CORALS AND CORAL REEFS OF THE CAPITAL AREA, OMAN

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based on the work of
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Introduction

Corals in Oman have been described for the Musandam Peninsula in the North (Glynn, 1983), for the Muscat area (Green, 1983, 1984; Glynn, 1983), for Masirah Island (Glynn, 1983) and for the Dhofar coast around Salalah in the South (Barrat, 1984; Glynn, 1983). Coral diversity has been mapped for the Muscat area (Salm and Dobbin, 1986) and, in more detail, for specific sites within it (Salm, 1985, 1986a). A detailed review of coral distribution and reef formation is being prepared for the entire coast of Oman (Sheppard and Salm, in preparation).

It is clear from these studies that major coral growth is restricted to three areas in Oman: the Musandam Peninsula, the rocky shores, bays and islands in and adjacent to the Muscat area, and the straits, shallows and shores west of Masirah Island. Other parts of the Oman coast either lack corals or support limited growth of small scattered colonies. This is due mainly to the absence of suitable substrate, such as along the sandy Batinah coast, or to seasonal upwellings of cold water and vigorous algal growth, such as along the Arabian Sea coast south of Masirah Island.

This paper presents additional information on the corals of Oman. It is the result of research directed specifically toward the formulation of a Coastal Zone Management Plan for 200 kilometres of coastline spanning the capital, Muscat. This project is the result of an agreement between the Ministry of Commerce and Industry and the International Union for Conservation of Nature and Natural Resources dated 18 January 1984.

Objectives

Coral substrates were surveyed between December 1984 and December 1985. The aim of the surveys was to identify areas that were most valuable for conservation and consequently least suitable for major coastal works, such as marinas.

The objectives of the coral surveys were to:

1) compile a comprehensive list of corals found in the study area;
2) map the distribution of coral communities;
3) determine the coral diversity (measured as the total genera) at different locations;

4) select candidate sites for the conservation of coral communities;
5) compile a named collection of corals for presentation to the Oman Natural History Museum.

Methods

The study area (map 1) extended from Ras Suwadi in the west to Quriyat in the south and included all offshore islands and shoals. The mainland coastline divides naturally in half: a western sandy coast that forms the eastern extremity of the long Batinah coastal plain; and an eastern embayed rocky coast. In addition there are numerous nearshore islands and rocky stacks, and the offshore islands at Ras Suwadi, the Daymaniyat Islands lying 18-20 kilometres off the central part of the sand coast, and Fahl Island situated 4 kilometres off the western end of the rocky coast.

The likely location of coral communities was determined from aerial photographs, two helicopter overflights of the entire study area and boat and underwater reconnaisance.

Using either snorkelling or scuba diving, corals were identified and recorded in situ at a total of 65 sites. A representative collection of corals was made for reference. Those which could not be identified underwater were collected, cleaned and identified by comparison with the reference collection and from the following texts: Burchard (1980), Scheer and Pillai, 1983), Veron and Pichon (1976, 1980, 1982), Veron and Wallace (1984), Veron, Pichon and Wijsman-Best (1977), Wells (1956). Dr. C.R.C. Sheppard was engaged as a consultant specialist to confirm the identification of all corals before they were presented to the Oman Natural History Museum.

Corals were recorded by the following standard procedure developed to enable rapid comparative surveys of numerous reef areas.

Upon entry into the sea, one or two minutes were devoted to orientation and recording of the nature of the substrate and coral community. Next corals were identified along a course chosen to yield most variety of corals. They were recorded continuously in sequential five minute intervals onto a plastic slate. This procedure yielded a characteristic genus discovery curve (total genera x 5-minute interval) for each study site.

Distribution and Nature of Coral Communities

Corals of the Muscat area are listed in Appendix 1, together with the sites at which they were recorded.

Hard-base corals are largely confined to islands, shoals and the rocky eastern coast (Figure 1). The exposed north and east facing coasts tend to support relatively small scattered coral colonies and more extensive patches of alcyonarians, chiefly Sarcophyton.

Coral communities of the Muscat and adjacent areas tend to be confined to above 12-18 metres, but certain corals will grow on rocky outcrops deeper than 30 metres (e.g. Culicia, Balanophyllia, Polycyathus, Leptoseris). The maximum depth of coral communities is determined by at least two parameters: the general progression from rock to soft substrate below 15-20 metres and the usual presence of a thermocline at a depth of 12-15 metres (occasionally less), below which the water is both turbid and cold.

