included in the original proposal, it was considered necessary to establish mixed mangrove plantations of *Avicennia marina* and one two other species. Since *Ceriops tagal* is being grown in other Arabian Gulf countries, it was included in this study. Eighteen-month-old hardened seedlings with five to six well-developed leaves were used for field planting (Plate 48).

Plate 48. Acclimatized *Ceriops tagal* seedlings used for establishing the experimental plantations.

Locations. A field survey was carried out of the coastline of Kuwait, and 14 sites were provisionally selected. These 14 sites were assessed based on the selection criteria developed by the project team (Taha et al., 2000) and, finally, five sites (Shuwaikh, Sulaibikhat (Site 1), Sulaibikhat (Site 2), Doha and Subiya) that best fulfilled the selection criteria had the greatest potential for mangrove establishment, were selected. Soil samples were collected from these five sites and characterized in the laboratory for important physical and chemical parameters (Taha et al., 1999, 2000; Bhat et al., 2000, 2001).

Planting. Seedlings were planted in three to four rows (outer sandy, middle silty loam and inner clayey muddy zones). The layout of the field planting is shown in Plates 49 and 50).

Plate 49. A general view of planting of mono-species plantation of *Avicennia marina*.

Plate 50. A general view of the field planting of a mixed plantation of *Avicennia marina* and *Ceriops tagal*.

Thirty centimeter planting holes were prepared at a spacing of 1X1 m. Seedlings were carefully handled to prevent any damage to the root system. The taproot with its root ball intact was carefully inserted into the planting holes and backfilled with native soil (Plates 51 and 52). A view of the site after planting is shown in Plate 53.

The Shuwaikh site was planted with 1300 *Avicennia* seedlings in May 1999. Additional seedlings were planted at this site in October 2000. The other sites were planted in October 2000, and dead seedlings were replaced February 2001.

Data Recording. Seedling heights were recorded at the time of planting. Plant establishment was monitored by frequent visits to the sites. Seedling height was recorded at three month intervals until December 2001, to ascertain the growth performance of the two mangrove species at these sites. Side-by-side on-site assessment was carried out by a team of horticulturists and soil scientists to determine potential problems for seedling establishment and growth at each of the sites. Soil samples were collected from various locations within each site during the post-planting period to identify factors contributing to the successful establishment of seedlings at each of the sites.

Plate 51. Field-established *Avicennia marina* seedlings.

Plate 52. Field-established *Ceriops tagal* seedlings.

Plate 53. A general view of the site after planting of *Avicennia marina.*

Results

Initial Seedling Establishment. Initial establishment of seedlings in terms of survival was recorded one and three months after planting. The survival percentages were recorded for each row separately to determine the most ideal locations in the intertidal mudflats in Kuwait's coastal setting.

Shuwaikh (KISR) Site. The data presented in Table 24 indicate that location influenced the survivability of plants, with a higher number of surviving plants in the first row (one meter from the shore) than in the other rows.

Table 24. Initial Seedling Survival and Height in the Shuwaikh (KISR) Site (May 2000 Planting)

Row	Distance from Shoreline (m)	Subsite	Survival (%)	Height (cm)
		A	75.0	61.0
First 1	3-5	B	37.5	56.0
		C	70.0	23.7
Second Row 3	5-7	A	18.2	54.0
		B	38.5	54.0
		C	27.2	30.0
Beyond third Row	7 m+	A	0.0	0.0
		B	0.0	0.0
		C	10.0	18.0

Seedling survivability was the highest (37.5 to 75%) in the first row and lower in both the second (11 to 38.5%) and the third (0 to 10%) rows. No seedlings survived beyond the fourth row (7 m from the shore).

Ninety days after planting, seedlings in the first row had attained an average height of between 23.7 and 61 cm, while those in the second row had attained an average height of 30 to 54 cm, and those in the third row had attained an average height of 18 cm. The main stem died in some of the plants that were planted farther away from the shore. However, auxiliary buds started growing after some time.

Additional seedlings were planted in Subsites A and C in October 2000 The seedling establishment was monitored in terms of periodic seedling survival and increase in height, and the data are presented in Table 24. In the initial 30 days period, almost all seedlings survived, but the seedling mortality increased progressively with the onset of winter. *Ceriops tagal* seedlings appeared to be more susceptible to low temperatures, as the majority of these seedlings died at both locations. In contrast, more than 75% of the newly planted *Avicennia marina* seedlings were surviving after three months. However, a number of established seedlings in Subsite C died due to a deposition of seaweed during March 2001. The seedlings planted during May 2000, produced multiple branches and a few pneumatophores (Plate 54) by November 2000.

Plate 54. Production of branches and pneumatophores in *Avicennia marina* seedlings planted in May 2000.

The placement of the seedlings within the site influenced the survivability of seedlings. The seedlings planted in the middle zone along the tidal line established better than those planted either in the sandy beach or in the clayey muddy zone below the tidal line. The physical characteristics of the soil in the vicinity of the seedlings appeared to exert a considerable influence on the establishment of seedlings in the field. Seedlings in coarse-textured sand-loam tended to establish better than those planted in clayey or coarse sandy substrate.

In three months, seedlings attained an average height of 39.2 cm (Table 25). The main threats to seedling establishment at this site included exposure of seedlings to stranded oil pollution (Plate 55), deposition of seaweeds left behind by receding tidal water (Plate 56), strong wind and tidal movement, and a storm water outlet in the southern portion, which discharges liquid pollutants onto the intertidal mudflats.

Sulaibikhat Site 1. This site is located in the southern corner of the children's entertainment park on Sulaibikhat Bay. A general view of the site is shown in Plate 37. Approximately 1.5 to 2 ha was used for establishing a mixed plantation of *Avicennia marina* and *Ceriops tagal*.

Seedling establishment of both species was high in all three portions of the site. The survival rate was 100% in both species in the initial two months; however, a few seedlings died during December and January, apparently due to low temperatures. Mortality was much lower in subsites A and C than in Subsite B (Table 26). Hence, periodic observations on height were recorded and pooled to calculate averages.

Table 25. Seedling Survival and Height in *Avicennia marina* and *Ceriops tagal* at the Shuwaikh (KISR) Site

Subsite	Distance (m)	Survival (%) after		Height (cm)	Species
		30 days	90 days	90 days	
A	0-3	90	0	---	*Ceriops tagal*
	3-5	100	28	20.5	*Ceriops tagal*
	5-7	90	62	39.2	*Avicennia marina*
	10	59	35	---	*Avicennia marina*
C	0-3	90	0	---	*Ceriops tagal*
	3-5	91	73	38.2	*Ceriops tagal*
	5-7	90	76	39.9	*Avicennia marina*
	7-10	57	71	33.6	*Avicennia marina*

KISR= Kuwait Institute for Scientific Research, 0-3 m = Upper sandy zone; 3-5 m = Middle silty loam zone; 5-7 m = muddy zone; 10 m = Clayey muddy zone.

Plate 55. Stranded oil pollution in the intertidal mudflat poses a threat to mangrove establishment and growth.

Plate 56. Seaweeds and waste materials left behind by receding tidal water pose a threat to young mangrove seedlings.

Seedling survivability varied with location. A higher number of seedlings survived in Subsites A and B than in Subsite C. Within the subsites, seedlings planted either along the tidal line or 1 m below the tidal line showed higher survival rates than those planted above the tidal line.

Table 26. Seedling Survival and Height in *Avicennia marina* and *Ceriops tagal* at the Sulaibikhat Site 1

Subsite	Distance from Shoreline(m)	Soil Type	Survival (%) after		Height (cm) After 90 days	Species
			30 days	90 days		
A	0-2	Sandy	100.0	100.0	17.1	*Ceriops tagal*
	2-3	Silty loam	100.0	90.0	26.1	*Ceriops tagal*
	3-4	Muddy	90.0	85.7	22.6	*Avicennia marina*
	4-5	Muddy	100.0	100.0	25.1	*Avicennia marina*
	Average		97.5	93.9	22.7	
B	0-2	Sandy	100.0	83.3	20.5	*Ceriops tagal*
	2-3	Silty loam	95.0	71.1	20.1	*Avicennia marina*
	3-4	Muddy	100.0	95.1	18.8	*Avicennia marina*
	4-5	Muddy	100.0	87.7	21.6	*Avicennia marina*
	5-6	Muddy	100.0	88.8	20.5	*Avicennia marina*
	Average		99.0	85.1	20.3	
C	0–2	Sandy	86.0	79.0	25.3	*Avicennia marina*
	2-3	Silty loam	86.4	80.4	27.3	*Avicennia marina*
	3-4	Muddy	88.0	77.2	29.1	*Avicennia marina*
	Average		86.8	78.9	27.2	

Avicennia marina seedlings attained average heights of 23.3, 20.3 and 27.2 cm in Subsites A, B and C, respectively. *Ceriops tagal* seedlings had an average height of 21.6 cm (Table 26). Seedlings at this site were vulnerable to uprooting by receding tidal water, the presence of stranded oil pollution and dumping of waste materials.

Sulaibikhat Site 2. This site is situated on Sulaibikhat Bay. It has a narrow sandy beach with physical and topographic features similar to those of Sulaibikhat Site 1. The site contains low levels of oil contamination and an easily accessible mudflat. The site was divided into three subsites (A, B, and C) along its length to identify the most suitable area for mangrove plantation within this site.

Although both sites in Sulaibikhat appeared to have similar physical and chemical characteristics, seedling establishment at this site was poor compared with that at the first site. The survival rate ranged from 45 to 80% in the initial two months (Table 27). However, a number of seedlings did not make it through the winter months.

Seedling survivability varied with location. A higher number of seedlings survived at Subsites A and C than at Subsite B. Within the subsites, seedlings planted either along the tidal line (in silty loam) or 2 m below the tidal line (in silty mud) showed higher survival rates than those planted above the tidal line.

Seedlings attained average heights of 30.5, 24.7, and 25.8 cm at Subsites A, B and C, respectively. Soil samples from different locations within the site were collected to ascertain the causes for poor seedling establishment.

Table 27. Seedling Survival and Height in *Avicennia marina* at Sulaibikhat Site 2

Subsite	Distance from Shoreline (m)	Soil Type	Survival (%) after		Height (cm) after 90 days
			30 days	90 days	
A	0-2	Sandy	60.0	30.0	26.9
	2-3	Silty loam	80.4	58.5	31.9
	3-4	Muddy	35.6	28.5	31.7
	Average		58.7	39.0	30.2
B	0-2	Sandy	20.0	0.7	23.0
	2-3	Silty loam	50.0	25.7	24.3
	3-4	Muddy	45.6	8.8	25.3
	Average		38.5	11.7	24.2
C	0–2	Sandy	76.0	73.3	25.3
	2-3	Silty loam	80.4	72.7	27.3
	3-4	Muddy	36.8	30.0	24.3
	4-5	Muddy	64.6	55.5	24.8
	Average		64.5	57.9	25.4

Doha Site. The site is located behind Entertainment City. After a visual on-site assessment to ensure daily tidal coverage, seedlings of *Avicennia marina* and C*eriops taga*l were planted in the selected area during October 2000. Although only good quality seedlings were used for planting, a majority of them died within the first two weeks, probably due to extremely high salt levels in the soil and inadequate daily coverage by seawater during high tide. Hence, this site was abandoned, and a new site was selected on the south of this site for planting during November 2000. Both *Avicennia marina* and *Ceriops tagal* were planted at this new site.

The *Avicennia marina* seedlings from the November planting established very well. The survival rate at this site was 93 to 96% during the first three months (Plate 57). However, all *Ceriops tagal* seedlings died within four weeks of planting (Table 28). *Avicennia* seedlings attained an average height of 18.6 cm during the first three months. The possible causes for the high mortality at the first site were investigated through on-site investigation by the project staff, and the findings are discussed under the post-planting assessment.

Subiya site near Bubiyan Bridge. The site is situated on the right side of the bridge leading to Bubiyan Island. This site was subdivided into two units: a broad inner silty loam mudflat area approximately 5 to10 m from shoreline (A) and an outer (up to 5 m from the shoreline) sandy loam/silty area (B). While Subsite B was planted with one row of *Ceriops tagal* and two rows of *Avicennia marina,* Subsite A was planted with eight rows of *Avicennia marina*. In addition, a few plants of each species were planted beyond Subsite A to ascertain if planting can be extended further deep into the sea.

Plate 57. Improved establishment of *Avicennia marina* seedlings at the second site in Doha.

Table 28. Seedling Survival and Height in *Avicennia marina* and *Ceriops tagal* at Doha Site

Species	Distance from Shoreline (m)	Survival (%) after		Height (cm) after 90 days	Remarks
		30 days	90 days		
A. marina	5	100	95.8	18.6	Site was uniform
	5-6	100	93.4	18.5	in topography
Ceriops tagal	5	---	---	---	Plants died within
	5-6	---	---	---	1 mo.

Subsite A produced the maximum number of surviving seedlings compared with Subsite B (Table 29). Planting beyond 15 m from the shoreline affected seedling establishment. Seedlings attained average heights of 22.6 to 24.2 cm in the first three months. Important threats to seedling establishment at Subsite B included: insufficient tidal coverage, absence of a silt or loam soil fraction and, possibly, high soil salinity.

Table 29. Seedling Survival and Height in *Avicennia marina* and *Ceriops tagal* at the Subiya Site

Subsite/Species	Distance from Shoreline (m)	Survival (%) after		Height (cm) after 90 days
		30 days	90 days	
Subsite A				
A. marina	0-5 5-10	25 86	10 75	22.6 24.6
Ceriops tagal	0-5	---	---	---
Subsite B				
A. marina	0-5 5-10	75 37	0 25	24.2 22.6
Ceriops tagal	0-5	---	---	---

Detailed on-site investigations were undertaken to determine the exact cause of the poor seedling establishment at Subsite B.

Final Establishment and Growth of Seedlings

Shuwaikh (KISR) Site. The seedlings that survived at the end of the first three months established very well and showed satisfactory growth during spring and summer 2001. In *Avicennia marina*, 78.6% of the seedlings planted in the middle silty loam zone (5 to 7 m from the shoreline) finally survived (Table 30). In contrast, only 40% of the seedlings planted in the inner muddy zone (7 to 10 m away from the shoreline) survived, whereas those planted farther into the muddy zone (beyond 10 m from the shoreline) appeared to be highly vulnerable to adverse site conditions, as most seedlings were unable to establish.

