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Significance of Mangroves in the Arid Environment of the Sultanate of Oman

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خلاصة : تتوافر معلومات قليلة عن الدور البيئي للنوع الوحيد لأشجار القرم (أفانسينا مارينا) في عمان. لذا تقدم هذه الدراسة معلومات عن البيئة الطبيعية للمناطق الثلاث التي تعيش فيها أشجار القرم (القرم بمسقط، محوت وشناص) شاملة الصفات الرئيسية لكل منطقة (مثل هيكل الجماعة، تحاليل المياه والتربة والكائنات الحية). يتميز مناخ البيئات الثلاث والمناطق المحيطة بها بأنه حار وجاف، فمعدل سقوط الأمطار قليل (أقل من ١٠٠ مم سنويا) ودرجة حرارة الهواء مرتفعة (متوسط ٢٧ درجة مئوية) وكذا الرطوبة النسبية (٥٧٪ في القرم، ٧٢٪ في محوت وشناص) وأيضاً الإشعاع الشمسي (أكثر من ٥٠٠ ميجا وات ساعة/سم٢) كما أن معدل بخر المياه عال جداً (أكثر من ٣٠٠٠ مم سنويا). تزهر أشجار القرم في يناير - مارس وتكون ثمارها في إبريل - مايو وتسقط بذورها في يونيو وتنبت البذور في يوليو - أغسطس وتتكون الأوراق لأول مرة في سبتمبر. وقد أظهرت الدراسة فروقاً معنوية بين المناطق الثلاث من حيث المساحة (١٦٢ هكتار في محوت، ٧٤ هكتار في القرم و٥٣ هكتار في شناص)، وهيكل الجماعة المتمثل في ارتفاع الأشجار ونصف قطرها ومساحة الغطاء الخضري. وقد وجدت علاقة طردية بين نصف قطر الأشجار والكثافة العددية. وأظهرت الدراسة اختلافات معنوية في الصفات الطبيعية والكيمائية للتربة داخل كل منطقة وأيضاً بين المناطق الثلاث. نسبة الرمل سائدة في التربة في حين يتواجد الطمي (أعلى نسبة في القرم، ٣٢٪) والطين (أعلى نسبة في محوت ١٠,١ ٪) بكميات معقولة. وتميزت تربة محوت بإرتفاع نسبة المواد العضوية (١٠,٢ ٪) والنيتروجين الكلي (٠,٢ ٪) والفسفور (٥٦,٢ جزء في المليون) والكبريتات (١٧,١ ملي مكافئ لكل ١٠٠جم). وتراوحت درجة حرارة المياه بين ٢٢ - ٣٨ درجة مئوية، ولم تتغير كثيراً ملوحة المياه في محوت (٣٧ - ٤٠ جم/لتر) وشناص (٣٦ - ٣٧ جم/لتر) عدا القرم التي تفاوتت ملوحة مياهها بين شبه عذبة وشبه مالحة (١٠ جم/لتر) إلى مياه مشبعة بالأملاح (أكثر من ١٠٠ جم / لتر). وقدر الأكسجين المذاب في الماء بمتوسط ٨,١ (٤,٨ - ١٢,٧) مجم/لتر، والرقم الهيدروجيني كان بمتوسط ٧,٨ (٦,٨ - ٨,٩). وقد تميزت بيئة أشجار القرم بمجموعات وأنواع كثيرة من الحيوانات شملت الطيور (أكثر من ٢٠٠ نوع)، والأسماك (٤٥ نوعاً)، والقشريات (٣١ نوعاً) والرخويات (٥١ نوعاً). وأظهرت بعض المجموعات نمطاً معيناً في توزيعها (مثل السرطان والمحاريات) والبعض الآخر مجرد زائرة (أسماك وطيور). في حين تعتبر معظم الحيوانات مستقرة في بيئة أشجار القرم.

ABSTRACT: Little is known of the ecological role of the only species of mangrove, *Avicennia marina*, in Oman. This study provides information on the physical habitat of three mangrove areas (Qurm, Mahout and Shinas) in relation to the main features of each area (i.e., community structure, soil and water analyses and biota). The climate of the three mangrove areas and the surrounding regions is hot and arid: all have very low rainfall (< 100 mm yr^{-1}), high air temperature (mean 27°C yr^{-1}), relative humidity (57.8% at Qurm and 72% at Mahout and Shinas), solar radiation (> 500 MWH cm^{-2}) and evaporation rates (> 3000 mm yr^{-1}). Mangrove trees flowered during January-March, fruits matured during April-May, seedlings fell in June, seeds germinated in July-August and leaves were produced in September. Differences among sites included areal extent (162 ha in Mahout, 74 ha in Qurm and 53 ha in Shinas) and high variability in mangrove structure within and between sites. The most obvious differences between sites related to tree height, diameter, density and basal area. The increase in tree diameter was associated with increase in tree height and basal area, but an inverse relationship existed between tree diameter and density. Significant differences in soil texture and chemical analysis were found within and between the three mangrove sites. Soil texture was dominated by sand; however, silt (highest at Qurm, 32%) and clay (highest at Mahout, 10.1%) were present in considerable amounts. Soils of Mahout had the highest organic matter (10.2%), total nitrogen (0.2%), available phosphorus (56.2 ppm) and sulphate (17.1 meq 100 g^{-1}) contents compared to those from Qurm and Shinas. Water temperature ranged 22 - 38°C and salinity showed small variations at Mahout (37-40‰) and Shinas (36-37‰), but at Qurm, salinity showed remarkable variation from fresh and brackish water (10‰) to hypersaline water (> 100‰). Dissolved oxygen averaged 8.1 (4.8 - 12.7) mg l^{-1} and pH was 7.8 (6.9 - 8.9). Mangrove communities included a faunal assemblage of many species of birds (> 200 species), fish (54 species), crustaceans (31 species) and mollusks (51 species). Some groups exhibited clear zonation pattern (e.g. crabs and oysters), others were just visitors (fish and birds), but the majority were resident in the mangroves.