Most corals grow directly on bedrock or dead parts of other coral colonies to form a shallow veneer over the underlying substrate. However conditions have favoured the build-up of small reefs in places (reef development will be discussed in greater detail by Sheppard and Salm, in preparation). These incipient patch and fringing reefs are generally restricted to sheltered coasts, such as in bays, coves and along the south coasts of islands. Exceptions are found at Kharabah Island and Darsayt where the gradient of the seabed is gradual and suitable substrate is found between depths of 8-12 metres.

Porites is an important reef builder. In the shallows adjacent colonies fuse to form planed platforms (reef flats), which may be settled by other coral species and which extend seawards to a border of colonies attaining 2-4 metres in diameter. These large Porites colonies and Porites dominated reefs probably form the oldest continuously living reefs in the Muscat area.

Pocillopora damicornis forms monospecific banks of living coral up to about 2-4 metres thick. In places these have been totally or extensively destroyed (e.g. Daymaniyat Islands, Bandar Jissah, Ras Abu Daud) and are being recolonised by algae, alcyonarians, Acropora, Pocillopora and other corals.

As noted by Glynn (1983) acroporid reefs were once extensive and widely distributed. Those off the Daymaniyat and Fahl Islands, in Bandar Jissah and at many sites off the mainland coast were totally killed, but are being recolonised by Acropora and other