Table 30. Final Survival and Periodic Seedling Height in *Avicennia marina* at Shuwaikh (KISR) Site

Soil Type	Final Survival (%)	Seedling Height (cm) on Day			No. of Branches on Day		
		90	360	450	90	360	450
Silty loam (5-7m from shoreline)	78.6	39.2	41.8	57.1	1.93	4.85	14.3
Muddy (7-10m from Shoreline)	40.0	35.4	38.8	60.7	1.81	3.21	10.7

Periodic data on seedling height are presented in Table 30. Seedlings attained an average height of 57.1 to 60.7 cm and produced an average of 10.7 to 14.3 branches per plant at the end of 15 months. The height growth and production of branches were higher between May and July than between February and April. Most plants produced pneumatophores at the base. One plant at this site flowered during July 2001 (Plate 58).

Plate 58. Flowering in one-year-old *Avicennia marina* plants.

The placement of the seedlings within the site also influenced both establishment and number of branches, with seedlings planted in the silty loam areas near the shoreline establishing better and producing a higher number of branches than those planted farther away from the shoreline. The physical characteristics of the soil in the vicinity of the surviving and dead seedlings were found to be different. The soil profile near the surviving seedlings contained a muddy layer at the top and a fine-textured sandy layer below. In contrast, the soil near dead plants was silty or clayey in nature. Seedlings in very coarse textured sandy beach did not establish at all.

Sulaibikhat Site 1. Nine months after planting in the field, 86% of the seedlings that were planted in the silty loam area 2 to 3 m away from the shoreline had established very well, whereas the final survivability was 16.1% for seedlings that were planted in the clayey muddy zone 5 to 6 m away from the shoreline (Table 31). A few seedlings died during recent fish crisis in the late summer at fall of 2001 due to heavy deposition of dead fish on or near the plants. The *Ceriops tagal* seedlings that survived during the winter finally died during the summer. At the completion of 12 months from initial planting, the *Avicennia marina* seedlings had attained an average height ranging from 26.2 to 30.5 cm, depending upon the location of the seedlings (Table 31). Similarly, the plants had produced an average of 4.5 to 6.3 branches (Plate 59). Seedlings planted near the shoreline grew faster and produced a higher number of branches than those that were planted farther away from the shoreline. Seedlings were vulnerable to damage from uprooting by receding tidal water and dumping of waste materials (Plate 60).

Table 31. Final Survival and Periodic Seedling Height in *Avicennia marina* at Sulaibikhat Site 1

Distance from Shoreline (m)	Final Survival (%)	Seedling Height (cm) after				No. of Branches after			
		90 days	180 days	270 days	360 days	90 days	180 days	270 days	360 days
0-2	70.9	20.5	24.8	30.5	31.9	1.30	1.35	4.5	6.17
2-3	86.0	20.1	26.2	28.3	30.4	1.36	1.71	3.38	5.43
3-4	68.8	18.8	26.6	27.8	30.9	1.45	1.80	3.31	4.56
3-4	72.5	21.6	17.5	26.5	26.9	1.20	1.24	3.90	4.82
4-5	16.1	20.5	15.7	26.1	26.2	1.24	1.37	3.20	3.16

Sulaibikhat Site 2. Seedlings planted in the silty loam area about 2 to 3 m away from the shoreline established and performed better than those that were planted in muddy areas farther away from the shoreline. The final plant survivability at this site ranged from 65.8 to 21.4% (Table 32; Plate 61).

Seedlings attained an average height ranging from 28.2 to 38.1 cm depending on the location of the seedlings, with seedlings planted in the silty area about 2 to 4 m away from the shoreline growing faster than those planted either in sandy areas (0 to 2 m from the shoreline) or farther away in the muddy areas (4 to 5 m from the shoreline).

Plate 59. Branching in *Avicennia marina* seedlings in Sulaibikhat Site 1.

Plate 60. Washing away of sand by receding seawater results in uprooting of seedlings.

Table 32. Final Survival and Periodic Seedling Height in *Avicennia marina* at Sulaibikhat Site 2

Distance from Shoreline (m)	Final Survival (%)	Seedling Height (cm) after				No. of Branches after			
		90 days	180 days	270 days	360 days	90 days	180 days	270 days	360 days
0-2	33.3	25.1	25.6	27.9	28.2	1.30	2.61	3.10	5.13
2-3	65.8	27.3	26.7	31.3	34.2	1.36	2.13	3.92	5.30
3-4	44.4	24.3	33.9	37.8	38.1	1.45	1.92	3.47	4.30
4-5	21.4	24.8	27.5	29.5	32.0	1.05	1.33	2.49	6.00

Similarly, the number of braches produced also varied according the placement of the seedlings in the intertidal mudflats. Twelve months after planting, seedlings had produced 4.3 to 6.0 branches.

Doha Site. *Avicennia marina* seedlings from the November planting established very well. The survival rate at this site was 71-81% during the first nine months (Table 33, Plate 62). Also at this site, the seedlings planted in the silty loam area approximately 5 m away from the shoreline established better than those planted farther away from the shoreline.

Plate 61. Established *Avicennia marina* seedlings in the Sulaibikhat Site 2.

Plate 62. Established *Avicennia marina* seedlings with pneumatophores at the Doha site.

Table 33. Final Survival and Periodic Seedling Height in *Avicennia marina* at the Doha Site

Distance from Shoreline (m)	Final Survival (%)	Seedling Height (cm) on Day				No. of Branches on Day			
		90 days	180 days	270 days	360 days	90 days	180 days	270 days	360 days
5	81.2	18.6	19.2	21.7	30.7	1.93	3.00	7.20	8.18
5-6	71.0	18.5	16.8	18.3	31.3	1.81	1.90	3.62	6.17

Avicennia seedlings attained an average height of 30.7 to 31.3 cm during the first 12 months. Plants produced an average of 6.2 to 8.2 branches during this period.

<u>Subiya Site Bubiyan Bridge.</u> As indicated in earlier, the silty loam subsite (subsite A) produced a higher number of surviving seedlings than the fine sandy Subsite B. The seedlings in Subsite A that were surviving at three month stage, had established very well and grew satisfactorily (Table 34). These seedlings had attained an average height of 31.7 to 34.3 cm at the end of 9 months. The number of branches varied between 2.83 and 3.28 at that time.

Table 34. Final Survival and Periodic Seedling Height in *Avicennia marina* at the Subiya Site, Subsite A

Distance from Shoreline (m)	Final Survival (%)	Seedling Height (cm) after			No. of Branches after		
		90 days	180 days	270 days	90 days	180 days	270 days
0-3	63.75	22.6	27.4	31.9	1.00	1.80	2.83
3-5	50.00	24.6	29.7	34.3	1.56	1.70	2.98
7-10	40.00	22.6	25.4	31.7	1.35	1.60	3.28

Discussion

As mangroves grow in a dynamic environment of coastal zones, they are consequently influenced by environmental conditions. Chapman (1976) (in Hutchings and Saenger -1987) identified seven factors, i.e., temperature, mud substrate, protection, mangrove growth and distribution. Once mangroves are present in a region, the abundance and structure of the mangrove community will be affected by local environmental factors, such as temperature, insulation, wind and evaporation, drainage and aeration, salinity (of both the water and the interstitial soil water), nature of the soil and proximity of the freshwater source (Hutchings and Saenger, 1987; Clough et al., 1982; Ogino, 1993; Saenger, 1996).

Temperature is an important factor as it affects physiological processes, such as photosynthesis and respiration. Mangroves are long-day plants and require full, high-intensity sunlight. The range of optimal light intensity for mangrove growth is 3,000 to 3,800 kcal/m^2/d. Wind has, either directly or indirectly, a number of effects on the mangrove ecosystem. It may affect the evapotranspiration of plants. Wind can also increase the salinity of the surrounding water, and influence waves and currents in coastal waters, which, in turn, can affect newly planted mangrove seedlings. Soil aeration plays an important role in providing oxygen for mangrove respiration. In this regard, sandy and clayey soils can usually be considered as the most suitable substrates for mangroves. The salinity of the water and interstitial soil water affect the growth, survival, and zonation of mangroves. The nature of the soil controls the mangrove ecosystem providing substrates for root attachment as well as being a nutrient source. Mangrove trees can be found in a wide variety of substrates; however, mangroves appear to be best developed on mud and fine-grained sand.

Clough et al., (1982) stated that anaerobic conditions could influence plant growth in the following four ways:

- The absence of oxygen in the soil means that below ground, roots must rely on internal gas transport to satisfy their oxygen requirement.

- Low oxidation-reduction potentials favor chemical transformations of a number of essential elements.
- Extreme degrees of anaerobiosis can lead to the formation of H^2S and other compounds that may be toxic to plants.
- Most mangroves grow best in moderately saline solutions; the optimum salinity for *Avicennia marina* is between 10 and 25% of the salinity of seawater (Hawang, 1995).

A number of researchers (e.g., Hayes and Gundlach, 1979; Snedakar et al., 2001) consider mangroves to be the most sensitive of all coastal ecosystem types to oil spills. In this regard, Odum (1985) speculated that mangroves would take many decades to recover from oil spills. The effects of the physical stranding of oil in intertidal mangrove habitats is largely dependent on the oil type, the elapsed time between a spill and its stranding, wind and current conditions, and tidal stage. With regard to oil type, the more highly refined products tend to be relatively more toxic, but because they are also relatively volatile, they are quickly dissipated. The volatile fractions (e.g., naphtha and benzene) are also lost from the heavier oils that remain at sea for extended periods of time prior to stranding. In this regard, the stranding of relatively weathered oils that are depleting in the lighter fractions has a lesser potential to produce acute toxic effects than fresh oil and highly refined products. Whether or not refugee oil eventually becomes stranded along a shoreline is highly dependent on the ambient wind and current conditions. For example, longshore winds and currents tend to move oil parallel to the shoreline, painting long stretches of the seafront, whereas strong onshore winds tend to push oil onto a smaller length of shoreline, but further inland. Similar to wind-driven oil, oil arriving at the shoreline on incoming tides has the potential to reach deep into intertidal and supratidal habitats. However, it also has a greater potential for washout (Levings et al., 1994) on the retreating tide except when trapped in paludal depressions inland from the shoreline fringe. Such stranded oil pollution increases mortality in young mangrove seedlings.

Nutrient availability is another factor influencing the growth rate of plants. Generally, existing mangrove plantations have adequate supply of organic matter and nutrients from litter and organic wastes. Under such situations, a regular fertilizer application program is not necessary. However, since the sites selected for mangrove planting were new, nutrient availability could have been too low to support the required plant growth. In some pockets, debris or seaweed deposited on plants could also have contributed to poor establishment of new plants in the field.

To find answers to some of the problems mentioned here, a detailed site assessment was undertaken. The main objective of the assessment was to find the reasons for plant mortality, and to relate them to site characteristics of plant growth.

Comparison of Plant Performance with Site and Soil Characteristics

Introduction

Site selection and evaluation task is the beginning task in many projects. This facilitates the successful implementation of an action plan as well as improving the success rate of any operation, such as the establishment mangrove plantation in new sites. In view of this, the site selection and evaluation task was completed during the first year of the project. Initially, a field survey of the coastlines of Kuwait was carried out, from which 14 sites were provisionally selected. These 14 sites were assessed on selection criteria developed by the project team (Shahid et al., 2000; Taha et al., 1999), and finally five sites that best-fulfilled the selection criteria and had potential for mangrove establishment were selected. Soil samples were collected from these five sites, and characterized in the laboratory for important physical and chemical parameters (Taha et al., 1999; 2000). The results are presented under Task 2.

Based on the findings of the site selection and evaluation task, experimental mangrove plantations using acclimatized *Avicennia marina* and *Ceriops tagal* seedlings were established on the five selected sites. The plant performance in terms of periodic survival and vegetative growth of plants was compared with site characteristics, and the physical and chemical properties of the areas where the plants established and performed very well, and in areas where significant numbers of seedlings died after initial establishment.

Post-Planting Site Assessment

Post-planting site assessment during the establishment and growing stages of mangroves is necessary for a valid explanation of the observed success or failure of newly planted seedlings. A site characterization strategy should identify the core issues specific to the site under investigation. This clarifies what is important in order to achieve the set objectives. Formulating a hypothesis is a way of forecasting all possible impacts, including unintended and detrimental ones. If this is followed, a variety of scenarios can be developed. The scenarios can be set for a direct hypothesis that may be tested scientifically if a multidisciplinary team is involved and reviews the application or the methods as a means of designing a method tailored to a given situation. The team must develop a hypothesis and suitable methods for assessing the hypothesis, should be sought and applied in the study.

Hypothesis. The project team undertook a number of visits to the planting sites and developed the following hypothesis and follow-up question:

The sites where plants are dying or wilting are significantly different in character from the sites where plants are surviving.

Testing of Hypothesis. The hypothesis was tested in two phases: on-site assessment and detailed physical and chemical characterization. A team comprised of soil scientists and a horticulturist completed the on-site investigation as follows:

- Visual evaluation of the five sites to develop strategies for further investigation.
- Demarcation of each site into different zones for surface and subsurface investigation.
- Excavation of subsites to study the physical setup of the coastal material at the surface and subsurface.
- Collection of soil samples for laboratory investigation (physical and chemical aspects).

The post-planting characteristics of the five sites are given below.

Shuwaikh Site. The Shuwaikh (KISR) Site was divided into three subsites and that were assessed individually.

Subsite A. Subsite A was further subdivided into three zones: an upper sloping sandy zone; a middle zone that had a muddy surface underlain by gravel, and an internal muddy flat without subsurface gravel. Soil samples were collected from the three zones for their characterization. A schematic diagram of Subsite A, showing the upper sandy sloping, middle gravelly muddy and lower muddy site, is presented in Fig. 4.

Zone 1: Upper Sloping Sandy Zone. Three pits were made to characterize the upper sloping sandy site, divided into three parts, and soil samples were collected (Plate 63). Tables 35 and 36 present the physical and chemical characteristics of the three parts, respectively.