Mangrove communities in Arabia, one of the most arid regions of the world, have low species diversity which is attributed to the severe climatic and environmental conditions in conjunction with limited range of suitable habitats and niches (Sheppard *et. al.* 1992). Options for utilization of mangroves in the arid

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environments are more restricted than those from wet humid tropics, partly because environmental constraints on growth tend to limit the range of suitable sites and partly because growth may be too slow to provide sustainable usable products (Clough 1993). However, in Oman, pre-historic fishermen exploited the mangrove resources at Qurm more than 7000 years ago (Biagi *et. al.* 1984) and the small island Mahout, fringed with luxuriant development of mangroves, still provides sustainable fisheries, mostly shrimps (Fouda and Al-Muharrami 1995).

There is only one species of mangrove, *Avicennia marina*, in Oman and very little is known on its ecological role in this area. The Qurum Nature Reserve (QNR) at Muscat is one of the most popular recreational areas in Oman and offers excellent opportunities for fisheries, education, research and nature interpretation, making its conservation even more important. However, its natural resources are not well known, as is the case with other mangroves in Oman. Therefore, the objectives of this study were to compare the mangroves of QNR with other mangrove areas in Oman and to identify important features of QNR. This has been achieved by collecting meteorological data on three mangrove sites (Qurum, Mahout and Shinas) and by studying mangrove structure (areal extent, phenological events, tree size, density and basal area), soil and water analyses and faunal assemblages.

Materials and Methods

Data on climate (air temperature °C), relative humidity (%), solar radiation (MWHcm^{-2}), evaporation (mm yr^{-1}) and precipitation (mm yr^{-1}) during the last 10 years were obtained from the Department of Meteorology, Ministry of Communication. Data were collected from localities close to the mangroves at Mina Qaboos (few km from Qurm), Masirah where Mahout Island is located in the Gulf of Masirah, and Majlis, Sohar (40 km from Shinas), and annual and monthly means were calculated.

Maps of the three mangrove areas at a scale of 1:20000, obtained from the National Survey Authority, were used to calculate surface areas, together with aerial photographs taken in 1982 and 1993. Field surveys around the periphery of each mangrove site were made to confirm and modify (when necessary) the current areal extent of each area. Search was made on new growth of mangroves and then plotted on the map of each area. Regular visits were made to Qurm where phenological information were collected on the time of: (a) flowering, (b) fruit production, (c) seedling fall, (d) seed germination and (e) leaf production.

The structure of the mangrove forests (tree height and diameter at breast height (dbh), density and basal area) was studied by the Point-Centre Quarter Method of Cottam and Curtis (1956) and Cintron and Novelli (1984). Eight transect lines were established along the mangroves of Qurm, three in Mahout and one in Shinas (Figure 1). These transects were selected in sites to allow easy and safe crossing along the mangal from the upper to the lower level of the shore. These sites were usually at places where mangrove creeks could be traced from the shore in Mahout, but in Shinas and Qurm transects were across the mangrove creeks which were separated from the sea by a sand bar.

A total of 56 soil samples were obtained from Qurm (31 samples representing transects 1,3,5,6,8), Mahout (11 samples representing transects 1 and 3) and Shinas (14 samples representing one transect), Figure 1. Soil analyses included soil texture (% of sand, silt and clay) and chemical analyses: (electrical conductivity (E.C.), % organic matter, % total nitrogen, available phosphorus (ppm) and sulphate (meq. 100 g^{-1} soil). Methods of soil analyses followed those of Butler *et. al.* 1987.

Water analysis, carried out in the field using a Hydrolab Environmental Data System, Model SWR2-SU, measured water temperature (°C), dissolved oxygen (mg. l^{-1}), pH and salinity (‰).

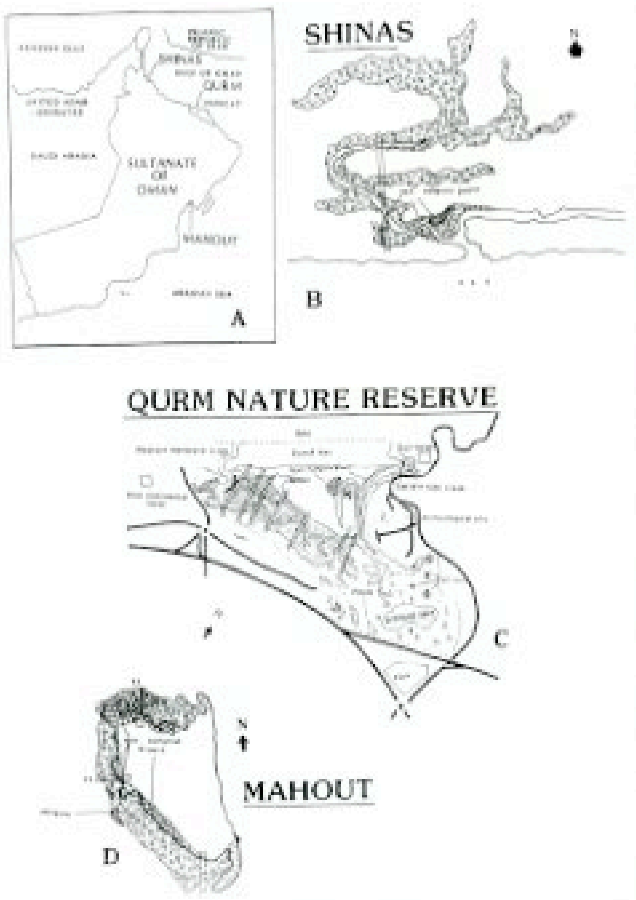

Figure 1. Map of the Sultanate of Oman (A) and the three sites studied: (B) Shinas, (C) Qurm and (D) Mahout.