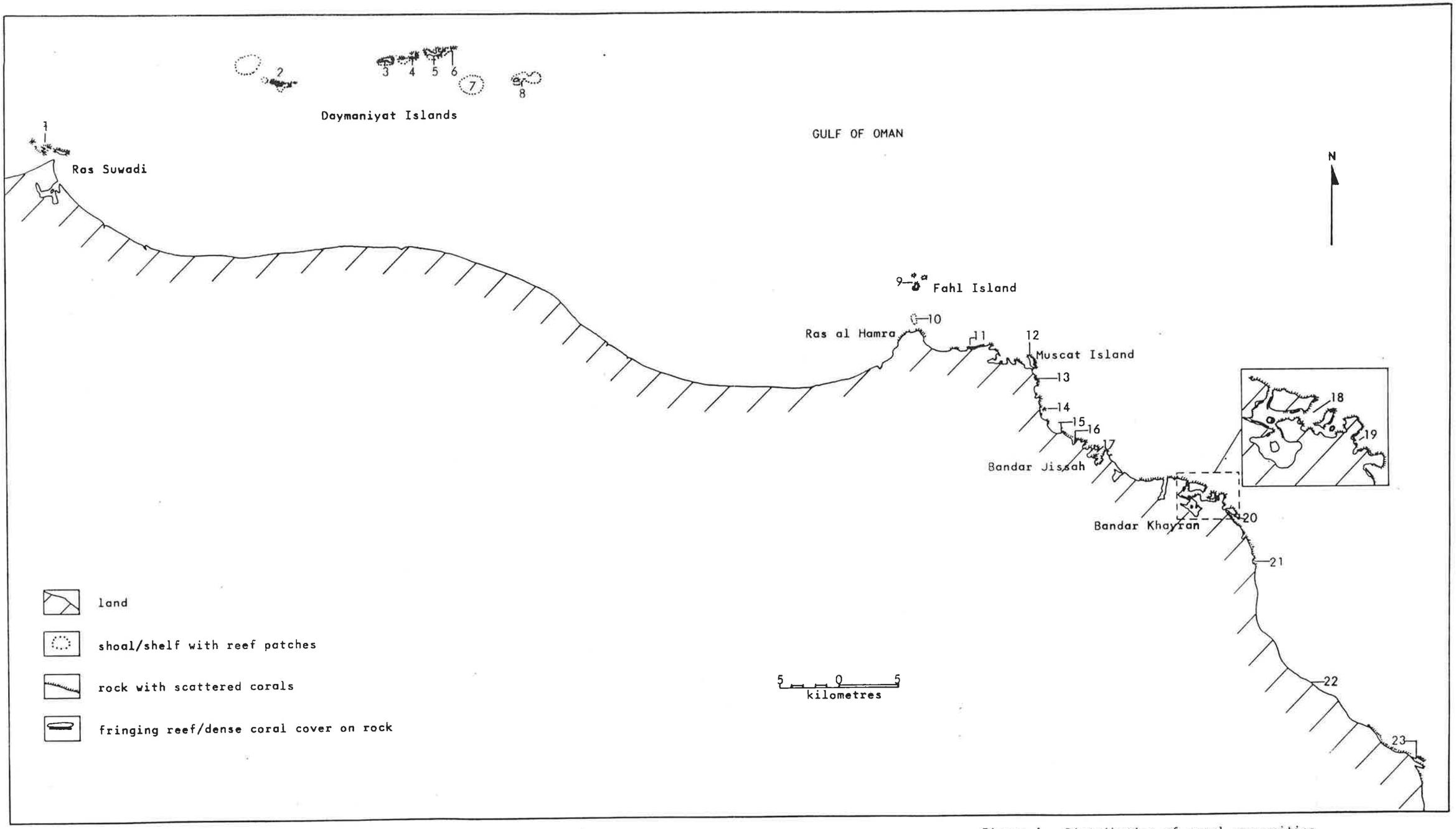


Figure 1. Distribution of coral communities

corals.

Unaffected Acropora communities occur in two sheltered bays: Bandar Jissah (1 small site with discontinuous cover) and Bandar Khayran (3 sites). The most extensive site is in the latter bay where 2 metre diameter tabular Acropora species with a cover of up to 100% form an incipient fringing reef 200 metres long.

Other sites where coral growth has continued uninterrupted for a considerable time are the southeast cove of the Cemetary Bays, and the small islet in the northwest bay at Bandar Khayran. At the former location, individual Porites colonies reach diameters of 3-5 metres and those closer to shore have fused to form a flat-topped pavement which is exposed at low tide. The age of these colonies is currently under study. At the latter site individual colonies reach diameters of 3 metres and have fused to form a reef-flat which extends more than 100 metres west of the islet. "Younger" Porites reefs formed of colonies 2-3 metres in diameter in various stages of fusion and reef-flat formation are found at many sites among the Daymaniyat Islands (Salm, 1986a) and in the Bandar Khayran area.

The coral communities of the Muscat area conform to 6 main types, each of which has a characteristic genus-discovery curve.

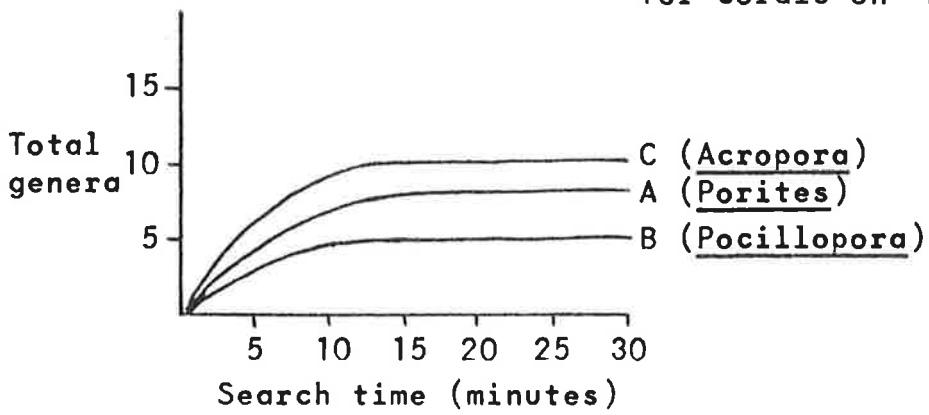
1) Incipient patch or fringing reefs dominated by Porites (e.g., Daymaniyat Islands, Cemetary Bays, coves between Yiti and As Sifah, Bandar Khayran, Ras Abu Daud) with few small scattered colonies of other corals (Figure 2A).

2) Incipient patch reefs dominated by Pocillopora damicornis (e.g. Daymaniyat Islands, Fahl and Muscat Islands, Cemetary Bays, Bandar Jissah, Bandar Khayran and Ras Abu Daud) with few small scattered colonies of other corals, particularly around the periphery (Figure 2B).

3) Incipient fringing reefs dominated by tabular and ramose Acropora species (e.g. Bandar Khayran) (Figure 2C).

4) Mixed coral assemblages:
   a) on incipient fringing reefs structurally dominated by Porites (e.g., Bandar Khayran) (Figure 3A);
   b) on incipient fringing reefs with a largely obscured underlying framework showing patchy distribution of corals (e.g., Bandar Khayran) (Figure 3B); and
   c) forming anything from a 10% to an almost complete cover of underlying baserock (e.g., Ras Suwadi, Daymaniyat and Fahl Islands, mainland rocky coast and associated islets) (Figure 3C and 3D).