It is apparent from Table 35 that the upper sandy zone is almost devoid of gravel, whereas in the middle gravelly sandy zone, the coarse gravels are dominantly in the fine size range. In the lower part of Zone 1, fine (2 to 5 mm), medium (5 to 15 mm) and coarse (15 to 75 mm) gravels were identified. The gravel contents increase from the upper to the lower end of Zone 1. The depth of sandy material also decreases from the upper to the lower end of the upper sloping sandy area. The particle size distribution clearly revealed the dominance of the sand fraction over the silt and clay. Sand constitutes more than 90% of the mineral matter, and sorted out into all subfractions; however, the coarse (0.5 to 1.0 mm) and very coarse (1 to 2.0 mm) subfractions are dominant (Table 35). The soil texture is sand in all zones and depths. The upper sandy zone has sandy, and the lower zones have gravelly sand textures.

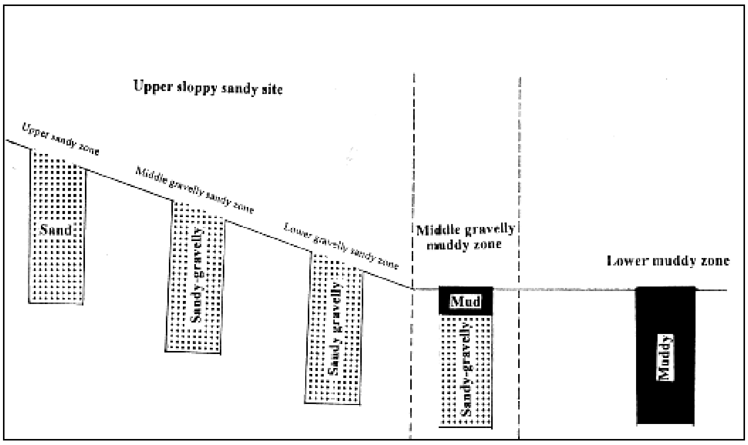


Fig. 4. Landscape features at KISR Site A, showing the upper sloppy sandy site (upper sandy zone, middle gravelly sandy and lower gravelly sandy zone), middle muddy gravelly zone and lower muddy zone. Cross sectional view of each site and nature of soil particles as a factor of depth is also shown.

Plate 63. Sample collection from the upper sandy sloping beach Zone 1 of the Shuwaikh (KISR) Site, Subsite A.

Table 36 characterizes the upper sloppy sandy site, and shows that the highest salinity and sodicity levels are located at the lower end of the site. The upper and middle zones present relatively lower salinity and sodicity levels. The lower salinity and sodicity at the upper end is due to the higher drainage capacity facilitated by the higher gradient and its farther position from the seawater level. On the other hand, the lower gravelly sandy zone presents higher salinity than the upper and middle zones.

Table 35. Particle Size Distribution of Soil Samples from the Shuwaikh (KISR) Site, Subsite A (Upper Sloping Sandy Zone 1)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Subzone 1: Upper sandy zone														
0-30	1.5	3.5	95.0	2.5	1.0	3.0	12.0	35.0	26.0	19.0	Sand	0.4	0	0
Subzone 1: Middle gravelly sandy zone														
0-30	1.0	3.0	96.0	2.9	0.1	1.0	4.0	8.5	35.5	47.0	Sand	18.0	2.0	0
Subzone 1: Lower gravelly sandy zone														
0-3	2.0	2.5	95.5	1.9	0.6	0.4	1.1	4.0	48.0	42.0	Sand	28.0	10.0	0
3-30	4.0	4.5	91.5	1.9	2.6	5.4	11.1	15.0	28.0	32.0	Sand	17.0	17.0	22.0

Table 36. Physical and Chemical Characteristics of the Upper Sloping Sandy Zone 1 of the Shuwaikh (KISR) site, Subsite A

Depth	ECe (dS/m)	pH	SAR $(mmol/l)^{0.5}$	$CaCO_3$ (% eq)	Eh (mV)	DO_2 (mg/l)	SP	Color (Dry)
Subzone 1: Upper sandy zone								
0-30	26	7.9	73	10.7	6	5.1	23	10YR 8/2
Subzone 1: Middle gravelly sandy zone								
0-30	16	7.9	53	7.9	-24	5.0	21	Grey 1 5/10GY
Subzone 1: Lower gravelly sandy zone								
0-3	38	7.7	82	8.5	-41	5.3	20	10YR 8/2
3-30	37	8.0	84	12	10	5.2	23	Grey 1 7/10Y

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; DO_2 = Dissolved oxygen; SP = Saturation percentage; Eh = Redo potential; SAR = Sodium adsorption ratio; 10YR 8/2 Very pale brown; Grey 1 5/10GY = greenish grey; Grey 1 7/10Y = Light greenish grey.

Zone 2: Middle Muddy Gravelly Zone. Zone 2 was identified as a superficial (0 to 5 cm) non-gravelly, muddy zone. A continuous layer of gravel bed (50 to 59% gravel) holds down the muddy material. Collection of gravelly mud from a pit near the surviving 60 cm, the lower deep muddy zone devoid of gravel started. Tables 37 and 38 characterize the middle muddy gravelly site. Its relative position is shown in Fig. 4. In this middle mangrove plant is shown in Plate 64. The gravels are more or less uniformly distributed in the fine, medium and coarse fractions below 5 cm depths. The middle muddy gravelly zone is located 60 cm away from the upper sloping sandy site. Beyond muddy gravelly zone, most plants survived. Table 38 shows the particle size distribution as a factor of depth. The texture ranged from clay (0 to 5 cm), to gravelly sand (5 to 30 cm), to gravelly loamy sand (30 to 60 cm). The high clay content at the surface (0 to 5 cm) is also reflected in a relatively high saturation percentage (SP) with values of 75 vs. 23. The high SP indicates that the upper mud has a higher water-holding capacity than to the sandy zone below. The higher SP dilutes the effect of salt under field conditions. The data presented in Table 37 shows the highest salinity in the surface layer, which is muddy in nature and completely devoid of gravel, and has low a drainage capacity. The gravelly subsurface presented comparatively low salinity levels. Gravel content is associated with lower salinity, and the zone has a higher drainage capacity. The position of the middle muddy zone is shown in Fig. 4.

Plate 64. Site investigation of the middle muddy gravelly Zone and collection of soil samples at the Shuwaikh Site.

Table 37. Physical and Chemical Characteristics of the Middle Muddy Gravelly Zone 2 of the Shuwaikh (KISR) Site, Subsite A

Depth	ECe (dS/m)	pH	SAR $(mmol/l)^{0.5}$	$CaCO_3$ (% eq)	Eh (mV)	DO_2 (mg/l)	SP	Color (Dry)
Subzone 2: Middle muddy gravelly zone								
0-3	115	7.6	193	25.1	36	2.5	75	Grey 1 7/10Y
3-30	56	7.8	126	10.8	31	4.5	23	Grey 1 7/10Y
30-60	65	7.8	26	14.8	40	4.9	22	Grey 1 7/10Y

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; Eh = Redo potential; DO_2 = Dissolved oxygen; SP = Saturation percentage; SAR = Sodium adsorption ratio; Grey 1 7/10Y = Light greenish Grey.

It is clear that the areas where the plants survived had a layer of gravelly sand below the 5 cm clay-textured mud layer. This layer provided an ideal substrate for successful mangrove establishment.

Table 38. Particle Size Distribution of Soil Samples from the Shuwaikh (KISR) Site, Subsite A (Middle Muddy Gravelly Zone 2)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Middle muddy gravelly zone														
0-5	46.0	31.9	22.1	30.0	1.9	1.1	1.0	1.0	8.0	11.0	Clay	0	0	0
5-30	6.0	2.5	91.5	2.0	0.5	3.0	6.5	8.0	32.0	42.0	Sand	20.0	15.0	24.0
30-60	6.9	5.1	88.0	4.5	0.6	6.0	12.0	11.0	38.0	21.0	Loamy Sand	20.0	15.0	15.0

Zone 3: Lower Muddy Site. The lower zone, about 2.5 m from the middle zone, was recognized as deep mud, without any apparent sand or gravel fractions. To confirm the nature of the subsurface material, a shovel was pushed down to a depth of about one meter in a number of subsites (Plate 65). The shovel entered without any resistance, confirming the silty/muddy nature of the native soil material. In the middle zone, where a gravel bed occurred, it was not possible to push the shovel below a few centimeters. The texture was either silty clay (0 to 3 cm) or silty clay to clay (3 to 60 cm and below) (Table 39). Laboratory determination confirmed the absence of gravel in this zone. Table 40 shows uniform distribution of high salinity and sodicity levels with depth. The uniform nature of the material was also reflected in its similar SP, $CaCO^3$, Eh, SAR, and pH values.

Plate 65. Penetration of a shovel without any restriction showing the absence of gravels in the lower muddy Zone in the Shuwaikh (KISR) Site, Subsite A.

The assessment of the site A revealed that in the outer and the lower zones, plants had either died or were dying; however, plants were surviving in the middle zone, where the upper 0 to 3 cm of muddy material was underlain by fine gravelly sand fractions. It appears that the mud, which is predominately silt and clay (92 to 97%), maintains waterlogging for a longer period and does not support plant growth. A high mud content also contributes to poor drainage ability in soils.

Table 39. Particle Size Distribution of Soil Samples from the Shuwaikh (KISR) Site, Subsite A (Lower Muddy Zone 3)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Lower muddy site														
0-3	55.0	42.0	3.0	36.0	6.0	2.0	0.0	0.0	0.2	0.8	Silt Clay	0	0	0
3-60	52.0	40.0	8.0	39.0	1.0	2.0	3.0	1.2	1.7	0.1	Silt Clay to Clay	0	0	0

Table 40. Physical and Chemical Characteristics of the Lower Muddy Zone 3 of the Shuwaikh (KISR) Site, Subsite A

Depth	ECe (dS/m)	pH	SAR $(mmol/l)^{0.5}$	$CaCO_3$ (% eq)	Eh (mV)	DO_2 (mg/l)	SP	Color (Dry)
Lower muddy site								
0-3	97	7.7	138	27.7	37	5	79	Grey 1 8/10Y
3-60	63	7.8	128	27.9	37	2.3	80	Grey 1 7/10Y

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; Eh = Redo potential; DO_2 = Dissolved oxygen; SP = Saturation percentage; SAR = Sodium adsorption ratio.

Site characteristics in relation to plant survival. *Avicennia marina* and *Ceriops tagal* seedlings were planted in three different sites, i.e., a lower sandy gravelly zone; a middle muddy gravelly zone, and a lower muddy zone. Site investigation on February 10, 2001 (three months after planting) showed that up to 80% of the plants had survived in the middle muddy gravelly zone. Also, most of the *Ceriops tagal* seedlings planted in the lower sandy gravelly zone (lower end of the sloping sandy gravelly area) had died, and almost all of the *Avicennia marina* seedlings planted in the inner muddy zone had also died. Apparently, the *Avicennia marina* is very sensitive to drainage conditions. It shows better survival in a shallow muddy surface zone which is underlain with a muddy gravelly bed to ease drainage. *Avicennia marina* was not planted in the lower sandy gravelly zone of the upper sloping sandy site. It would be appropriate to plant this site with *Avicennia marina* to test its survival and to locate a best-bet subsite. The site needs to be cleaned of debris and algal blooms, which are affecting the surviving plants. The main difference in the sites where plants were surviving was greater the drainage capacity in comparison to sites where plants had either died or were dying.

Subsite B. Subsite B is located in between Subsites A and C. Three zones were selected at Subsite B: outer, middle and lower. A general view of Subsite B is shown in Plate 66.

Plate 66. Collection of soil samples near the plants surviving in the Shuwaikh (KISR) Site, Subsite B.

The outer zone was recognized as 0 to 3 cm of clean sandy material. The texture was determined to be "sand". Sand was the dominant component, measured as about 99%. The zone from 3 to 30 cm was identified as gravelly (67% gravel) sand highly contaminated with oil. During the site investigation and sample collection, oil contamination was observed below 3 cm depths (Plate 66) as well as on the surface of water (Plate 67) in the depression where the sample was collected. This depth needs further exploration of the oil contents and their effects on plant growth. Tables 41 and 42 characterize the three zones. The middle and lower zones were similar with regard to oil contamination; however, they presented different soil textures (Table 40). The lower zone was deep mud (Plate 68), similar to Subsite A at this location.

Plate 67. Oil contamination below 3 cm layer of clean sand at the Shuwaikh (KISR) Site, Subsite B.

On-site investigation on February 10, 2001, revealed that most plants had died at this location. The reasons for excessive plant mortality were low mud content, the high oil contamination, poor soil health, and sensitivity of *Avicennia* to the prevailing site

Table 41. Particle Size Distribution in Soil Samples from the Shuwaikh (KISR) Site, Subsite B (Outer, Middle and Lower Zones)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Outer zone														
0-3	1.0	0.2	98.8	0.1	0.1	6.8	15.0	37.0	24.0	16.0	Sand	3.0	2.0	-
3-30	3.0	1.0	96.0	1.0	0.0	9.5	16.5	31.0	21.0	18.0	Sand	10.0	17.0	40.0
Middle zone														
0-15	41.9	28.6	29.5	23.1	5.5	10.5	9.5	3.7	3.0	2.8	Clay	0	0	0
15-30+	5.0	7.0	88.0	3.9	3.1	9.0	24.5	37.5	8.0	9.0	Sand	7	5.0	39.0
Lower zone														
0-15	60.0	37.0	3.0	35.0	2.0	1.0	0.9	0.1	0.5	0.5	Clay	0	0	0
15-30	36.0	25.5	38.5	23.0	2.5	11.5	17.0	6.5	2.7	0.8	Clay Loam	0	0	0
30-100+	**Non gravelly muddy subsurface (sample not collected)**													

conditions. The extent of damage to the site due to oil contamination and heavy metals perhaps should be explored. Other hardier species or ecotypes of *Avicennia marina* may be tested for the prevailing site conditions. The chemical characteristics of the site are shown in Table 42.