TABLE 1

Summary of meteorological data of the last 10 years (1983-1993), from the Department of Meteorology, Ministry of Communication.

PARAMETER		AREAS					
		QURM		MAHOUT		SHINAS	
Rainfall (mm/yr)	Mean (range)	68.3	(0.7 - 161)	53.9	(6.6 - 278)	103.0	(8.0 - 260)
	Maximum (range)	524.0	(17.0 - 1824)			902.0	(79.0 -2647)
Air Temperature (°C)	Mean (range)	26.7	(16.8 - 29.4)	26.3	(26.0 - 27.0)	26.5	(26.0 - 27.0)
	Minimum (range)	20.6	(12.7 - 23.2)	15.8	(12.4 - 18.4)	7.6	(5.7 - 10.6)
	Maximum (range)	34.2	(20.9 - 37.6)	29.9	(28.6 - 31.0)	46.8	(44.0 - 50.0)
Relative Humidity (%)	Mean (range)	57.7	(54 - 61)	72.1	(69.0 - 77.0)	72.7	(71.0 - 75.0)
	Minimum (range)	6.0	(4 - 7)	11.7	(8.0 - 14.0)	9.0	(6.0 - 18.0)
	Maximum	100.0		100.0		100.0	
Global Solar Radiation (MWH/cm^2)	Mean (range)	555	(497 - 584)	479	(454 - 535)	---	
	Minimum (range)	113	(49 - 163)	163	(81 - 785)	---	
	Maximum (range)	786	(733 - 834)	672	(601 - 785)	---	
Evaporation (mm/yr)	Mean (range)	3976	(3066 - 4270)	---		2336	(1716 - 3066)
	Minimum (range)	694	(110 - 1095)	---		694	(73 - 1387)
	Maximum (range)	11205	(10475 - 16096)	---		7994	(6023 - 1095)

Fishes and shrimps were collected by a small seine net, a cast net and gill nets of different mesh sizes (2, 5 and 7.5 cm), in mangrove creeks and the surrounding shallow water. They were preserved immediately in 4% formaldehyde. Invertebrates, mostly crabs and mollusks were collected at low tide by hand from different places of the upper and lower level of the shore and within the mangrove swamp. Faunal zonation in different habitats of the mangroves was noted and the dominant species were recorded. In the laboratory, samples were sorted and identified to species level (when possible) following the available literature (Crosnier 1965, Bosch 1982, Smythe 1983, Jones 1986, Fouda and Hermosa 1993). The size of the dominant species was measured and size frequency distributions plotted.

Occurrences on large wildlife were noted. Turtles were identified following Salm and Salm (1991), birds following Gallagher and Woodcock (1980) and mammals following Harrison (1977). Lists of birds recorded during the last 20 years in Qurm, Mahout and Shinas were obtained from Oman Bird Record. They were analyzed in terms of number of species and the number of birds in each area. The bird fauna of each mangrove area was then compared with the other two to find out the common species in more than one site.

Data on mangrove structure and soil were analyzed using various statistical procedures (Correlation, t-test and analysis of variance) (SAS 1985, Ott 1993).

Results

CLIMATE: The climate of the three mangrove areas and the surrounding regions was hot and arid. All had low rainfall, high air temperatures, low relative humidity, high solar radiation and high evaporation rates (Table 1). The mean annual rainfall was 54 mm yr^{-1} at Mahout, 68 mm yr^{-1} at Qurm and 103 mm y/r at Shinas. However, values varied considerably, from a minimum of 0.7 mm (1985) at Qurm to a maximum of 279 mm (1983) at Shinas. Rainfall was mostly concentrated during February in all the three areas and extended till May. No consistently very humid months existed but there was considerable variation from one year to another and among areas. The annual mean relative humidity was 73% at Mahout , 58% at Qurm and 73% at Shinas.

Air temperatures were high throughout the year with annual means of 26.3 - 27.1°C in the three areas studied. However, there were increases in the annual maximal mean temperatures from south to north being 29.9°C at Mahout, 34.2°C at Qurm and 46.8°C at Shinas. Monthly mean air temperatures exhibited the same pattern in the three areas. At Qurm, there were gradual increases from February (20°C) till June (35°C), followed by decreases till (21°C) December.

Global solar radiation varied from 479 (163-672) MWH cm^{-2} at Mahout to 555 (117-786) MWH cm^{-2} at Qurm, and evaporation rate from 2336 (1716-3066) mm/yr at Shinas to 3796 (3068 - 4270) mm/yr at Qurm. Monthly global solar radiation means and evaporation followed the same pattern observed for air temperature.

As for evaporation, according to UNESCO's (1979) classification of the World Distribution of Arid Climate and the degree of aridity, based on rainfall, Qurm was the most arid area with a ratio of 1:0.0179, followed by Shinas (1:0.04409) and then Mahout (1:0.054).