Figure 2. Genus-discovery curves for corals on "monogeneric" reefs



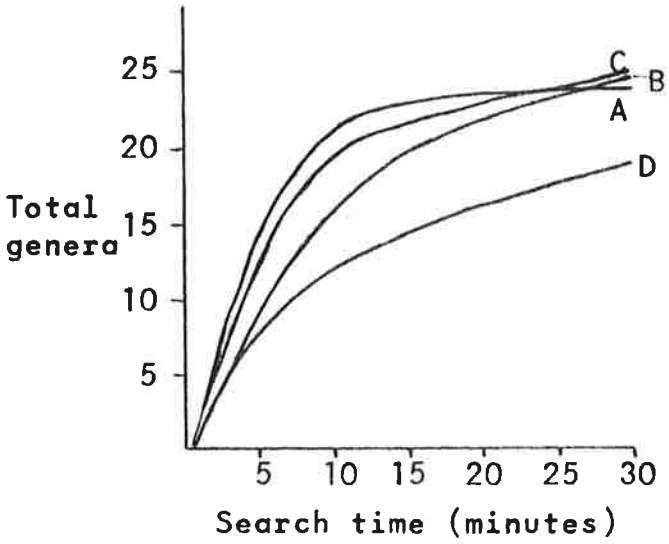


Figure 3. Genus-discovery curves for corals in mixed assemblages (A = Porites framework obvious; B = obscured reef framework; C = % cover of baserock over 60%; D = % cover of baserock less than 30%)

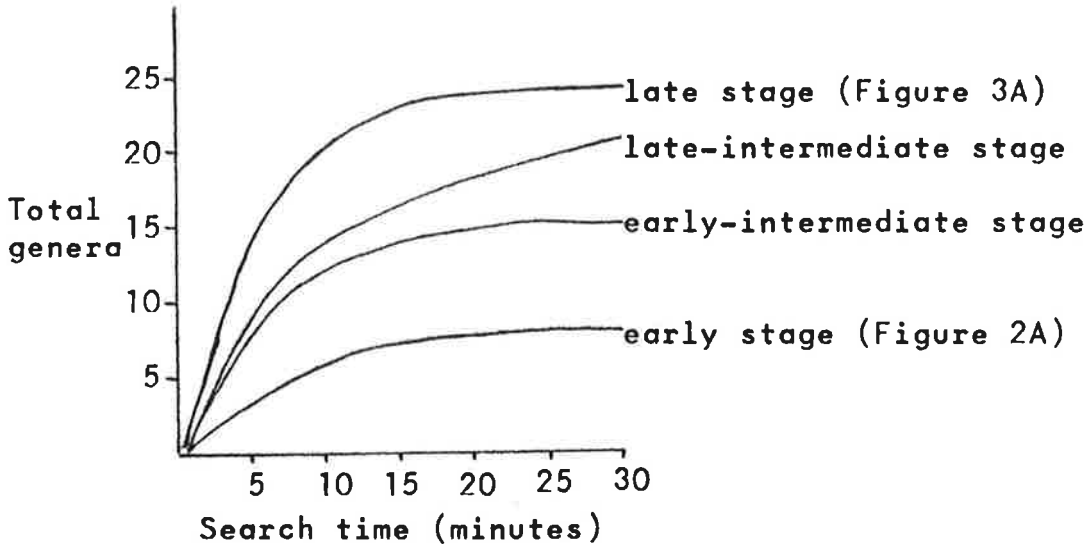


Figure 4. Genus-discovery curves for corals in the primary successional stages of reef development

5) Talus banks formed of dead branching corals (a) with little or no recolonisation (e.g., Daymaniyat Islands, Bandar Jissah), (b) in the process of recolonisation by the same species (e.g., Daymaniyat Islands, Muscat Island), (c) in the process of recolonisation by different species (e.g., Bandar Jissah).

6) Soft coral covering rock or dead coral colonies.

In addition, areas of rocky or sandy substrate may be covered by small discrete patches (less than 500 square metres) of Galaxea (e.g., Daymaniyat Islands) or Montipora (e.g., Daymaniyat Islands, Bandar Khayran).