Table 42. Physical and Chemical Characteristics of the Shuwaikh (KISR) Site, Subsite B

Depth	ECe (dS/m)	PH	SAR $(mmol/l)^{0.5}$	$CaCO_3$ (% eq)	Eh (mV)	DO_2 (mg/l)	SP	Color (Dry)
Subzone 1: Upper sandy zone								
0-3	40	8.0	80	9.3	23	4.6	22	10YR 8/2
3-30	44	7.8	116	11.5	-5	6.0	21	Grey1 7/10Y
Subzone 1: Middle gravely sandy zone								
0-15	74	7.8	67	30.5	20	2.3	82	Grey1 8/10Y
15-30+	66	7.9	116	14.1	15	4.6	24	Grey1 7/10Y
Subzone 1: Lower gravely sandy zone								
0-15	57	7.6	102	42.1	16	3.8	95	Grey1 5/5G
15-30	41	7.5	72	25.1	15	3.2	70	Grey1 4/10Y
30-100+	**Non gravely muddy subsurface (sample not collected)**							

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; Eh = Redo potential; DO_2= Dissolved oxygen; SP = Saturation percentage; SAR = Sodium adsorption ratio 10YR 8/2 = Very pale brown; Grey 1 5/5GY = Greenish grey; Grey 1 4/10Y = Dark greenish grey; Grey 1 8/10Y = Light greenish grey; Grey 1 7/10Y = Light greenish grey.

Subsite C. Subsite C was the last subsite near KISR's main campus. The subsite was divided into three zones: an upper sloping gravelly sandy zone (Table 43, Plate 69), a middle muddy sandy zone and an inner muddy zone. Sample collection from the upper sloping and inner zones is shown in Plate 70. Physiographically, these zones have features that are similar to those of Subsite A.

The upper sloping gravelly sandy zone is divided into three zones. The outer (deep sand without any gravel contents), the middle gravelly sand will gravel contents up to 20% (0-10 cm) and 30% (10-50 cm) were recorded, and the lower gravelly sand (gravel contents up to 50% (0-10 cm) and 57% (10-50 cm) were recorded). After

Plate 68. Stranded oil in the intertidal mudflat posing a threat to seedling establishment in the Shuwaikh (KISR) Site, Subsite B.

Plate 69. Investigating the depth of mud by pushing a shovel into the muddy zone at the Shuwaikh (KISR) Site, Subsite B.

Table 43. Particle Size Distribution in Soil Samples from the Shuwaikh (KISR) Site, Subsite C (Upper Gravelly Sandy Sloping Zone)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Outer deep sandy site														
0-10	0.5	1.0	98.5	0.4	0.6	2.4	15.1	30.5	21.0	29.5	Sand	0	0	0
Middle gravelly sandy site														
0-10	1.0	0.9	98.1	0.0	0.9	2.1	7.0	16.5	32.5	40.0	Sand	11.0	8.0	1.0
10-50	1.0	0.0	99.0	0.0	0.0	6.0	13.0	24.0	27.0	29.0	Sand	20.0	9.7	0.3
Lower fine/coarse gravelly site														
0-10	1.5	1.0	97.5	0.5	0.5	2.0	5.5	11.0	34.0	45.0	Sand	23.0	21.0	6.0
10-50	1.9	3.1	95.0	1.0	2.1	9.0	19.0	26.5	21.5	19.0	Sand	14.0	19.0	24.0

removing the gravel contents from the soil samples, the texture was determined to be "sand" throughout the upper gravelly sandy sloping site (Table 43). The sand fraction (0.05 mm to 2 mm) was the dominant fraction, determined to constitute more than 95% in zones and depths. The results presented in Table 43 indicate an increase of gravel from the upper to the lower end of the upper gravelly sloping zone. The subsurface of the middle and the lower zones showed high gravel contents.

On-site investigation on February 10, 2001, revealed that the lower fine to coarse gravelly zone of the upper sloping sandy zone was planted with three rows of *Ceriops*, which could not withstand the prevailing site conditions. Although underlain by a bed of gravel, surface mud was lacking. This planted zone contained predominately sand fractions, which were also reflected in the SP values. No visible oil contamination was noticed in this zone. The salinity was also maintained at the lowest level. It is more likely that the *Ceriops* species is sensitive to the prevailing conditions, and other species such as *Avicennia marina* should be tested in this zone. The low mud content caused plant uprooting at the site. Chemical characteristics presented in Table 44 suggest lower salinity levels due to high drainage capacity as a factor of the presence of sandy material and the sloping topography of this zone.

Plate 70. Sampling strategy covering both the sandy beach and the muddy zones at the Shuwaikh (KISR) Site, Subsite C.

Table 44. Physical and Chemical Characteristics of the Outer, Middle and Lower Zones at the Shuwaikh (KISR) Site, Subsite C

Depth	ECe (dS/m)	PH	SAR $(mmol/l)^{0.5}$	$CaCO_3$ (% eq)	Eh (mV)	DO_2 (mg/l)	SP	Color (Dry)
UPPER GRAVELY SANDY SUBSITE								
A. Outer deep sandy subsite								
0-10	16	7.8	62	7.4	-3	5.0	23	10YR 8/3
B. Middle gravely sand								
0-10	14	8.1	65	7.8	-31	5.3	21	10YR 8/2
10-50	31	8.1	85	7.8	17	5.2	20	10YR 8/3
C. Lower fine/coarse gravely zone								
0-10	43	8.0	95	8.1	15	5.0	22	10YR 8/2
10-50	41	8.0	75	12.4	33	4.7	26	10YR 7/1

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; Eh = Redo potential; DO_2 = Dissolved oxygen; SP = Saturation percentage; SAR = Sodium adsorption ratio 10YR 8/2 = Very pale brown; 10YR 8/3 = Very pale brown; 10YR 7/1 = Light grey.

The middle zone was identified as a muddy sandy area, which is located about three meters away from the upper gravelly sloping zone. The contents of coarse and finer fraction contents are given in Table 45. The surface (0 to 6 cm) was devoid of the coarser fraction; however, the subsurface (6 to 30+ cm) contained 25% coarser sand fraction, distributed as finer, medium and coarser gravels. In this zone, *Ceriops tagal* was planted. On-site investigation on February 10, 2001, revealed that *Ceriops* plants had died after initial establishment; however, a few *Avicennia marina* plants still survived. The important characteristics of this zone are presented in Tables 45 and 46. Plate 71 also shows the depth of the mud; the edge of shovel is hitting the upper boundary of the gravelly layer.

The inner zone is identified as a muddy zone as indicated by the absence of gravel fractions (Table 47). This was also confirmed by the fact that the shovel pushed into the soil profile up to 1.25 m did not detect a gravelly layer. The texture was that of clay throughout the soil depth, and the gravel as absent. The zone's chemical characteristics are shown in Table 48. No plants had survived at this site. It is likely that this zone had poor drainage and was similar to the lower muddy area in the Shuwaikh (KISR) Site, Subsite A, where high plant mortality was recorded. It is, therefore, clear from the on-site investigation that surface mud underlain by a gravelly layer is a required condition for successful establishment and growth of *Avicennia marina* seedlings.

Table 45. Particle Size Distribution in Soil Samples from the Shuwaikh (KISR) Site, Subsite C (Middle Muddy Sandy Zone)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Middle subzone (Muddy sandy)														
0-6	55.0	37.5	7.5	35.0	2.5	3.0	2.7	0.8	0.5	0.5	Clay	0	0	0
6-30	0.7	10.3	89.0	9.3	1.0	24.0	36.5	12.5	9.0	7.0	Sand	10.0	6.0	9.0

Table 46. Physical and Chemical Characteristics of the Middle Muddy Sandy Zone of the Shuwaikh (KISR) Site, Subsite C

Depth	Ece (dS/m)	PHs	SAR $(mmol/l)^{0.5}$	$CaCO_3$ (% eq)	Eh (mV)	DO_2 (mg/l)	SP	Color (Dry)
Middle Muddy Sandy Zone								
0-6	62	7.7	189	29.2	28	3.2	98	Grey 1 7/10Y
6-30	33	7.8	17	11.9	-22	4.4	33	Grey 1 8/10Y

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; Eh = Redo potential; DO_2 = Dissolved oxygen; SP = Saturation percentage; SAR = Sodium adsorption ratio; Grey 1 7/10Y = Light greenish grey; Grey 1 8/10Y = light greenish grey.

Plate 71. Shovel penetration showing the depth of the muddy layer near a live plant at the Shuwaikh (KISR) Site, Subsite C.

Doha Site. Two locations were selected for investigation, one where plant survival was high and another, where a majority of the plants had died in the initial three months. Field observations revealed that the soil in the area which had high plant mortality was very dry and highly saline around the rhizosphere due to higher evaporation, which might have resulted in plant mortality. On the other hand, the area where the plants had established well had sufficient moisture in the root zone to minimize the effects of the salinity.

Table 47. Particle Size Distribution in Soil Samples from the Shuwaikh (KISR) Site, Subsite C (Lower Muddy Zone)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Lower muddy zone														
0-70	48.0	24.9	27.1	23.0	1.9	8.1	12.0	1.5	2.5	3.0	Clay	0	0	0

Table 48. Physical and Chemical Characteristics of the Lower Muddy Zone of the Shuwaikh (KISR) Site, Subsite C

Depth	ECe (dS/m)	PH	SAR $(mmol/l)^{0.5}$	$CaCO_3$ (% eq)	Eh (mV)	DO_2 (mg/l)	SP	Color (Dry)
Lower Muddy Zone								
0-70	57	7.6	116	25.3	23	1.6	92	Grey 1 8/10Y

ECe = Electrical conductivity of soil saturation extract; pH = pH of soil saturated paste; DO_2= Dissolved oxygen; SP = Saturation percentage; Eh = Redo potential; SAR = Sodium adsorption ratio; Grey 1 8/10Y = Light greenish grey.

To investigate the soil condition at various depths, five pits were dug in each location, and soil samples were collected from representative pits. The soil profile in the area where majority of the plants had survived was comprised of a 5 cm wet, sandy loam mud followed by a sandy loam layer (5 to 30+ cm below the surface) with a slightly higher sand content (Table 49). The water table appeared at a 30 cm depth at the time of sampling; however, it fluctuated with the water level in the sea. Due to the muddy nature of the soil surface, it was difficult to walk around to collect soil samples (Plate 72).

Table 49. Particle Size Distribution in Soil Samples from the Doha Site (Subsites Where Plants Had Died)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Subsite A														
0-5	15.0	11.0	74.0	10.0	1.0	11.0	19.0	29.0	11.0	4.0	Sand Loam	0	0	0
5-30	16.0	9.0	75.0	8.0	1.0	8.0	20.0	29.0	14.0	4.0	Sand Loam	0	0	0
Subsite B														
0-5	9.0	14.0	77.0	11.0	3.0	8.0	22.0	30.0	14.5	2.5	Sand Loam	0	0	0
5-30	12.5	6.5	81.0	6.5	0.0	7.5	20.5	39.0	10.0	4.0	Sand Loam	0	0	0
Subsite C														
0-5	16.0	10.5	73.5	8.0	2.5	9.5	20.0	31.0	10.5	2.5	Sand Loam	0	0	0
5-30	19.5	17.0	63.5	14.5	2.5	5.5	13.0	31.5	11.0	2.5	Sand Loam	0	0	0

In contrast, the soil profile in the area where plants either had died or were dying, consisted of an upper 5 cm of dry sandy loam mud (Table 50), where surface

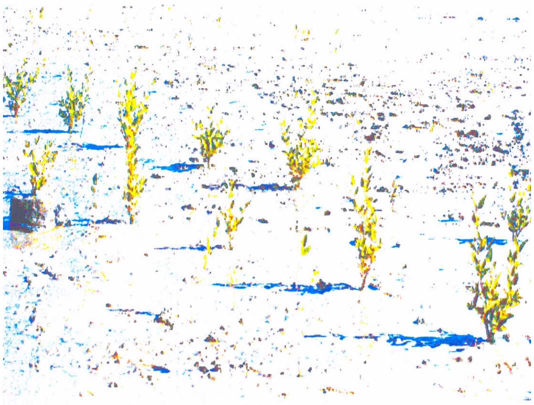


Plate 72. A view of the intertidal mudflat area with a healthy *Avicennia marina* plant at the Doha Site.

accumulation of white salt crystals was clearly visible, indicating the prevalence of high field salinity status near the root system (below 5 cm) of the mangrove plants. It was also recorded that in the area where the plants were dead, the high tide persisted only for a short period, and tidal coverage was not sufficient to flush out salts from the soil matrix. Additionally, the 5 to 30 cm layer of the profile was a dry sandy loam to a sandy clay loam with high field salinity levels, and below 30 cm, it had only sandy loam fractions. The soil surface supported the movements within the site and the team had no difficulty in site characterization and soil sample collection. Site investigation clearly revealed differences in the salinity levels and soil textural compositions of the two areas at this site (the first area where a majority of the plants had survived, and the other area having high plant mortality), which probably contributed to the observed differences in plant establishment and growth.

Table 50. Post-Planting Characteristics of Mangrove Sites at the Doha Site (Subsites Where Plants Had Survived)

Depth	PH	ECe (dS/m)	ESP	$CaCO_3$	SP	Color
Plant Survival subsite-1						
0-5	7.1	109.8	74.0	44.0	29.4	5Y 7/1
5-30	8.1	33.3	55.7	45.4	28.6	5Y 7/1
Plant Survival subsite-2						
0-5	8.4	80.5	71.4	43.1	28.6	5Y 7/1
5-30	8.6	24.3	53.6	45.4	27.8	5Y 7/1
Plant Survival subsite-3						
0-5	8.4	94.0	71.3	51.8	32.7	5Y 7/1
5-30	8.6	39.7	59.3	44.7	34.3	5Y 7/1

pH = pH of the saturated soil paste; ECe = Electrical conductivity of the saturated extract; ESP = Exchangeable sodium percentage; SP = Saturation percentage; 5Y 7/1 = Light grey.

The characteristics the two locations are shown in Tables 49 to 52. The major difference in the characteristics of the areas where the plants had survived, and had died or were dying, was the salinity status of the active root zone (below 5 cm). The ECe ranged between 24.3 and 39.7 dS/m in the area where plants had survived. However, the ECe values in areas where plants had died ranged between.53.2 and 58.4 dS/m. Additionally, on-site investigation clearly showed areas where plants were surviving to contain adequate moisture to dilute the salinity effects; however, locations where the plants had died, had lower moisture contents. The violent white salt-efflorescence observed in these areas was an indicator of hypersaline conditions.