Mangrove Structure

VEGETATION COVER: The estimated total mangrove area of the three sites was 298 ha; Qurm contributed 74 ha, Mahout 162 ha and Shinas only 53 ha. Considerable growth for Qurm was shown by comparing recent aerial photographs with those taken in 1982. Newly developed mangrove trees were concentrated at the eastern and western sides of the mangrove channels in Qurm (Figure 1C). Newly developed mangrove trees at Mahout were concentrated at the northern site of the island (Figure 1D), whereas at Shinas they were on the extensive shallow areas close to the entrance of the mangrove channel (Figure 1B).

Dead mangrove trees at Qurm occurred at the south-eastern site where swamp areas of hypersaline waters existed. In addition, considerable numbers of recently dead large mangrove trees were observed along the western mangrove channel as well as in areas where dense vegetation existed.

Phenology and Life History of Mangroves

Mangrove trees flowered during January-March, fruits matured during April-May, seedlings fell in June, seeds germinated in July-August and the new foliage were produced in September. By December small mangrove stems became abundant, usually close to the waters edge, with an average of 5.6 stems m^{-2}. They varied in height from 12 to 55 cm with an average of 31.6 cm and an average of 5.6 (4-8) leaf/stem. Older stems produced in the previous year were identified by their branches (usually 3), height (an average of 74.8 cm) and number of leaves (an average of 26 leaf/stem).

Structure of Adult Mangrove Trees

The average tree height, density and mean basal area were higher in Shinas than in Qurm and Mahout (Table 2). On the other hand, the average tree diameter at breast height (dbh) was quite similar in the three sites studied. Differences in tree height were statistically significant between Qurm and Shinas, but not between Qurm and Mahout nor between Shinas and Mahout. On the other hand, densities and mean basal area were similar between Qurm and Mahout, but significantly different from Shinas.

In Mahout there were progressive increases in tree height, diameter (dbh) and basal area from the upper to the lower elevation of the shore (Fouda and Al-Muharrami 1995). In Shinas, there were increases in tree size (height and diameter) from the upper level of the shore to a distance of 70-100 m. Another increase in tree size occurred at 170-180 m. The location of the large trees at 100 and 180 m corresponded to the presence of mangrove creeks. On the other hand, inverse data were obtained for density where higher densities were found close to the shore and at 160-170 m, when large trees were fewer. Lower densities were obtained at 50-100 m and 130-150 m when tree size was high.

In Qurm, data on tree size, density and basal area along the 8 transects did not exhibit specific patterns. However, when data were analyzed by analysis of variance, it was found that the differences in the average tree height, dbh, density and basal area were significant ($P < 0.01$), (Table 3).

For Mahout, correlation analysis has shown that the increase in tree diameter was associated with increases in tree height, with a high correlation value of 0.96 (highly significant, $P < 0.01$). On the other hand, an inverse relationship existed between tree height and density ($r = -0.708$) and between dbh and density ($r = -0.738$). In Shinas, a positive correlation existed only between tree height and dbh ($r = 0.664$), whereas in Qurm no correlation was obtained between tree size and density.

Soil Analysis

Soil texture was dominated by sand (Table 4) and the highest percentage of silt was from Qurm soil(32.3%), followed by Mahout (20% and then Shinas (12.6%). Clay contents were similar in Mahout (10.1%) and Shinas (9.2) but low in Qurm (6.4%). Clay was statistically significant in all three sites but sand and silt were similar in Qurm and Mahout, and Mahout and Shinas and different between Qurm and Shinas.

Soils of Mahout have higher organic matter (10.2%) total nitrogen (0.2%), available phosphorus (56.2 ppm) and sulphate (17.1 meq 100. g^{-1}) than those from Qurm and Shinas (Table 4). Organic matter was significantly different between the three sites whereas sulphate, nitrogen, phosphorus and E.C. were the same at Qurm and Shinas, but different from Mahout.

Within each area, there were considerable variations in soil analysis. Soil from the southern side of Mahout Island (transect 3) had more sand (80%) than the northern side (transect 1) (61.5%), whereas silt and clay were higher in the northern side (26.8% and 11.7%) than in the southern side (11.8% and 8.3%). The differences were highly significant for sand ($P < 0.01$); significant for silt ($P < 0.05$) and not significant for clay. The differences in organic matter were highly significant; significant for sulphate but not for phosphorus, total nitrogen and E.C. (Table 5). In Qurm, although there were considerable variations in soil texture and chemical analyses among the 8 transects, the differences were not statistically significant.

TABLE 2

Mangrove structure of Qurm, Mahout and Shinas.

Parameter Area	Height (m) Mean ± SE (Range)	Dbh (cm) Mean ± SE (Range)	Density (stems/0.1 ha) Mean ± SE (Range)	Mean Basal Area (m^2/0.1 ha) Mean ± SE (Range)	No. of Samples
Qurm	3.9 ± 0.04 (2.0 - 5.3)	13.0 ± 0.3 (5.9 - 26.9)	42.4 ± 1.3 (15.2 - 139.8)	0.7 ± 0.03 (0.004 -2.9)	227
Mahout	4.1 ± 0.30 (1.8 - 8.0)	15.6 ± 1.1 (5.0 - 30.0)	41.6 ± 4.2 (14.7 - 125.3)	0.7 ± 0.06 (0.06 - 1.8)	60
Shinas	4.5 ± 0.26 (2.8 - 6.5)	14.4 ± 1.9 (5.6 - 32.0)	56.5 ± 4.7 (26.0 - 97.0)	1.1 ± 0.03 (0.08 - 4.3)	20
F-value	4.8*	2.4	4.6*	6.1*	

* Significant ($P<0.05$).
Data were analyzed using SAS GLM procedure and mean of separation was done using Tukey's test.