It is possible to separate these six coral community types visually based on the conspicuous predominance of one or another coral (types 1, 2, 3, 6) which, until closer scrutiny, appears to be the sole genus present. Types 4 and 5 are also clearly distinguishable visually: the former because of the conspicuous abundance of different corals, which is borne out by the rapid yield of coral genera per unit search time (Figure 3A-D); and the latter because of the conspicuous abundance of talus and other dead coral colonies.

The genus-discovery curves (G-D curves) for the "monogeneric" incipient reefs level off rapidly and at a low total yield of coral genera (Figure 2A-C). It is interesting that mixed coral assemblages yield similar G-D curves irrespective of the underlying substrate, whether Porites reef (Figure 3A), largely obscured reef framework (Figure 3B), or baserock (Figure 3C).

The G-D curves support another intuitively obvious observation: mixed coral assemblages with a high percentage cover (more than 60%) yield genera more rapidly per unit search time than those with less than 30% cover (Figure 3C and D, respectively). Thus, the G-D curve method of recording and displaying coral survey data offers a useful rapid survey tool for classifying coral communities. Its application in this respect merits further investigation.

There is a continuum in G-D curves between those for Porites dominated communities (Figure 2A) and mixed assemblage communities (Figure 3). These illustrate different stages of reef development. For example:

Early stages of reef development conform to a type 1 community: substrate colonised by juxtapposed Porites colonies in different stages of fusion with adjacent colonies. This is characterised by a G-D curve with a low rate and total yield of coral genera (Figure 2A).

Intermediate stages of reef development which have Porites as the conspicuous structurally dominant coral, but adjacent colonies are fused, flat-topped and dead centrally (micro-atoll form), and colonised by an intermediate variety of corals. These are characterised by G-D curves with genus yield rates and totals (Figure 4) intermediate between those for coral community types 1 and 4a.

Late stages of reef development in which the Porites matrix is weakened, colonies die and/or cleave apart providing new hard substrate for colonisation by corals (coral community types 4a and 4b). This is the final primary successional stage of reef development (cf., Salm 1976), which is characterised by the highest yield rate and total coral genera (Figure 3A, B).

There are three, possibly four, sites of unique coral growth in the Muscat area: two coral assemblages in Bandar Khayran, the deep communities off Fahl Island, and the rocky shelf communities between Fahl and the adjacent mainland peninsula. These are discussed below.

One is the southern shore of the main bay at Bandar Khayran which is fringed by an incipient reef 200 metres long, formed exclusively of two tabular and two ramose species of Acropora (community type 3 above). The tabular species reach diameters of 1-2 metres. Tabular species dominate from the intertidal to a depth of 8 metres and ramose species from 8-10 metres. Living coral cover is essentially 100% with many overlapping colonies. This is the only well-developed example of such a coral community. Similar table coral communities existed elsewhere, but are now either totally dead, or support few scattered surviving colonies.

The small islet at the southeast corner of the main bay at Bandar Khayran is surrounded by a fringing reef (community type 4b) with a reef-flat extending 40 metres west of the islet, this is the best example of a fringing reef in the capital area. A total of 28 coral genera were recorded from this reef which extends from the surface to sand at 12 metres. The reef is generally covered by a mixed assemblage of coral genera, though parts may be dominated by vast fused Porites colonies (which forms the wide reef-flat at the west end) or patches of other corals, such as Acropora.

A second area includes three rock outcrops off Fahl Island in depths of 17-25 metres, 20-35 metres and 22-42 metres. These are the sole location in the capital area for four coral genera (Phyllangia, Rhizopsammia, Polycyathus, Madracis). Other corals which are rare elsewhere in the capital area are also found here in abundance (Leptoseris, Culicia smithi, Balano-

phyllia). The rock outcrops have the best examples of deep water corals in the Muscat area, and are the deepest sites there where corals grow.

The vertical limestone strata of the mainland peninsula opposite Fahl Island dip seawards and protrude from the sandy substrate as a series of low parallel underwater ridges, which are a third unique area of coral growth. The ridges, which are swept by strong currents, support unusual coral growth, including the largest colonies of Turbinaria (1-1.5 metres diameter) and Anomastrea, numerous Turbinaria peltata colonies, and are the sole location in the Muscat area of the new species Acanthastrea maxima (Sheppard and Salm, in preparation).