Table 51. Particle Size Distribution in Soil Samples from the Doha Site (Subsites Where Plants had Died)

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Subsite C														
0-5	34.0	18.0	48.0	15.5	2.5	1.0	9.0	26.0	9.0	3.0	Sandy Clay Loam	0	0	0
5-30	29.0	10.5	60.5	9.0	1.5	2.5	14.0	34.0	8.0	2.0	Sandy Clay Loam	0	0	0
Subsite D														
0-5	14.0	15.5	70.5	12.0	3.5	8.5	16.0	32.0	12.0	2.0	Sandy Loam	0	0	0
5-30	18.5	16.0	65.5	13.5	2.5	4.5	12.0	34.0	12.5	2.5	Sandy Loam	0	0	0

Other characteristics, such as pH, Exchangeable sodium percentage (ESP), $CaCO^3$ and color, did not reveal any significant differences between sites (Tables 51 and 52). The ECe in the upper 5 cm was not significantly different in the two sites. From the laboratory characterization, it was clear that mangrove plants had survived where ECe levels were less than 40 dS/m below 5 cm depths. The SP measured in the laboratory showed higher values in the areas where plants had died, which means that the soil there contained less water, probably due to high drainage capacity.

Table 52. Post-Planting Characteristics of Mangrove Sites at the Doha Site (Subsites Where Plants Had Died)

Depth	pH	ECe (dS/m)	ESP	$CaCO_3$	SP	Color
Dead plant subsite-1						
0-5	8.4	96.3	69.1	41.6	37.9	5Y 7/1
5-30	8.5	58.4	63.9	42.9	38.7	5Y 7/1
Dead plant subsite-2						
0-5	8.4	88.1	68.9	42.2	31.9	5Y 7/1
5-30	8.5	53.2	62.4	44.9	36.7	5Y 7/1

pH = pH of the saturated soil paste; ECe = Electrical conductivity of the saturated extract; ESP = Exchangeable sodium percentage; SP = Saturation percentage; 5Y 7/1 = Light grey.

It was concluded that wet sandy loam sites with good daily coverage by tidal water provide an ideal location for mangrove establishment, as opposed to dry and highly saline sites that are not flushed daily by tidal water.

Sulaibikhat Site 1. A number of field visits by the project team were made to both sites on Sulaibikhat Bay. It was noticed that there was increased competition between the mangrove plants and the existing *Zygophyllum* plant community at the site. This effect of nutrient competition was evident from the general yellowing of the mangrove plants. The nutritional deficiency was corrected through soil and foliar applications of inorganic fertilizer. The effects of fertilizer application were evident in subsequent visits to the site, when the plants were found to be healthier and greener than before. Plantation at Sulaibikhat Site 1 is shown in Plate 73.

Two subsites were selected in Sulaibikhat Site 1, one where the plants were surviving and another with dead or dying plants. Five soil pits were made on each site, and soil samples from representative soil pits were collected for laboratory characterization.

The soil profile in areas where plants were surviving was comprised of an upper 5 cm clay-loam-textured mud layer. Below this layer, a sandy loam zone was observed between 5 and 20 cm from the surface (Table 53). This layer showed iron (red mottling) contamination from dumped material. The sandy loam layer (74% sand) had a higher drainage capacity than the silty-clay-(15% sand) and clay-loam (32% sand) textured layers at the site where the plants had died. Relatively higher moisture contents were found at 20 cm depths. The competition for nutrients between the plants was negligible as the site was clear of plants other than mangroves.

Plate 73. Established *Avicennia marina* and *Ceriops tagal* seedlings in Sulaibikhat Site 1.

Table 53. Particle Size Distribution in Soil Samples from Sulaibikhat Site 1

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Plant survival site														
0-5	35.0	26.5	38.5	24.5	2.0	10.5	11.0	12.0	4.0	1.0	Clay Loam	0	0	0
5-20	18.5	7.5	74.0	6.5	1.0	15.0	22.0	19.5	10.5	7.0	Sandy Loam	0	0	0
20+	39.0	39.0	22.0	28.5	10.5	7.0	6.0	4.0	3.0	2.0	Clay Loam	0	0	0
Dead plant site														
0-20	36.0	32.0	32.0	23.0	9.0	13.5	15.5	1.0	1.0	1.0	Clay Loam	0	0	0
20+	41.0	44.0	15.0	33.0	11.0	9.0	4.0	0.0	1.5	0.5	Silty Clay	0	0	0

The site where the plants were either dying or had died also presented hypersaline conditions, as was evidenced by surface salt-efflorescence. The physical and chemical characterization of the soil samples is shown in Table 54.

The on-site investigation indicated that the 5 to 20 cm layer of the profile was an active zone affecting plant growth (based on the rooting depth), where major differences were recorded in soil texture, ECe and $CaCO^3$ content. An ECe value of 46.6 dS/m (where plants were surviving) was recorded compared to 100 dS/m in areas where plants had already died. The $CaCO^3$ contents were also higher in the areas with dead plants, which eventually also increased the soil pH, and reduced the nutrient availability to plants. The sandy loam texture in areas with well established plants also showed lower SP, i.e., 36.7, vs. 64.8 in areas with dead plants at 5 to 20 cm below the surface.

Table 54. Post-Planting Characteristics of Mangrove Sites at the Sulaibikhat Site 1

Depth	pHs	ECe (dS/m)	ESP	$CaCO_3$	SP	Color
Plant Survived						
0-5	7.5	66.4	65.4	20.6	60.8	5Y 7/1
5-20	7.7	46.6	59.2	14.3	36.7	5Y 7/1
20+	7.9	62.8	64.6	23.2	62.8	5Y 7/1
Plant Dead or Dying						
0-20	8.5	100.0	71.5	28.2	64.8	5Y 7/1
20+	7.9	74.8	68.0	28.2	64.8	5Y 7/1

pH = pH of the saturated soil paste; ECe = Electrical conductivity of the saturated extract; ESP = Exchangeable sodium percentage; SP = Saturation percentage; 5Y 7/1 = light gray.

It was concluded that high salinity, textural differences and poor drainage are the main factors contributing to plant failure at this location. Ideal conditions are recognized as being 74% sand, 7.5% silt and 18.5% clay as opposed to the 32% sand, 32% silt and 36% clay at the site where the plants had died. The latter combination of soil fractions resulted in poor drainage in the intertidal mudflats.

Sulaibikhat Site 2. The following field observations were recorded at the

Sulaibikhat Site 2. For this purpose, five soil pits were dug on each site (areas where plant establishment was good and those with higher plant mortality). On-site investigation indicated that the areas where plants were either dead or in the process of dying, had an upper 3 cm loam textured layer, below which a hard clay loam zone was observed (Table 55).

Table 55. Particle Size Distribution in Soil Samples from Sulaibikhat Site 2

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Plant survival site														
0-3	21.0	22.0	57.0	16.0	6.0	18.5	25.5	9.5	2.5	1.0	Sandy Clay Loam	0	0	0
3-20	35.0	32.0	33.0	24.0	8.0	12.5	12.5	6.0	1.5	0.5	Clay Loam	0	0	0
20+	42.0	37.0	21.0	28.9	9.0	10.0	6.0	3.0	1.5	0.5	Clay	0	0	0
Dead plant site														
0-3	27.0	24.5	48.5	18.0	6.5	2.5	20.0	4.0	1.5	0.5	Loam	0	0	0
3+	38.0	36.0	26.0	25.0	11.0	10.0	5.0	7.0	3.5	0.5	Clay Loam	0	0	0

In the area where the plants were surviving, the upper 3 cm was a sandy clay loam zone, followed by a 3 to 20 cm clay loam, and a clay moist muddy layer below 20 cm (Table 55). The upper 20 cm was relatively dry and well drained. In contrast, the soil below 20 cm from the surface was moist and poorly drained.

The laboratory characterization (Table 56) showed a major difference in ECe values, with hypersaline conditions (Ece = 136.2 dS/m) observed in areas where the plants were dead, and Ece values of less than 84 dS/m in areas that contained a greater number of healthy plants. The differences in other characteristics were not significant; however, considerable difference was recorded in the texture of soil particles in the rooting zone. The main contributing factor to plant failure at this location appeared to be the existence of hypersaline conditions, textural differences and the resultant drainage capacity.

Subiya Site near the Bubiyan Bridge. The site at Subiya is relatively clean and uniform compared to the Doha and Sulaibikhat sites. It is less contaminated with household wastes. The objective was to compare plant performance with site characteristics and assess site suitability laterally.

For this purpose, five zones were selected for investigation. Three zones were selected in areas containing a greater number of dead or dying plants (Subsite B), and two in areas having good plant establishment (Subsite A). At the time of investigation, the water table ranged between 30 to 40 cm in the area with dead or dying plants, and it decreased towards dry land.

Table 56. Post-Planting Characteristics of Mangrove Sites at the Sulaibikhat Site 2

Depth	PHs	ECe (dS/m)	ESP	$CaCO_3$	SP	Color
Plant Survived						
0-3	8.3	84.4	69.2	21.8	46.7	5Y 7/1
3-20	8.2	63.0	64.9	31.4	60.8	5Y 7/1
20+	8.2	57.6	63.8	38.0	64.8	5Y 7/1
Plant Dead or Dying						
0-3	8.0	136.2	75.1	24.5	44.7	5Y 7/1
3+	8.2	84.3	69.6	40.4	60.8	5Y 7/1

pHs = pH of the saturated soil paste; ECe = electrical conductivity of the saturated extract; ESP = exchangeable sodium percentage; SP = saturation percentage; 5Y 7/1 = light grey

Out of the two zones in the area with healthy plants, in one zone, the water table appeared at a 30 cm depth. The upper 25 cm layer of the soil profile in this zone was sandy loam; below 30 cm, it was loamy sand (Table 57). The second zone, where the plants were surviving, contained loamy sand particles in the upper 15 cm layer and sandy fractions at 15 to 45 cm depths. Particle size distribution analysis showed the presence of sand (77 to 93%), silt (7.5 to 15%) and clay (4 to 10%).

Table 57. Particle Size Distribution in Soil Samples from the Subiya Site near the Bubiyan Bridge, Subsite A

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Zone 1														
0-10	8.0	15.0	77.0	9.0	6.0	37.0	37.5	1.0	1.0	0.5	Sandy Loam	0	0	0
10-25	10.0	12.0	78.0	9.5	2.5	33.0	43.0	1.0	0.5	0.5	Sandy Loam	0	0	0
25-30+	6.5	7.5	86.0	4.5	3.0	38.0	46.0	1.0	0.5	0.5	Loamy Sand	0	0	0
Zone 2														
0-15	6.0	9.0	85.0	6.0	3.0	33.0	45.0	5.0	1.5	0.5	Loamy Sand	0	0	0
15-45	4.0	3.0	93.0	1.0	2.0	41.0	47.5	3.0	1.0	0.5	Sand	0	0	0

In the zones where plants were dead, heterogeneity of the nature of sites was recorded. In zone 1, the upper 20 cm was loamy sand, and below 20 cm it was sandy loam (Table 58). Zone 2 presented a loamy sand texture at all depths studied. Zone 3 was different from the rest, as it presented uniform sandy particles throughout. The water table appeared at 30 cm, and the zone contained very fine to fine sand and had a very high drainage capacity. In all three zones, the soil contained sand (79 to 93.55%), silt (2 to 13%) and clay (3 to 10.5%).

Table 58. Particle Size Distribution in Soil Samples from the Subiya Site near the Bubiyan Bridge, Subsite B

Depth (cm)	Total			Silt		Sand					Textural Class	Gravels % on whole soil basis		
	Clay	Silt	Sand	Fine	Coarse	Very Fine	Fine	Medium Fine	Coarse	Very Coarse		(2-5 mm) Fine	(5-15 mm) Medium	(15-75 mm) Coarse
Zone 1														
0-10	8.0	13.0	79.0	9.0	4.0	32.0	44.5	1.5	0.5	0.5	Loamy Sand	0	0	0
10-20	10.5	10.5	79.0	9.5	1.0	41.0	36.0	1.0	0.5	0.5	Sandy Loam	0	0	0
20-40	8.0	9.0	83.0	7.0	2.0	33.0	47.0	2.0	1.0	0.0	Loamy Sand			
Zone 2														
0-10	9.0	11.5	79.5	7.5	4.0	34.5	42.0	2.0	1.0	0.0	Loamy Sand	0	0	0
10-25	7.5	7.5	85.0	4.0	3.5	37.0	46.0	1.0	1.0	0.0	Loamy Sand	0	0	0
25-40	8.0	8.0	84.0	6.0	2.0	32.0	48.5	2.5	1.0	0.0	Loamy Sand			
Zone 3														
0-2	5.0	2.0	93.0	1.0	1.0	40.0	33.0	14.5	4.5	1.0	Sand	0	0	0
2-30	3.5	3.5	93.5	1.5	2.0	32.5	38.0	18.0	4.5	0.5	Sand	0	0	0

Table 59. Post-Planting Characteristics of Mangrove at the Subiya Site, Subsite A

Depth	PH	ECe (dS/m)	ESP	$CaCO_3$	SP	Color
Zone 1						
0-10	7.8	60.5	63.4	10.0	30.6	10YR 5/2
10-25	8.0	47.6	60.1	20.5	29.8	10YR 5/2
25-30+	8.0	47.2	58.8	18.6	30.6	10YR 5/2
Zone 2						
0-15	8.0	54.1	62.4	17.8	29.8	10YR 5/2
15-45	8.1	44.5	56.7	13.7	30.2	10YR 5/2

pH = pH of the saturated soil paste; ECe = Electrical conductivity of the saturated extract; ESP = Exchangeable sodium percentage; SP = Saturation percentage; 10YR 5/2 = Greyish brown.