TABLE 3

Detailed analysis of mangrove structure at Qurm.

Transect No.	Height (m) Mean ± SE (Range)	Dbh (cm) Mean ± SE (Range)	Density (stems/0.1 ha) Mean ± SE (Range)	Mean Basal Area (m^2/0.1 ha) Mean ± SE (Range)	Size of Samples
1	3.3 ± 0.13 (2.5 - 4.0)	10.0 ± 0.8 (6.5 - 15.9)	54.8 ± 4.5 (33.7 - 90.5)	0.40 ± 0.05 (0.20 - 0.9)	13
2	4.3 ± 0.11 (2.9 - 5.0)	12.2 ± 0.5 (5.9 - 18.7)	37.9 + 1.6 (24.2 - 60.2)	0.41 ± 0.03 (0.004-0.8)	32
3	3.7 ± 0.11 (2.0 - 5.4)	12.6 ± 0.5 (7.1 - 20.4)	37.2 ± 1.6 (21.3 - 62.5)	0.42 ± 0.03 (0.03 - 0.9)	36
4	4.1 ± 0.11 (2.8 - 5.3)	14.1 ± 0.6 (6.9 - 22.2)	36.5 ± 1.6 (20.9 - 83.9)	0.60 ± 0.05 (0.04 - 1.6)	42
5	3.9 ± 0.11 (3.0 - 5.0)	14.2 ± 0.6 (8.9 - 22.6)	55.9 ± 6.4 (23.7-139.8)	0.81 ± 0.07 (0.19 - 1.8)	29
6	3.9 ± 0.09 (2.8 - 4.9)	15.1 ± 0.6 (9.7 - 26.8)	38.6 ± 2.6 (15.2 - 94.7)	0.81 ± 0.09 (0.11 - 2.8)	40
7	3.6 ± 0.14 (2.8 - 4.4)	16.2 ± 1.1 (11.9-23.8)	48.9 ± 4.4 (29.0 - 76.1)	1.05 ± 0.12 (0.40 - 1.8)	12
8	3.8 ± 0.12 (2.3 - 4.9)	16.4 ± 0.9 (10.4-26.9)	46.3 ± 4.2 (15.7 - 96.1)	1.02 ± 0.13 (0.30 - 2.9)	23
F-value	4.8*	7.4*	5.4*	6.1*	

* Significant ($P<0.05$).
Data were analyzed using SAS GLM procedure and mean of separation was done using Tukey's test.

TABLE 4

Soil analysis of Qurm, Mahout and Shinas mangroves.

Parameter Area	Sand (%)	Silt (%)	Clay (%)	Sulphate (meq/100 g)	Nitrogen (%)	Phosphorus (ppm)	Organic matter (%)	E.C. (Mmhos/cm)
Qurm	63.5 ± 3.8 (17.5 - 94.4)	32.3 ± 3.6 (3.3 - 71.7)	6.4 ± 0.6 (1.1 - 15.8)	1.7 ± 0.2 (0.2 - 3.7)	0.04 ± 0.01 (0.002-0.1)	7.0 ± 0.7 (2.8 - 18.1)	5.2 ± 0.4 (1.0 - 9.2)	3.0 ± 0.2 (1.1 - 4.9)
Mahout	71.0 ± 3.7 (17.5 - 95.4)	20.1 ± 3.5 (2.5 - 46.0)	10.1 ± 1.4 (3.5 - 16.5)	17.1 ± 4.1 (5.4 - 48.6)	0.20 ± 0.03 (0.05 - 0.4)	56.2 ± 13.1 (26.0 - 168.9)	10.2 ± 1.8 (0.6 - 17.6)	15.1 ± 2.1 (3.2 - 26.0)
Shinas	78.2 ± 2.9 (52.0 - 93.5)	12.6 ± 1.8 (3.0 - 28.4)	9.2 ± 0.2 (0.7 - 2.4)	5.8 ± 1.1 (1.0 - 14.2)	0.06 ± 0.02 (0.02 - 0.3)	18.3 ± 4.2 (2.8 - 63.7)	1.1 ± 0.3 (0.6 - 2.4)	4.6 ± 0.3 (3.1 - 6.6)
F-value	3.7*	8.3*	19.7**	22.3**	26.0**	23.3**	17.6**	61.9**

* Significant ($P < 0.05$), ** highly significant ($P < 0.01$).
Data were analyzed using SAS GLM procedure and mean of separation was done using Tukey's test.

TABLE 5
Comparisons of soil analysis between transects 1 and 3 at Mahout Island.

Parameters	Transect 1	Transect 3	T-test
Sand (%)	80.00	61.50	3.65**
Silt (%)	11.80	26.80	3.07**
Clay (%)	8.30	11.70	1.39
SO_4(meq/100g)	25.30	10.30	2.33
Phosphorus (ppm)	75.40	40.10	1.58
Nitrogen (%)	0.18	0.19	0.02
Organic matter (%)	5.14	14.47	4.76
E.C. (Mmhos/cm)	11.68	18.00	1.80

* Significant ($P < 0.05$), ** highly significant ($P < 0.01$).

Water Analysis

Dissolved oxygen varied from 4.8 to 12.7 with an average of 8.1 $mg.l^{-1}$, pH from 6.9 - 8.9 with an average of 7.8 at all three sites. Water temperatures ranged 22-38°C, and salinity showed small variation at Mahout and Shinas, whereas at Qurm it varied greatly from almost fresh and brackish water to hypersaline water.