Heteropsammia cochlea has so far only been found on the sandy substrate between Fahl and the mainland, although it may well be found elsewhere. Similarly, Heterocyathus aequicostatus probably also occurs here, but has so far only been found dead along the mainland beaches immediately west of this area. This sandy area may prove to be a fourth unique coral area.

Diversity

Rosen (1971) reports 15 coral genera for the Trucial Oman coast and Sawqirah Bay. Green (1983) increases the list to 22 coral genera from the Muscat area, and later revises this to 28 for Oman (Green, 1984). A total of 42 coral genera and at least 69 species that were collected in the Muscat area during the course of this study are listed in Appendix 1. The list includes one genus and at least two species that are new to science (Sheppard and Salm, in preparation).

The Fahl Island area is the centre of high coral diversity in the Muscat area (Figure 1). Fahl Island has a total of 36 coral genera, which is high for such a relatively small area (see Appendix). The three deep rock outcrops at Fahl contribute 6 genera to this total. An additional two genera are found between Fahl and the adjacent mainland peninsula. Thus all but three of the known Muscat area coral genera (Stylocoeniella, Galaxea, Echinopora) have so far been found around Fahl and between it and the mainland. The great variety of suitable substrates available to corals appears to be the principal determinant of the high coral diversity here.

Coral Mortality

Reef growth is interrupted by episodic destruction of corals. This appears to be confined to corals in more exposed loca-

tions, such as the Daymaniyat Islands, exposed portions of the mainland coast and the entrances to bays (see Salm, 1986a). But the pattern of die-off is confusing, as the damage may affect only part of a reef or one in a series of adjacent coral patches.

All that remains of former reef development at the die-off sites are large dead Porites and Symphyllia colonies, the stumps of once large tabular Acropora or talus banks formed of dead Pocillopora damicornis or Acropora.

Glynn (1983) concludes that recurring outbreaks of Acanthaster planci may have a large influence on the development of coral communities in the Muscat area. This may well explain the destruction of large tracts of Acropora. However, as Glynn points out, Acanthaster is a fairly selective feeder, which generally avoids colonies of Porites and Symphyllia. Thus, it is unlikely that starfish predation would explain the extensive mortality of large colonies of these two corals.

Collapse of the undercut coastal limestone cliffs destroys coral colonies, as was also noted by Glynn (1983). However this phenomenon would not explain die-offs in areas far from cliffs or signs of recent rock falls, such as along the southern shores of the Daymaniyat Islands.

Pocillopora damicornis patches are particularly vulnerable to damage from abandoned fishing nets. The nets entangle and break off coral branches which roll up in it. A net thus weighted can bounce and drag over the reef patch leaving a swathe of dead coral rubble. In the Daymaniyats 25-80% of some P. damicornis patches have been destroyed in this manner. Although nets were found to kill part or all of the corals they entangled, this would still not explain the pattern of complete coral die-off, especially in areas lacking any sign of nets or physical damage to the corals.

Episodic massive discharge of freshwater and silt into the sea certainly would destroy corals in affected areas. However, this phenomenon is more likely to explain the absence of incipient reef formations than the die-off pattern. It is unlikely to have any effect on the corals of the Daymaniyats which lie 18-20 kilometres offshore.

Temperature stress is another likely cause of coral mortality and its effect on reef development requires study in Oman. The sudden chilling of surface water during summer is a well-known phenomenon among the diving community. Summer is a period of unpredictable upwelling in the Muscat area. Cells of cold upwelling water drawn by winds or currents over an incipient reef would displace the heated shallow water and could cause a

localised precipitous drop in temperature of as much as 15 degrees centigrade (from 32°C to 17°C) over a 14 day period as in July 1983 (Green pers. comm.) and monthly fluctuations of as much as 8°C during summer (Green, 1983). If this is indeed a cause of coral mortality, it would help to explain the disjunct pattern of coral die-off, the mortality of large Porites and Symphyllia colonies, and the location of dead corals in areas swept by currents near deep water.

It is likely that the present pattern of coral community development and die-off is a product of all the above parameters. Recreational diving also causes some damage to corals (Salm, 1986b), but this is currently localised and relatively insignificant.

Corals are recolonising the damaged areas. In the Daymaniyats tabular Acropora colonies have reached a diameter of about 40-50 centimetres.

Conservation

Protected areas are proposed at Ras Suwadi, Daymaniyats, Fahl, Bandar Jissah, Bandar Khayran and Ras Abu Daud (Salm and Dobbin, 1986). By coincidence, these sites also correspond to the main coral areas.