Table 60. Post-Planting Characteristics of Mangrove at the Subiya Site, Subsite B

Depth	PH	ECe (dS/m)	ESP	$CaCO_3$	SP	Color
Zone 1						
0-10	7.3	52.9	62.2	21.6	29.8	10YR 7/2
10-20	7.7	47.2	59.5	21.4	30.2	10YR 7/2
20-40	7.8	45.8	59.1	18.8	28.6	10YR 7/2
Zone 2						
0-10	7.8	60.3	64.8	20.0	28.6	10YR 7/2
10-25	8.0	47.2	59.7	28.9	29.8	10YR 7/2
25-40	8.1	47.3	60.0	17.9	29.8	10YR 7/2
Zone 3						
0-2	7.3	73.5	63.0	12.4	26.6	10YR 7/2
2-30	7.7	89.3	67.4	19.1	29.4	10YR 7/2

pH = pH of the saturated soil paste; ECe = Electrical conductivity of the saturated extract; ESP = Exchangeable sodium percentage; SP = Saturation percentage; 10YR 7/2 = Light grey

The laboratory analysis did not show clear evidence of differences in soil characteristics to infer probable causes of plant failure (Tables 59 and 60). While *Avicennia marina* survived under these prevailing site conditions, the majority of *Ceriops tagal* died at this site.

The difference in the performance of *Avicennia marina* could be due to the differences in soil texture and chemical characteristics.

Summary

Phase II of the mangrove project was started with the aim of introducing mangroves for the protection and enrichment of Kuwait's coastlines. To achieve its objectives, the coastlines of Kuwait were visited, and on-site investigation of 14 potential sites was undertaken. These sites were assessed using the site selection criteria prepared by the project team. Out of the 14 sites, only five fulfilled the criteria, and therefore, they were further investigated for their morphological characteristics in the field, their soils were classified, and soil samples were collected and analyzed in the laboratory.

Experimental mangrove plantations were established on the five sites selected in Task 2. Seedling establishment was very good during the first two to three months, after which seedling mortality increased in some locations at all sites. The maximum seedling mortality was observed during the winter and summer months, which could have been due to unfavorable coastal environmental conditions. However, plant performance differed greatly between sites and within each site. The seedling establishment was the best in the Doha site, followed by Sulaibikhat Site 1. The highest seedling mortality was observed in the Subiya and Shuwaikh (KISR) Sites (Subsites B and C).

In general, planting of seedlings in the middle silty loam zone promoted seedling establishment and growth. In contrast, planting in the upper sandy or inner clayey muddy zones increased seedling mortality and, hence, should be avoided.

Although these sites appeared uniform, plant performance differed widely at various locations within each site. Therefore, frequent post-planting field visits were made to monitor plant survival and growth. Besides monitoring plant performance, on-site investigations were carried out during these visits, and soil samples were collected from different areas where plants had established very successfully as well as from areas where plant mortality was relatively high. The soil samples were analyzed in the laboratory. It is clear from the data from the post-planting analysis that areas showing different plant responses also differed in their site and soil characteristics. However, it is rather difficult to generalize as to which site characteristics were conducive to successful mangrove establishment in all of the sites.

It was concluded from the site characterizations that at the Shuwaikh (KISR) Site, areas where the surface muddy material (0 to 5cm) was underlain by a layer of fine gravelly sandy material had higher plant survival and better vegetative growth. In contrast, both areas that are predominately sandy or clayey were found to be unsuitable

for mangrove plantation. Contamination of intertidal mudflats with fresh oil resulted in high plant mortality.

At the Doha Site, wet sandy loam areas that are covered daily by tidal water were found to be ideal for establishing mangrove plantations. Dry areas with relatively high field salinity and poor tidal coverage increased plant mortality and affected plant growth for *Avicennia marina*.

At Sulaibikhat Site 1, high salinity, textural differences and poor drainage capacity increased plant mortality and affected plant growth. The ideal site conditions at this location included 74% sand, 7.5% silt and 18.5% clay. In contrast, lower sand (32%) and higher silt (32%) and clay (36%) in the upper 30-cm zone of the soil profile increased plant mortality, reduced growth and reduced the drainage capacity of the soil.

In Sulaibikhat Site 2, the major differences were recorded in soil texture in the root zone. The main reasons for plant failure were found to be the hypersaline conditions, textural differences and the resultant poor drainage capacity.

At the Subiya Site, laboratory analysis did not show clear-cut differences in soil characteristics. *Avicennia marina* plants survived better than *Ceriops tagal* plants at this site.

Task 4. Evaluation of Each Genetic Population for Growth in Kuwait

Introduction

Forest tree breeding consists of phenotypic selection of superior individuals plus trees or lines followed by establishment of the selected plus trees in the seed orchards for the production of improved seeds that can be used for high-quality plantation (S. Rao et al., 2001). In the present investigation, different ecotypes of *Avicennia* were introduced from various mangrove-growing areas in the Arabian Gulf, USA and Pakistan. These ecotypes were planted in the field to ascertain their growth performance under Kuwait's coastal environmental conditions. Different morphological (vegetative and reproductive) and physiological markers are being used to select superior ecotypes/lines and they will be multiplied using conventional vegetative, or micropropagation techniques, whichever is appropriate. Several species of mangroves have been successfully multiplied in this fashion and reintroduced in the natural habitat both for conservation and afforestation (S. Rao et al., 2001).

The main objective of this task during the current phase of the project is to isolate the most suitable genotypes for growth in Kuwait and evaluate their suitability in future tree improvement programs.

Materials and Methods

Mangrove Ecotypes

Avicennia marina. Hardened, one-year-old seedlings of three introduced and two local *Avicennia marina* ecotypes with heights ranging from 25 to 50 cm were used in this study (Plates 74 to 77).

Avicennia germinans. *Avicennia germinans* from Florida, USA were included along with *Avicennia marina* ecotypes (Plate 78).

Planting. Thirty centimeter planting holes were prepared along the tidal line at one meter intervals. Seedlings were carefully handled to prevent any damage to the root system. The taproot with its root ball intact was carefully inserted into these planting holes and backfilled with native soil.

Plate 74. Hardened seedlings of a Pakistani ecotype of *Avicennia marina*.

Data Recording. Seedling heights were recorded at the time of planting. Plant establishment was monitored by frequent visits to the sites. Seedling height was recorded at three month intervals to ascertain growth performance.

Results and Discussion

In this task, three introduced (from Pakistan, the UAE and Bahrain) and two local ecotypes of *Avicennia marina* and one ecotype of *Avicennia germinans* (from the USA) were evaluated for their growth performance under Kuwait's coastal conditions.

Plate 75. Hardened seedlings of a UAE ecotype of *Avicennia marina*.

Plate 76. Hardened seedlings of a Bahraini ecotype of *Avicennia marina*.

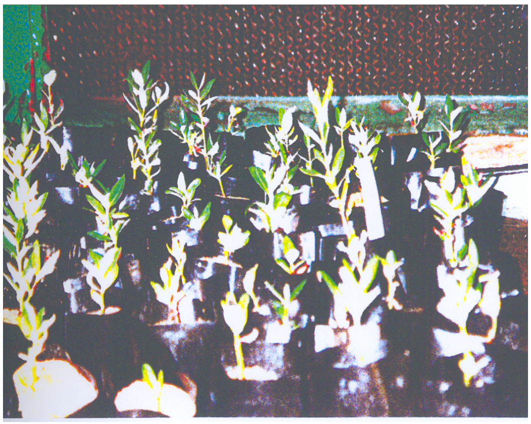


Plate 77. Hardened seedlings of a local ecotype of *Avicennia marina.*

Seedling Growth. The seedlings of the *Avicennia* ecotypes were planted in the field in October and November 2000. Although seedling establishment was nearly 100% in the first 90 days, most of the plants of the Bahrain and UAE ecotypes were affected due to the deposition of oily substances during the winter. Dead plants were replaced in September 2001, and the plants are now in excellent condition.

After 270 days, seedlings of the *Avicennia germinans* ecotype had attained an average height of 35.8 cm (Table 61). The average heights of the newly planted Pakistani, Bahraini and UAE ecotypes were 65.4, 14.7 and 11.4 cm, respectively. In addition, progenies of the promising plants from the existing Bahraini and UAE ecotypes had been raised in the greenhouse. These seedlings are being acclimatized for field planting.

Plate 78. Ready-to-plant seedlings of *Avicennia germinans*.

Table 61. Seedling Survival and Height Growth in Different *Avicennia* Ecotypes

Ecotype	Source	Seedling Survival (%)	Average Height (cm)
Avicennia germinans	USA	67.3	35.8
Avicennia marina	Pakistan	100.0	65.4
	UAE	100.0	14.7
	Bahrain	100.0	11.4

These plants are expected to flower within a year or two. They will be used for production of half-and full-sibling progenies.

Initiation of a Tree Breeding Program for *Avicennia marina*. Tree improvement for *Avicennia marina* is being approached through selection of promising individuals from the existing local population and initiation of a systematic hybridization program to develop half-and full-sibling progenies of the introduced and local ecotypes. For this purpose, the two existing *Avicennia* populations were surveyed for phenotypic traits physical condition, growth and sensitivity to prevailing coastal conditions) to select promising individuals. Production of propagules in a local ecotype is shown in Plate 79. Propagules from these promising individuals were collected and propagated in the greenhouse (Plates 80 and 81). They will be planted in selected areas near KISR's main campus for further evaluation.

Additionally, seedlings of all the ecotypes have been grown in large containers for systematic and controlled hybridization to produce half-and full-sibling progenies.

Hybridization will also be carried out in the field. This work will be conducted during the next flowering season.

Plate 79. Seed setting of a local Ecotype in Shuwaikh site.

Summary

Seedlings of both introduced and local ecotypes have established successfully in the field and are making very good growth. A few seedlings of each ecotype have been planted in containers and maintained in greenhouse for controlled hybridization.

Plate 80. Seedlings of promising individuals of a local (Bahrain) ecotype.

Tree improvement in *Avicennia marina* has being approached in two ways; firstly by selecting promising individuals from the existing local *Avicennia marina* populations and evaluating their progenies in the field, and secondly by producing half-and full-sibling progenies of both introduced and local ecotypes. Seedlings of promising individuals have been raised and will be evaluated in the coming years.

Plate 81. Seedlings from promising individuals of local (UAE) ecotype.

Task 5. Preparation of Environmental Impact Statement

Introduction

Coastal habitats in Kuwait are extremely variable and support a large variety of productive marine ecosystems, ranging from exposed beaches to rocky highlands. Sand, mud and rock exist in both intertidal and sub-tidal littoral zones. Artificial structures (platform, jetties, etc.) and offshore islands play a significant role in the variability of resources existing in Kuwait.

In his study, Jones (1985) reviewed the coastal and marine habitats in the Arabian Gulf and noted that the interaction of the physical factors produces a severe regime for the marine biota of the region, especially intertidally, so that diversity is lower within the inner part of the area (from the Strait of Hormuz north) than in the Gulf of Oman and the Indian Ocean, in general. Biological and ecological data on the marine biota of the region are inadequate, with some coastal areas receiving more attention than others. At least four critical marine habitats, namely, coral reefs, intertidal marshes, mangrove and sea grass beds and, kept forest, have been recognized in the region (Price et al., 1993).

In an early study on saline irrigation for agriculture and forestry in Kuwait, it was suggested that mangrove species, *Avicennia marina*, was ecologically the most suitable for the muddy flats of Bubiyan island and some of the northern coast of Kuwait Bay that contains enough clay (Firmin, 1968). Due to their biological importance, initially mangroves were introduced at three sites along the southern part of Kuwait Bay in 1992-93. Because of the overall importance of the coastal zone as a principal national natural resource, it is, therefore, critical that an environmental assessment be conducted the mangrove plantation along the coastline of Kuwait.

KISR's division of Environment and Urban Development conducted this assessment. Particular attention was given to probable impacts that would result from the existence of such mangroves on the ecosystem of Kuwait Bay.

Coastal Geomorphology and Environmental Setting

Based on the sediment's nature and morphology, the coastal zone of Kuwait was classified into two main provinces: a northern muddy (material finer than 62.5 µm) province and southern rocky/sandy (coarser than 62.5 microns) province. These provinces were subdivided into several zones (Abu-Seida and Al-Sarawi, 1990).

The northern coastal area is characterized by the presence of Khor Al-Subiya, which is a long tidal channel 60 km long and 1.5 km wide, separating Bubiyan and Warba Islands from the mainland. The coastal strip of this area has a muddy intertidal flat 300 to 1300 m wide. The intertidal zone in this area is bound landward by a wide coastal sabkha (lowland occasionally flooded by water by high tide).

One of the features of the Kuwaiti marine environment is Kuwait Bay, an elliptical area that protrudes westward from the main Gulf water. The floor of the bay has an asymmetric slope with a maximum depth of about 20 m and an axis situated close to the southern coast.

According to Dames and Moore (1983) and Samhan et al. (1986), the water quality in Kuwait Bay and Khor Al-Subiya is acceptable. Dissolved oxygen levels are above minimum accepted limits, biological oxygen demand is low, trace metal concentrations are also low, and pH values are within acceptable limits. Moreover, strong tidal currents provide good flushing of the water of the bay, and about 30% of the water of the bay is exchanged in a normal tide cycle (Al-Ghadban and Al-Ajmi, 1993). Other physical and chemical parameters such as alkalinity, phosphorous level, salinity, and oil and grease are within acceptable and normal values for this region of the world.

The situation is somewhat different along the coastal zone. This area is exposed and stressed as a result of extensive man-made activities, such as dredging, indiscriminate solid and liquid waste disposal, and overfishing. In their extensive study of the coastal area of Kuwait, Al-Bakri et al. (1985) concluded that the alteration of the coastal zone had resulted in a greater impact on the ecosystem than the harsh environmental conditions. The environmental conditions of the coastal area became more critical as a result of war-related activities during the Gulf War (Al-Ghadban et al., 1993).

Influence of Mangrove Plantations along the Coastline

Mangroves in the Arabian Gulf region represent an important habitat that supports a large number of species of birds, crustaceae, fish, molluscs and other life, as well as contributing to the stability of the fragile ecosystem of this arid region. Mangroves are usually tolerant of harsh environmental conditions, in particular, low temperatures and high salinities. Research and publications on the ecological features and management of mangrove forests in the region are limited.