In Mahout, water temperature was lowest in January (22°C), increased in the following months till June (29°C), remained at 27-28°C till October, then fell gradually during November-December. Water salinity was usually lowest in February (36°/₀₀), increased gradually in the following months till June (40°/₀₀), then fell gradually until it reached the lowest level in February. In Shinas, salinity fluctuation was quite small, varying from 36°/₀₀ to 38°/₀₀. On the other hand, salinity at Qurm showed remarkable variation from almost freshwater to hypersaline waters. At the western channel (Fig. 1.c.) salinity varied from 36.7°/₀₀ to 38.8°/₀₀ at the entrance, then increased slightly to 40°/₀₀ at the middle and to 41‰ at the end of the shallow mangrove channel. The eastern side of the mangrove channel exhibited different patterns where water salinity was typical of sea water at the entrance, decreased to 30°/₀₀ at the middle, and less than 20°/₀₀ at the end of it, due to the discharge of sewage from residential houses into the mangrove channel and the mixing with groundwater of low salinity.

There were three small pools at the periphery of Qurm mangroves which were not connected directly with the mangrove channels. On February 1993, they exhibited wide variation in salinity from 0°/₀₀ to 2°/₀₀ at the extreme pool, probably connected with underground water. Other pools were located at the centre and salinity varied from 36°/₀₀ to more than 100°/₀₀. These pools were very shallow and probably received sea water irregularly during spring tide for a short period and were then isolated for a long time, leading to hypersaline conditions. The third pool system was a very small area surrounded by a cluster of mangrove stands, and received water from the mangrove channel at high tide, which when mixed with underground water, lead to a salinity of 29-30°/₀₀. In December 1993, salinity of this pool system had increased remarkably to 18°/₀₀ at the rear end pool (0 - 2‰ in February), and to 560°/₀₀ at the third pool (29-30°/₀₀ in February). The increase in water salinity was probably due to the change in water table, affected by the establishment of a large artificial lake where water evaporation and water seepage to the surrounding area were high.

Faunal Survey

AQUATIC FAUNA: Mangrove communities of the three sites included a faunal assemblage of many species (Table 6), mostly fish (54 species), crustaceans (31 species), mollusks (51 species) as well as smaller number of sponges, echinoderms, coelenterates and ascidians. Some groups exhibited clear zonation in distribution (crabs and oysters), others were just visitors (fish), but the majority were resident in the mangroves. In addition, some fish were found only in one area (e.g. mudskipper in Mahout) whereas others were everywhere, but exhibited significant differences in abundance.

The fiddler crabs, *Uca vocans*, *U. lactea* and *U. tetragononon* were restricted to the mangrove swamp while mud crab *Scylla serrata* and swimming crabs *Portunus pelagicus*, *Callinectes sapidens* and *Thalamita sp*. were usually seen in the mangrove channels. On the other hand, the ghost crabs *Ocypode saratan* occurred on the supratidal sandy shore, whereas the black crabs, *Grapsus tenuicrustatus* were usually found in or close to the waters edge of the mangrove channels and between the mangrove trees. Still others such as the red-spotted crab *Matuta lunaris* lived in or near the tidal channel, usually on sandy bottom areas.

Mollusks were the most diverse invertebrates and more than 80 species have been recorded from Qurm (Smythe, 1983). However only 51 species were collected during the present survey. Their distribution varied greatly, depending on substrata, tidal channels and pools at the eastern mangrove channel of Qurm. The rock oyster *Saccostrea cucullata* and the giant snail *Terebralia palustris* were most abundant at Qurm but rare in Mahout and Shinas. Oysters were usually found attached to solid objects (often the aerial root of the mangrove) or to each other. They were edible and varied in size from 1 cm to 8 cm, with an average of 5 cm, and in density from 51 cm to 104 cm, with an average of 78 individuals. m^{-2}. On the other hand, *Terebralia palustris* lived among the mangroves in large numbers in the thick mud of the upper creek. They were not edible, however their operculae were used for scent in Oman. Their densities varied from 24 to 47 with an average of 34 individuals. m^{-2}, and in size from 4.5 to 10 cm with an average of 8.5 cm.

Both Qurm and Mahout accommodated similar numbers of fish species, 38 and 39, respectively. However, species were not similar in most cases. For example, goatfish, soles, moonies, blennies and rabbitfish were collected only from Qurm, whereas catfish, sting ray, bluefish, whiting, slipmouth and puffers were collected from Mahout. However, both mangrove areas provide nursery and feeding grounds for juvenile fish (e.g., mullet) and shrimps of economic importance. The tooth carp, *Aphanius dispar* were found everywhere in the mangrove channels, salt pools and even fresh and brackish water pools at the periphery of Qurm mangroves. These fishes, together with gobies, tigerfish and silverbiddy were typical residents of mangroves. Closely associated fish included snapper, shad, carangids and seabreams.

Large Wildlife

The highest number of bird species was found in Qurm (194), followed by Shinas (92) and then Mahout (83). However the high species richness found at Qurm is probably due to more observation effort put into this area by orinthologists. On the other hand, the highest abundance of birds was from Mahout (157,542 birds), followed by Qurm (30,362) and then Shinas (7,859). Some birds were restricted to one area (e.g. Avocet and Great Knot at Mahout) whereas others were more abundant in one area than the other two. Dunlin, Bar-tailed Godwit, Socotra Cormorant, Greater Flamings, Little Stint, Turnstone and Slender-billed Gull were more abundant in Mahout than in Qurm and Shinas. Kentish Plover, Black-headed Gull and White-cheeked Tern were more abundant in Qurm than in Mahout and Shinas. Herring Gull was more abundant in Shinas than in Qurm and Mahout.