The conservation of coral communities was of paramount importance in the selection of only two of these sites: Fahl extension to the existing Sultan Qaboos Public Park and Nature Reserve which would include the coral habitats and seabed out to and surrounding Fahl Island; and the bays in and south of Bandar Khayran. These two sites are the most valuable for conservation of coral communities in the Muscat area. They include all four of the unique coral areas and colonies of all but one (Stylocoeniella) of the corals so far recorded from the Muscat area.

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APPENDIX 1. CHECKLIST OF CORALS AND THEIR LOCATION IN THE MUSCAT AREA, OMAN (numbers refer to sites in Figure 1)

	Suwadi Islands,1	Jun & adjacent reefs,2	Daymaniyat Iss.,3	Daymaniyat Iss.,4	Daymaniyat Iss.,5	Daymaniyat Iss.,6	New reef,7	Kharabah,8	All Daymaniyats,2-8	Fahl & adjacent reefs,9	Ras al Hamra reef ,10	Fahl & Ras al Hamra reefs,9-10	Darsait-Aint,11	Muscat Island,12	Cemetary Bays,13	CAYC,14	Bustan,15	Qantab,16	Bandar Jissah,17	Bandar Khayran,18	South Ras al Khayran,19	South Khaysat ash Shaikh,20	Bay north of As Sifah, 21	South As Sifah,22	Ras Abu Daud,23
Psammocora	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x			x
Stylocoeniella			x			x			x						x					x					
Pocillopora	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Stylophora	x	x	x	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x
Madracis										x		x													
Astreopora		x	x		x	x	x	x	x	x		x			x	x	x	x	x	x	x	x		x	x
Acropora	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Montipora	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Pavona	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x			x
Leptoseris										x		x								x		x			
Siderastrea					x				x	x	x	x					x		x	x					
Pseudosiderastrea							x		x	x	x	x			x	x			x	x					x
Anomastrea	x						x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x
Coscinaraea	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x
Porites	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Goniopora	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Galaxea		x	x	x	x				x						x	x		x	x	x	x				
Parasimplastrea*			x		x	x	x		x	x	x	x	x		x	x			x	x	x	x			x
Hydnophora	x		x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
Favia	x	x	x	x	x	x	x	x	x	x	x	x	x			x		x	x	x	x	x	x	x	x
Favites	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Platygyra	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Plesiastrea		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x

	Suwadi Islands,1	Jun & adjacent reefs,2	Daymaniyat Iss.,3	Daymaniyat Iss.,4	Daymaniyat Iss.,5	Daymaniyat Iss.,6	New Reef,7	Kharabah,8	All Daymaniyats,2-8	Fahl & adjacent reefs,9	Ras al Hamra reef ,10	Fahl & Ras al Hamra reefs,9-10	Darsait-Aint,11	Muscat Island,12	Cemetary Bays,13	CAYC,14	Bustan,15	Qantab,16	Bandar Jissah,17	Bandar Khayran,18	South Ras al Khayran,19	South Khaysat ash Shaikh,20	Bay north of As Sifah,21	South As Sifah,22	Ras Abu Daud,23
Leptastrea	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x		x
Cyphastrea	x		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Echinopora		x				x	x	x	x								x	x	x	x	x				
Culicia					x		x		x	x		x			x				x						
Phyllangia										x		x													
Blastomussa			x			x			x	x		x		x	x				x	x	x	x			x
Symphyllia	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Acanthastrea	x		x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Echinophyllia	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		x		x
Oxypora			x				x		x	x	x	x		x	x	x		x	x	x	x	x			
Polycyathus										x		x													
Heterocyathus												x**													
Balanophyllia										x	x	x													
Rhizopsammia										x		x													
Dendrophyllia		x	x	x	x	x	x		x	x		x								x	x	x			x
Tubastrea			x	x		x			x	x	x	x		x	x					x	x				x
Turbinaria	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x
Heteropsammia											x	x													
TOTAL GENERA	20	21	28	22	26	26	27	20	33	36	19	38	22	22	28	26	23	25	30	34	29	26	16	14	27

* new genus

** presumed to be from this general area as washes ashore on beaches immediately southwest

Note: the coral Paracyathus was found for the first time in the study are at Bandar Khayran after completion of this table. Its occurrence is reflected in the genus total for Bandar Khayran.