Plantation of mangrove requires a thorough investigation of shorelines. Suitable sites for such plantation require certain environmental conditions, such as fine-grained (muddy sand) material, areas from long waves and currents sheltered, and extended intertidal flats.

With intensive utilization and increased demand on the coastal zone in this region, problems of coordination, cohesion, and rationalization of insights of the different governmental authorities were apparent in the Regional Organization for the Protection of the Marine Environment countries of the Arabian Gulf, and Kuwait was no exception.

Environmental Impact Assessment

An environmental impact assessment (EIA) is a useful tool for evaluating the potential benefits and/or hazards that could occur to an environment by executing or operating a project, be it a factory, recreational area, or power station. The Scientific Committee on Problems of the Environment defined EIA as an activity designed to identify and predict the impact of a development or action on the bio-geophysical environment or on man's health and well being. EIA procedures, approaches, and methodologies outline the conditions for conducting an environmental impact investigation (i.e. the terms of reference by which the effects of a project are investigated, presented, and finally considered by decision-makers). The latter step is called an EIS. Such a statement could either be accepted for implementation or returned for more data generation and evaluation (i.e., for further assessment). In the present case, an integrated methodology was adopted as an EIA.

KISR promoted, developed, and completed several EIA studies. Ghobrial and Kassim (1986) implemented an environmental and hydraulic feasibility study of the proposed navigation channel in Kuwait Bay. El-Baroudi et al. (1986) conducted a preliminary assessment of the environmental impact of development projects in and around Sulaibikhat Bay (the southern sector of Kuwait Bay). Al-Bakri et al. (1984) undertook a project on “Evaluation and selection of disposal sites for solid wastes in the enlarged Shuaiba Industrial Area” (southern coast of Kuwait). Al-Nafisi and Al-Bakri (1990) developed a comprehensive legislative and administrative framework for EIA, which was proposed for adoption in Kuwait. Al-Ghadban and Al-Ajmi (1993) presented a summary of a detailed and comprehensive EIA of the Subiya Power and Desalination Plant that is now under commissioning.

Materials and Methods

The purpose of this task in the current study was to adopt an integrated approach for implementing an EIA and to develop potential mitigation measures for overcoming adverse impacts, should they develop. This integrated methodology incorporated the important findings realized from the potential ecological, physicochemical and aesthetic effects, and expressed them in a weighted model (a matrix), as detailed in previous progress reports (Taha et al., 2000). This report presents the results of the comparison between two sites of mangrove plantations: an old one in the KISR's main campus in Shuwaikh, where there are two stations, east (planted in 1993) and west (planted in July 1992); and a new one in Doha (planted in November 2000). These sites were compared using three parameters (water parameter measurements, total organic carbon content of the soil, and biodiversity) to ascertain the effects of mangrove plants on the environment. The data were recorded at periodic intervals, and a final statement was developed using the EIA perspective. The procedures employed for recording the data were as follows:

Water quality: The Horiba apparatus was used to estimate water quality parameters. For this purpose, a pit measuring 1.5 m in diameter was dug in the intertidal mudflat approximately 5 m away the plantation, and measurements were made using the apparatus.

Total organic carbon: Soil samples were collected from the upper layer in close proximity to the plant and analyzed for total organic carbon using the Wakeel and Riley method (Wakeel and Riley, 1957).

Biological Diversity: Five soil samples were collected at random from each of the two KISR sites and the Doha site. Various invertebrates were separated from the soil sample, which were then sorted, identified and classified to the species level by a taxonomist.

Results and Discussion

The water quality measured in two mangrove sites in Shuwaikh on January 31, 2001, and February 24, 2001, are presented in Tables 62 and 63, while the water quality data from Doha Site recorded on July 10, 2001, and October 2001, are shown in Tables 64 and 65. The results of the total organic carbon analysis in soil samples collected from the Shuwaikh and Doha Sites over a period of time are presented in Tables 66 and 67. The occurrence of various macroinvertebrates in the Shuwaikh East, Shuwaikh West and Doha Sites is shown Tables 68 through 70.

Table 62. Main Water Quality Parameters in the Shuwaikh (KISR) Sites (January 2001)

Station/Parameter	KISR (West)	KISR (East)
pH	7.5	7.7
Conductivity (ms/cm)	51.0	5.3
Turbidity (NTU)	50.0	29.3
Dissolved Oxygen (mg/l)	0.07l	0.1
Temperature (^{0}C)	14.0	14.0

NTU = Nephlometric turbidity units.

Table 63. Main Water Quality Parameters in the Shuwaikh (KISR) Sites (November 2001)

Station/Parameter	KISR (West)	KISR (East)
pH	8.2	6.6
Conductivity (ms/cm)	29	54
Turbidity (NTU)	99	81.3
Dissolved oxygen (mg/l)	3.7	0.3l
Temperature (^{0}C)	25	17

NTU = Nephlometric turbidity units

As far as water quality is concerned, some important outside factors occurred in Kuwait Bay that should be taken into account when assessing water quality. These include the discharge of about 30,000 cm^3 of untreated sewage water and the shutdown of seawater injection plant to the north along the Kuwait Bay (used to inject treated seawater into oil wells to maximize oil production), which led to the release of highly toxic and biocidal bacteria. These factors combined with the heat, humidity and high evaporation rate, might have lead to the fish kill incident that occurred in August 2001. This also caused the death of some mangrove plants in this area. Due to this impact, it is difficult to clearly pinpoint the influence of mangrove plants on water quality.

Nevertheless, a review of the literature (Kaly and Jones, 1998) suggested that mangrove plantations function as a cleansing system for sediments and nutrients, particularly in relation to aquaculture and sewage.

Table 64. Main Water Quality Parameters in the Doha Site (July 10, 2001)

Parameter	Value
pH	9.8
Conductivity (ms/cm)	41.0
Turbidity (NTU)	99.0
Dissolved oxygen (mg/l)	0.0
Temperature (^{0}C)	29.0

NTU = Nephlometric turbidity units

Table 65. Main Water Quality Parameters in the Doha Site (October 2001)

Parameter	Value
pH	7.3
Conductivity (ms/cm)	33.0
Turbidity (NTU)	17.0
Dissolved Oxygen (mg/l)	1.0
Temperature (^{0}C)	27.0

NTU = Nephlometric turbidity units

Table 66. Total Organic Carbon Percentage in the Shuwaikh Mangrove (KISR) Site (West)

Sample Number	Sample Date	Total Organic Carbon (%)
1	17 Jan 2001	2.60
2	22 Jan 2001	2.60
3	30 Jan 2001	2.40
4	7 Feb 2001	2.60
5	31 Feb 2001	2.06

Table 67. Total Organic Carbon Percentage in the Intertidal Mudflat at the Doha Site

Sample Number	Total Organic Carbon (%)
1	1.5
2	0.9
3	1.6
4	1.5
5	1.3

The percentage of total organic carbon in the soil ranged from 2 to 2.6% in the Shuwaikh Sites, while that in the Doha site ranged from 0.9 to 1.5%. This is because the mangrove plantations in the Shuwaikh Sites are nearly nine years old, and the accumulation of litter through the years as well as the eutrophication process have contributed to the presence of higher amounts organic carbon in the soil. In contrast, the mangrove plantation in the Doha Site is less than a year old and, hence, was low in organic carbon contents. In the long run, the increase in organic material leads to richness in animal species diversity. A comparison between the animal phyla and species in the Shuwaikh and Doha Sites indicated that the Shuwaikh Sites contained a greater number of phyla and richer species diversity. This was confirmed by the fact that the Shuwaikh East Site had Annelida, Mollusca, and Arthropoda phyla. Besides these phyla, the Shuwaikh West Site had Chordata phyla. In contrast, the Doha Site contained Mollusca and Arthropoda phyla only.

Table 68. Macro-invertebrates in the Mangrove Plantation in the Shuwaikh (KISR) Site, (East)

Taxa	Species	1	2	3
Phylum: Annelida				
Class: Polychaeta				
Family: Nereidae	*Nereis* sp.		X	
Phylum: Mollusca				
Class: Gastropoda				
Subclass: Prosobranchia				
Order: Mesogastropoda				
Family: Littorinidae	*Nodilittorina (Nodolittorina) arabica*		X	
Family: Planaxidae	*Planaxis sulcatus*		X	
Family: Potamididae	*Cerithidea cingulata*		X	
Family: Cerithiopsidae	*Seila* sp.		X	
Class: Bivalvia				
Subclass: Pteriomorpha				
Order: Taxodonta				
Family: Ostreidae	*Saccostrea cuccullata*		X	
Phylum: Arthropoda				
Class: Crustacea				
Subclass: Cirripedia	*Balanus amphitrite*		X	X
Subclass: Malacostraca				
Order: Isopoda	*Ligia exotica*	X		
Order: Decapoda				
Suborder: Reptantia				
Family: Paguridae	*Unknown hermit crab* sp.	X		
Phylum: Annelida				
Class: Polychaeta				
Family: Nereidae	*Nereis* sp.			X
Phylum: Mollusca				
Class: Gastropoda				
Subclass: Prosobranchia				
Order: Mesogastropoda				
Family: Potamididae	*Cerithidea cingulata*		X	X
Class: Bivalvia				
Subclass: Pteriomorpha				
Order: Taxodonta				
Family: Ostreidae	*Saccostrea cuccullata*		X	

X = present.

Also, all through the months of autumn, spring and early summer, greater numbers of the migratory birds, especially flamingoes, were found to have taken refuge near mangrove plants in these sites (Plates 82 and 83). This indicates an increased availability of food sources and fishes for these birds near mangrove sites.

Table 69. Macro-invertebrates in the Mangrove Plantation in the Shuwaikh (KISR) Site, (West)

Taxa	Species	1	2	3
Phylum: Arthropoda				
Class: Crustacea				
Subclass: Cirripedia	*Balanus amphitrite*			X
Subclass: Malacostraca				
Order: Decapoda				
Suborder: Reptantia				
Family: Paguridae	*Unknown hermit crab* sp.	X		
Family: Ocypodidae	*Ucalactea*	X		
	Nasima dotilliforme			X
	Manningis arabicum			X
	Macrophthalmus depressus		X	
	Llyoplax stevensi			X
Phylum: Chordata				
Subphylum: Vertebrata				
Class: Osteichthyes	*Scartelaos viridis*			X
	Boleophthalmus boddarti			X
Family: Ocypodidae	*Una sindensis*	X	X	X
	Uca lacteal	X	X	X
	Nasima dotilliforme		X	
	Manningis arabicum		X	
	Macrophthalmus depressus	X	X	
Family: Grapsidae	*Nanosesarma minutum*		X	
Phylum: Chordata				
Subphylum: Verterbrata				
Class: Osteichthyes	*Scartelaos viridis*			X
	Boleophythalmus boddarti			X

X = present

Plate 82. Mangrove plantations attract flamingoes and other birds.

In view of these observations and within the limited time available during this project, it was concluded that mangrove plantations have positive impacts on the marine and coastal ecosystem and environment. Therefore, the establishment mangrove plantations in appropriate sites along coastlines of Kuwait is recommended. However, it is important to recognize that these observations are preliminary and need to be supported by additional data as plants develop larger canopies and exert greater influence in the coastal ecosystem and marine environment.

Table 70. Macro-invertebrates in the Mangrove Planta-tion in the Doha Site

Taxa	Species	1	2	3
Phylum: Mollusca				
Class: Gastropoda				
Subclass: Prosobranchia				
Order: Mesogastropoda				
Family: Potamididae	*Cerithidea cingulata*	X	X	X
Class: Bivalvia				
Subclass: Pteriomorpha				
Order: Taxodonta				
Family: Mytilidae	*Brachidontes variabilis*	X		
Order: Heterodonta				
Family: Trapeziidae	*Trapezium sublaevigatum*			
Family: Chamidae	*Chama asperella*			
Phylum: Arthropoda				
Class: Crustacea				
Subclass: Cirripedia	*Balanus amphitrite*	X		
Subclass: Malacostraca				
Order: Amphipoda				
Family: Corophiidae	*Unknown amphipod*			
Order: Decapoda				
Suborder: Natantia				
Family: Alpheidae	*Alpheus djeddensis*			X
Suborder: Reptantia				
Family : Ocypodidae	*Uca sindensis*	X		
	Nasima dotilliforme			X
	Nasima sp.	X	X	X
	Manningis arabicum			X
	Iiyoplax stevensi		X	
Family: Grapsidae	*Sesarma plicatum*	X		
Family: Xanthidae	*Eurycarcinus orientalis*		X	

X = present

Plate 83. Another view of the Shuwaikh (KISR) Site (east).

Summary and the Final Environment Impact Statement

The integrated impact methodology indicated positive impacts of mangrove plants on all environmental parameters, particularly, physicochemical effects. Hence, it is concluded that positive impacts are associated with such plantation, and mangrove plantation in the study area had and will have more positive impacts on the surrounding ecosystem.

Due to the nonexistence of adverse or negative impacts, there is no need to suggest any mitigation measures at this time However, continuous follow-up and measurements of the water quality and other environmental parameters, especially of organic and nonorganic pollutants, should be continued to obtain additional information for evaluation and detailed assessment.

It can also be concluded that the EIA adopted here is meaningful and can be used for similar studies. It requires the existence of environmental baseline data and the formulation of a multidisciplinary team. The present study is the first study of its kind in Kuwait and, hence, the findings of this study will provide the baseline information and guidelines for future assessments. Based on the results of the present study, it is recommended that coastlines to be enriched in Kuwait through mangrove plantation. At the same time, it is suggested that long-term assessment be continued of the environmental impact of mangrove plantations on the coastal and marine environment to develop a final statement in this regard.

Conclusions and Recommendations

Mangroves are important not just biologically, but also historically in the Arabian Gulf region. The number of mangrove species, and associated flora and fauna in the Arabian Gulf is low compared with that in other mangrove-growing areas. Of the species known in the region, *Avicennia marina* is by far the most common species used for landscape beautification in the region, especially in the UAE, Bahrain, Oman and the KSA, although others like *Rhizophora mucronata*, *Ceriops tagal* and *Bruguiera gymnorrhiza* are planted on a limited scale.