At Mahout, green turtles were the most abundant (37 turtles), followed by loggerhead (12) and hawksbill (7). Ridleys and leatherback turtles were not observed during the present study. Turtles were not observed at Qurm, but older fishermen stated that they used to come to the sandy shore and because of the recent recreational activities along the shore, they no longer visit Qurm.

TABLE 6

List of aquatic fauna collected from three mangrove sites in Oman.

	Q	M	S		Q	M	S
CRUSTACEANS							
Penaeus indicus	+	+	-	*Dentalium octangulatum*	+	+	-
Penaeus semisulcatus	-	+	-	*Barbatia helblingii*	+	+	-
Metapenaeus monoceros	-	+	-	*Barbatia obliquata*	+	+	-
Grapsus albolineatus	+	+	+	*Acar plicata*	+	+	-
Grapsus granulatus	+	+	+	*Isognomon legumen*	+	-	-
Grapsus kakahor	+	+	-	*Pinctada radiata*	+	+	-
Grapsus tenuicrustatus	+	+	-	*Alectryonella plicatula*	+	+	-
Metopograpsus messor	+	+	+	*Saccostrea cucullata*	+	+	-
Metopograpsus frontalis	+	+	-	*Gari occidens*	+	-	-
Metopograpsus thukuhar	+	+	-	*Circenita callipyga*	+	+	-
Ocypode ceratophthalmus	+	-	-	*Circe corrugata*	+	+	-
Ocypode saratan	+	+	-	*Callista erycina*	+	+	-
Uca arcuata	+	+	-	*Callista lilacina*	+	+	-
Uca inversa	+	+	-	*Dosinia alta*	+	+	-
Uca lactea	+	+	-	*Marcia ceylonensis*	+	+	-
Uca thalassa	+	+	+	*Venerupis deshayesii*	+	+	-
Uca tetragonon	+	+	+	*Corbula modesta*	+	-	-
Uca spp.	-	-	+	*Thracia adenensis*	+	+	-
Macrophthalmus depressus	+	+	-	*Pinna muricata*	+	+	-
Macrophthalmus sp.	-	+	-	*Chiton peregrinus*	+	-	-
Metaplax indica	+	+	+				
Cleistostoma sp.	-	+	-	**FISHES**			
Callinectes sapidus	+	+	-	*Taeniura lymma*	-	+	-
Portunus pelagicus	+	-	+	*Nematalosa nasus*	+	-	-
Scylla serrata	+	+	+	*Sardinella longiceps*	-	+	-
Thalamita admete	+	-	-	*Stolephorus indicus*	-	+	-
Thalamita crenata	+	-	-	*Thryssa mystax*	-	+	-
Thalamita edwardsi	+	-	-	*Chanos*	+	+	+
Matuta lunaris	+	-	-	*Arius thalassinus*	-	+	-
Calappa hepatica	-	+	-	*Hemiramphus far*	-	+	-
Diogenes sp.	-	+	-	*Hyporhamphus dussumieri*	+	-	-
Nematopagurus sp.	-	+	-				
Petrolisthes sp.	-	+	-	*Aphanius dispar*	+	+	+
Pisidia sp.	-	+	-	*Coriella crocodila*	+	-	-
Balanus sp.	+	+	+	*Platycephalus indicus*	+	+	-
Chthamalus sp.	+	+	+	*Ambassis natalensis*	+	+	-
				Ambassis gymnocephalus	+	-	-
POLYCHAETES				*Terapon jarbua*	+	+	-
Nephtys sp.	+	+	-	*Apogon spp.*	-	+	-
Nereis spp.	+	+	-	*Sillago sihama*	-	+	-
				Pomatomus saltatrix	-	+	-
ECHINODERMS				*Echeneis naucrates*	+	+	-
Astropecten sp.	+	-	-	*Caranx sexfasciatus*	+	+	-
				Leiognathus fasciatus	-	+	-
SPONGES	+	-	-	*Gerres abbreviatus*	+	+	-
				Gerres filamentosus	+	+	-
ASCIDIANS	+	-	-	*Gerres oyena*	+	+	-
				Lutjanus coeruleolineatus	+	+	-
COELENTERATES	+	-	-	*Lutjanus ehrenbergi*	+	+	-
				Pomadasys commersonii	+	+	+
MOLLUSCS				*Pomadasys multimaculatum*	+	+	-
Diodora bombayana	+	-	-	*Acanthopagrus berda*	+		-
Fissurella townsendi	+	-	-	*Acanthopagrus bifasciatus*	+	+	-
Euchelus asper	+	+	-	*Argyrops spinifer*	-	+	-
Umbonium vestiarium	+	+	-	*Rhabdosargus sarba*	+	+	-
Nerita adenensis	+	-	-	*Otolithes ruber*	-	-	-
Nerita albicilla	+	+	-	*Mulloides flavolineatus*	+	+	-
Architectonica laevigata	+	-	-	*Monodactylus argenteus*	+	-	-
Vermetus sulcatus	+	-	-	*Liza macrolepis*	+	-	-
Pirenella conica	+	+	-	*Mugil cephalus*	+	-	+
Cerithidea cingulata	+	+	-	*Valamugil seheli*	+	+	-
Terebralia palustris	+	+	-	*Sphyraena barracuda*	+	-	-
Cerithium scabridum	+	+	-	*Istiblennius lineatus*	+	+	-
Strombus gibberulus	+	+	-	*Amoya grisea*	+	-	-
Strombus decorus	+	+	-	*Cryptocentroides sp.*	+	+	-
Polinices tumidus	+	+	-	*Favonigobius sp.*	+	-	-
Natica pulicaris	+	+	-	*Favonigobius reichei*	+	+	-
Cypraea gracilis	+	-	-	*Gobius nebulosus*	+	+	-
Cyprea felina fabula	+	-	-	*Glossogobius biocellatus*	+	+	-
Cyprea turdus	+	+	-	*Istiogobius decoratus*	+	+	-
Engina mendicaria	+	+	-	*Oxyurichthys ophthalmonema*	+	+	-
Latirus nassatula forskali	+	+	-	*Periophthalmus koelreuteri*	-	+	-
Ancilla scaphella	+	+	-	*Siganus canaliculatus*	+	-	-
Oliva bulbosa	+	+	-	*Trichiurus lepturus*	-	+	-
Vexillum acuminatum	+	-	-	*Bothus sp.*	+	+	-
Acteon affinis	+	-	-	*Solea elongata*	+	-	-
Bullaria ampulla	+	+	-	*Arothron immaculatus*	-	+	-
Atys cylindrica	+	+	+	*Chilomycterus orbicularis*	+	+	-
Aplysia cornigera	+	-	-				
Onchidium daemelii	-	+	-				