Kuwait's marine environment is characterized by a shallow shelf less than 30 m deep, with the depth tending to increase in the southeasterly direction. One of the important features of this ecosystem is Kuwait Bay, an elliptical engulfment protruding westward from the Gulf, with depths mostly between 0 and 10 m. Like in other parts of the Gulf area, the morphology of the marine environment favors the formation of a highly sedimentary environment, providing suitable habitats for sea grasses and algae. Soft substrate habitats (mudflats), which constitute nearly 57% of the Kuwaiti coast and spread around the northern area (Bubiyan Island) to Kuwait Bay, are very important as they provide habitats for large populations of mudskippers, crabs, gastropods and shrimp. As coastal and marine resources are important national resources for Kuwait, there is an immediate need to improve the quality of the country's coastal areas.

Kuwait has initiated comprehensive greenery and environmental enhancement programs in response to the desire of His Highness the Amir to beautify and enrich the country. Introduction of mangrove plantations can play a major role in achieving the objectives of the program in the intertidal areas of the mainland and the islands. Afforestation with mangrove in the intertidal flats is a good strategy for developing green cover and enriching wildlife populations. In areas where shoreline erosion is a problem, mangrove trees would provide reasonable protection from storm waves and play a secondary role in the accumulation of sediment. Natural stands of mangrove trees have a moderating influence on the local climate and enhance the aesthetic and recreational value of the coastlines.

Studies conducted elsewhere have clearly established that mangrove plantations along the coastlines would significantly improve marine productivity and the coastal environment. Further, a review of the literature on mangrove ecosystems worldwide, indicated a good potential for growing certain species of mangroves in arid climates.

Therefore, it was considered important to make concerted efforts to establish ecological and environmental feasibility for artificial afforestation with mangrove species along the coastlines, and to develop suitable nursery and silviculture practices to grow them under the harsh arid climate of Kuwait. Thus, a three year project was undertaken jointly by KISR and PAAFR in January 1999.

Five tasks involving several experiments were conducted to accomplish the project's objectives. The conclusions and recommendations are listed below:

- The results indicated a positive influence of propagule size and a negative influence of duration of presoaking on propagule germination and initial seedling growth. Large-sized propagules (weighing 4.7 g or more) that were soaked for 24 hours before sowing germinated faster than smaller propagules. An extended period of presoaking resulted in the browning of hypocotyls and adversely affected germination.
- September and October sowing produced more viable seedlings than May sowing. However, seedlings from the May sowing grew faster than those from the September and October sowing.
- Sowing the propagules in 500 ml polybags filled with 100% soil or soil mixed with sphagnum peat moss (1:1 v/v) produced quality seedlings.
- Propagules can be germinated either in flooded benches or under intermittent mist. Under Kuwait’s climate, propagules should be germinated in environment-controlled greenhouses and acclimatized to prevailing environmental conditions when they reach a transplantable stage.
- Although seedlings appeared to be healthy, they grew slowly during winter months. The Pakistani ecotype was severely affected by low temperatures and severe thrips infestations. In contrast, *Avicennia germinans* seedlings were completely free from pest infestations and also withstood low temperatures better than *Avicennia marina*.
- Germinating the propagules and growing the seedlings in freshwater in a greenhouse, and their acclimatization to the salinity of seawater was a more efficient and preferable approach to germinating them directly in saline water.
- It is important to recognize the fact that mangrove plantations cannot be established in every available vacant mudflat as site and environmental conditions largely determine the success of establishment, productivity and

sustainability of mangrove ecosystems. Therefore, a very detailed site survey and site selection are prerequisites for establishing successful mangrove plantations.

- The site selection criteria developed in the project for locating suitable sites for *Avicennia marina* plantations in Kuwait included site-specific characteristics (accessibility; human impact; dimensions of the mudflats; topography; presence of contaminants, rubble and construction material; likely environmental impact, and tidal coverage), and physical (color, SP, and particle distribution) and chemical (Eh, pH, EC, $CaCO^3$, and SAR) properties of soils in the intertidal mudflats. A taxonomy system (Soil Survey Staff, Soil Conservation Service, 1998) was used to classify each profile. Using these criteria, Kuwait's coastline was surveyed, and 14 potential sites were assessed for their suitability. Out of these, only five sites met all the criteria and were finally selected.
- Experimental mangrove plantations were established in five selected sites. Frequent post-planting field visits were made to monitor plant survival and growth. Besides monitoring plant performance, on-site investigations were carried out during these visits, and soil samples were collected from different areas where plants had established very successfully, as well as from areas where plant mortality was relatively high. Soil samples were analyzed in the laboratory. The data suggested that variations in site and soil characteristics contributed to the observed differences in plant performance. However, it is rather difficult to determine which site characteristics are conducive to successful mangrove establishment in all the sites as different characteristics seemed to have different levels of influence at different sites.
- It was concluded from site characterization that at the Shuwaikh (KISR) Site, areas with muddy surface material (0 to 5 cm) underlain by a layer of fine gravelly sandy material produced higher plant survival and better vegetative growth than other areas. In contrast, areas that were predominately sandy or clayey were found to be unsuitable for mangrove plantation. Contamination of intertidal mudflats with fresh petroleum oil resulted in high plant mortality.
- At the Doha Site, wet sandy loam areas that are covered by daily tidal water were found to be ideal for establishing mangrove plantations. Dry areas with

relatively high field salinity levels and poor tidal coverage increased plant mortality and affected plant growth in *Avicennia marina*.

- At Sulaibikhat Site 1, high salinity, textural differences and poor drainage increased plant mortality and affected plant growth. The ideal site conditions at this location include 74% sand, 7.5% silt and 18.5% clay.
- At Sulaibikhat Site 2, the major differences were recorded in soil texture in the root zone. The main reasons for plant failure were found to be the hypersaline conditions, textural differences and the resultant poor drainage.
- At the Subiya Site, laboratory analysis did not show any clear-cut differences in soil characteristics. *Avicennia marina* plants survived better than *Ceriops tagal* at this site.
- Tree improvement in *Avicennia marina* has been initiated through selection of promising individuals from the existing local population. Three additional *Avicennia marina* and one additional *Avicennia germinans* ecotypes have been established for a systematic hybridization program to develop half-and full-sibling progenies of the introduced and local ecotypes.
- The integrated impact methodology indicated positive impacts of mangrove plants on all environmental parameters, particularly physicochemical effects. Hence, it was concluded that mangrove plantation in the study area has and will add more positive impacts to the surrounding ecosystem.
- Due to the nonexistence of adverse or negative impacts, there is no need to suggest any mitigation measures at this time However, continuous follow-up and measurement of the water quality and other environmental parameters, especially the organic and nonorganic pollutants, should be continued to obtain additional information for evaluation and detailed assessment.
- It can also be concluded that the environmental impact assessment adopted here is meaningful and can be used for similar studies. It requires the existence of baseline environmental baseline data and the formulation of a multidisciplinary team. The present study is the first study of its kind in Kuwait, and hence, the findings of this study will provide baseline information and guidelines for future assessments.

Using the results of this project, a planting scheme has been proposed for establishment of mangrove plantation in Kuwait (Fig. 5).

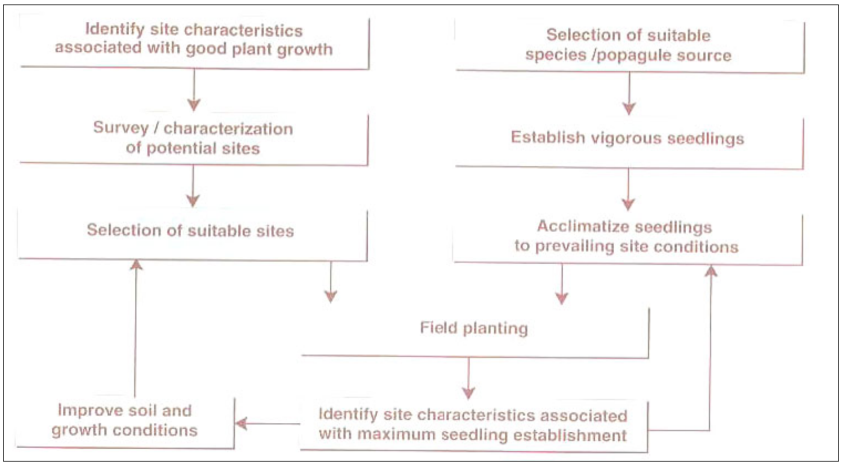


Fig. 5. Mangrove planting scheme for Kuwait.

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AUTHOR CURRICULUM VITAE

Name Narayana R. Bhat

Education

- Ph. D. (1982) - The Ohio State University, USA.
- M. Sc. (1975) - Punjab Agric. Univ., India.
- B.Sc. Agriculture (1973) - Univ. of Agric. Sci., India.

Professional Experience

December 1995 - Present.

Kuwait Institute for Scientific Research. (KISR)
Associate Research Scientist.

- As Project Leader (PL) completed three research projects and two in-house research activities. Currently, leading one research project.
- Served as Deputy PL in one and Principal Investigator (PI) in five additional completed client funded projects.
- Developed a number of projects for client funding
- Actively participated in marketing of projects and client negotiations.
- Developed linkage with local producers.
- Upgraded research facilities.
- Currently, involved in testing of hydrophilic polymers and mulches for water conservation in greenery projects, screening of new plants for salt- drought-tolerance, testing of modern revegetation technologies for rehabilitation of degraded lands and enhancement of water-use efficiency of ornamental and vegetable crops.
- Closely involved in national manpower development and rendering technical advice in plant production.

June 1991 - Dec. 1995.

Indo American Hybrid Seeds.
Associate Director.

- Led company's Biotechnology Division and managed both professionally and profitably a ten-million plantlet capacity commercial tissue culture laboratory.
- Established a new commercial tissue culture laboratory at their new production facility.
- Close involvement in the development/ commercialization of protocols and marketing of tissue-cultured plants.
- Coordinated establishment of new agri-horticultural projects, with bank finance.
- Interacted with financial and government institutions,
- Recruited high caliber production and marketing staff.
- Established the central region marketing office and provided effective leadership and motivation to marketing staff to expand the sales.
- Supervised/ Guided production and marketing staff.
- Recipient of President's appreciation award.

April 1990 - July 1990.

Kuwait Institute for Scientific Research (KISR).
Associate Research Scientist.

- Project Leader of the project that dealt with ornamental plant introduction and standardization of production technologies for arid growing conditions.

- Developed a project that was approved by KISR management and assured client funding, but could not implemented due the Iraqi invasion.
- Guided and supervised the research work of four Research Associates and three Technicians.
- Trained and developed human resources in plant production.
- Rendered technical advice in plant production.

December 1988 - March 1990.

Postdoctoral Fellow. The Ohio State Univ., USA.

Conducted research on:

- Regulation of growth, flowering and post production quality in greenhouse flower crops.
- Kinetics of wetting agent action in soilless container growing media.
- Wetting agent phytotoxicity in floral crops
- Quantification of wetting agent in soilless growing media.
- Closed production systems for containerized floral crop production.
- Controlled release fertilizer use in containerized floral crop production.

February 1983 - Dec. 1988.

Mahatma Phule Agric. Univ., India.

Assoc. Prof. of Horticulture.

- Taught graduate courses in horticulture physiology and seed production technology.
- Chaired advisory committees of seven postgraduate students in horticulture. Served on advisory committees of a number of students.
- Conducted research on production and post production physiology of horticultural plants.
- Managed (with both financial and operational control) a state-funded research project on onion production.
- Supervised Research Assistants and Technicians.
- Advised farmers on plant production.
- Enhanced professional capabilities through post doctoral fellowship from Dec. 1998 - Mar. 1990).

July 1982 - January 1983.

Post-doctoral Fellow, Paul Ecke Poinsettias, USA.

- Conducted research on production physiology of poinsettias and hydrangea.
- Tissue culture propagation for producing virus free stock plants in poinsettias and hydrangea.
- Hands-on experience in commercial growing of poinsettias and hydrangea.

January 1979 - June 1982.

Ph. D. Scholar, Ohio State University, Columbus, USA.

Actively participated in research on:

- Regulation of growth and development of horticultural crops,
- Soilless container growing media.
- Mode of action of plant growth regulators.

April 1976 - Dec. 1978.

Himachal Pradesh Agric. University, India.

Asst. Prof. of Floriculture.

- Taught undergraduate courses ornamental horticulture

- Conducted research in floriculture crop production.

June 1975 - March 1976.

Punjab Agricultural University, India.
Lecturer.

- Taught undergraduate courses in landscape planting designs, ornamental planting materials and commercial floriculture.
- Conducted research in floriculture crop production.

Publications

66 Research.
Seven Books.
17Conference Papers.
53 Technical/ Progress Reports.

Scientific Affiliation

Member of Global Biosaline AgricultureNetwork.
Member of Salinity and mangrove discussion groups.

Research Focus

Dr. Bhat’s research is aimed at developing a sustainable plant production sector in Kuwait through selection and naturalization of salt- and drought-tolerant crops, enhancement in water-use-efficiency in plant production and optimization of growth and visual greenery impacts under harsh arid climatic conditions.
Currently, Dr. Bhat is involved in testing of hydrophilic polymers and mulches for water conservation in greenery proejcts, screening of plants for salt- and drought-tolerance, naturalization of plants for greenery development and fruit production and development of efficient technologies for revegetation of degraded lands. Dr. Bhat is closely involved in project development, marketing, interaction with clients, project execution and strengthening local expertise through training of national manpower.

Honors and Awards

Recipient of a number of awards and recognition:

- 1995 - Appreciation award and plaque for outstanding performance (Indo American Hybrid Seeds)
- 1990 - Certificate for outstanding research performance (The Ohio State university)
- 1985 to 1988 - Expert member on the Vegetable and Floriculture Scientific Panel (Indian Council of Agricultural Research)
- 1975 - Merit certificate for academic excellence (Punjab Agricultural University)
- Member of honor societies:
  - Phi Alpha Xi –Flor. Scholastic Soc., USA
  - Gamma Sigma Delta – Agric. Scholastic Soc. USA
  - Phi Kappa Phi –Univ. Scholastic Soc., USA
- Name included in “International Who’s Who” and “Men of Achievement” by IBC, London
- National and merit scholarship holder (1978-82, 1973-75, 1972-73 and 1970-71)