Legend: Q - Qurum, M - Mahout, S - Shinas; + present, - absent

Although terrestrial mammals were rare, four species were recorded: two at Qurm (Arabian red fox, *Vulpes arabica* and the gerbil, *Gerbilus nanus*) and two at Mahout (the bushy-tailed gird, *Sekeetamys calarus*, and the sand fox, *Vulpes ruppelli*.

Discussion

The best developed mangroves occur along wet humid equatorial coastlines in Southeast Asia where they form extensive tidal forests of up to 45 species with trees of more than 1 m diameter and up to 45 m in height (Clough 1993). They provide living space for diverse faunal and floral assemblages of several thousand species, and support commercial and recreational fisheries. Arid mangrove systems have a much lower diversity, However, this does not mean that they are less important. The sole mangrove species in Oman, *Avicennia marina*, sustains an important shrimp fishery in Mahout Island. It also accommodates more than 50 fish species, some of commercial importance, and about 100 species of invertebrates, mostly crabs and mollusks. In addition, it provides feeding, roosting and nesting areas for a huge and diverse bird fauna as well as other wildlife. Thus, the significance of Oman mangroves, at least at national level, is recognized.

Data on the phenology of *Avicennia* are limited and available reports suggest major differences in different areas. Duke (1990) assessed 25 sites in Australia, Papua New Guinea and New Zealand, and found phenological trends with latitude in *A. marina*, where flowering shifts from November-December in northern tropical sites to May-June in southern temperate sites. Periods between flowering and fruiting increase from 2 to 3 months in tropical sites to 10 months in southernmost temperate sites. In Oman, Qurm mangrove trees flower during January-March and fruits mature during April-May. By contrast, the mangrove *A. marina* in Qatar flowers during April-July and fruits mature in mid August (Abdel-Razik 1991). The difference in latitude between Muscat (23.5 °N) and Qatar (25 °N) is small. However, environmental differences are great. Further study on the phenology of the Arabian mangrove *A. marina* is needed.

At Mahout, there were progressive increases in tree height, diameter (dbh) and basal area from the upper to lower elevation of the shore (Fouda and Al-Muharrami, 1995). Such patterns were not observed at Qurm and Shinas. This is probably due to the fact that mangroves at Mahout face directly to the sea, whereas those at Qurm and Shinas are separated from the sea by sand bars. In addition, the intertidal area at Mahout has a slow gentle slope, whereas the soils at Qurm and Shinas are characterized by irregular elevations which are interrupted by mangrove creeks. Thus, the differences in structural development of mangroves are site specific. However, correlation analyses for Mahout mangroves have shown that tree diameter increases with tree height and basal area, whereas density decreases with tree size.

It is known that mangroves grow on a wide variety of soil types, ranging from coarse and mineral sand through alluvial silts and heavy clay (Clough 1993). In the present study significant differences were observed in soil texture and chemical analyses within and between the three mangrove areas studied. Mahout soil contained more organic matter, total nitrogen, available phosphorus and sulphate than those from Qurm and Shinas. Consequently, mangroves of Mahout are more developed than those of Qurm and Shinas. The highest amount of silt was in Qurm soil which is believed to be of terrestrial origin. The periodic flooding at Qurm brings more silt which is trapped by the sand bar, and hence accumulates in the mangrove soil.

Results of water analysis of mangrove creeks at Qurm have shown that the most important variable was water salinity at the eastern mangrove channel, which ranged from the sea water at the inlet entrance to less than 10‰ at the extreme end of the mangrove channel, due to the seepage of groundwater of low salinity. Because of the continued recreational development at the south-eastern site of Qurm and the digging of a large artificial lake, it is likely that the groundwater table will drop in future, a view based partly on the fact that salinity has already increased from 4.7‰ to 8‰ during 1994. The underground water level changes with tide, suggesting that the lower level is connected to sea water. A monitoring programme is needed to understand the implications of changes in groundwater table and the consequences of increased salinity on mangrove growth.

The knowledge about faunal assemblage associated with Oman's mangroves is far from complete and needs intensive collection at different times and places. However, the present faunal diversity is higher than reported from some other Arabian regions (Price *et. al.* 1977, Por *et. al.* 1977, Jones 1984, Por 1984). For example less than 30 fish species and about 15 crab species are known from the mangroves of the Red Sea. On the other hand, the present faunal assemblage associated with Oman's mangrove is not expected to match those from wet humid tropical mangroves where more than 100 fish species and several hundred species of invertebrates have been reported (Robertson and Blaber 1992).

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