ALDABRA

MARINE PROGRAMME

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cordio

coral reef degradation
in the indian ocean

SHOALS
OF CAPRICORN

CCRU

Cover Image: NASA Space Shuttle Image (Atlantis - STS044-082-057) Aldabra Atoll, Indian Ocean 29 November 1991.

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EXECUTIVE SUMMARY

The coral and reef fish communities of the remote Aldabra Atoll, Republic of Seychelles were surveyed in November 1999. The main objectives were to:

- establish a permanent system for the long term monitoring of benthic and reef fish communities;
- conduct an assessment of the diversity and abundance of corals and fishes;
- quantify bleaching impacts on corals;
- establish a system for assessing larval supply of coral species to the lagoon and reef slope;
- resurvey the Drew (1977) transect adjacent to the settlement on Ile Picard.

Seven transects from western reef sites to those on the northeast side were established at depths of 10 and 20 m. Results revealed that high coral mortality was prevalent in shallow waters and that coral vitality increased with depth. Live coral coverage ranged from 11 - 27%, excluding one site on the northeast side of the island where the level of exposure created a rubble - macroalgae dominated environment. From west to east there was a prominent gradient of decreased coral growth, related to levels of increasing hydrodynamic energy. At all deep transects *Physogyra* sp. was the most abundant coral genus.

Although mortality was widespread in all growth forms, there was a high degree of spatial heterogeneity of tissue death within and between colonies. It was not uncommon to encounter partial mortality in massive corals where live tissue existed on the periphery and/or underside of the colony.

Comparison with coral coverage data collected in April 1998, at the peak of the bleaching event, revealed that at the shallow depths bleaching translated primarily into mortality, but that deep water bleached corals where more successful at recovery.

Recruitment of corals is occurring, with records of Acroporid and Pocilloporid colonies 2-3 cm in diameter.

Qualitative and quantitative surveys of fish gave a total of 212 species for November 1999. The size of the fish at the majority of sites was dominated by those in the 0-10 cm total length category, which contained from 86% to 98% of the fishes surveyed at these sites. The abundance of fishes in the 0-10 cm category was primarily caused by large numbers of small-sized species, and secondarily by juvenile life-stages.

There was significant positive correlation between the species and number of Chaetodontids, and live coral habitat, but no significant correlation with dead coral habitat. There was also significant positive correlation between the number of Labrids, and the species of Serranids, and live coral habitat.

The high diversity of the fishes found at Aldabra Atoll in the November 1999 surveys appears to indicate that the overall productivity of the reef system has not yet been significantly affected by the loss of live coral habitat due to the bleaching event.

However, the significant positive correlation of the number and species of Chaetodontids, and the species of Serranids, with the live coral habitat remaining, indicates that the distributions and number of these fishes on Aldabra Atoll reefs will be eventually affected by the loss of coral habitat.

"Every day we wake up to the harsh reality of the level of sea rising around us; every day our divers report new patches of coral that have been affected by global warming."
Albert Rene, President of the Seychelles, 1999 - Our Planet

"…local dive operators in the Seychelles first noticed the coral turning white at the very end of 1997. Apparently they were pleased at first because the snowy white Acropora looked so pretty!"
Burnett and Teleki, 1999 – Reef Encounter

"As I understand it, the island of Aldabra is inhabited - like Her Majesty's Opposition Front bench - by giant turtles, frigate birds and boobies. Nevertheless it may well provide useful facilities for aircraft."
Denis Healy, Minister of Defence, 1966

INTRODUCTION

The great importance of coral reefs to the tropical oceans and the human populations which reside in proximity to these complex, diverse and productive systems has been well documented (Wilkinson, 1998; Hodgson, 1999; Lindén and Sporrong, 1999; Pomerance, 1999). Yet with rising levels of overexploitation of reef resources and inputs of pollution, the vulnerability of coral reefs continues to increase, leading to a global decline in reef health. Already 58% of coral reefs have been classified as being at risk from anthropogenic sources (Bryant et al., 1998). Transboundary analysis of the Western Indian Ocean (WIO) has revealed that decreasing harvests of marine and coastal living resources, and loss of critical habitats (mangroves, seagrass beds and coral reefs) and biodiversity are major environmental problems and issues in the region (UNEP, 1999). These problems are likely to be further exacerbated by the mass mortality of coral reefs in the WIO.

With the increased presence of these environmental perturbations, naturally occurring phenomena such as sea surface temperature (SST) anomalies, or inputs of fresh water, can have a much greater effect than might have been otherwise the case without the influence of these anthropogenic stressing agents. This will undoubtedly lead to longer recovery times, and less than ideal conditions for return to a healthy and productive state.

Since the 1998 coral bleaching and related mortality event, interest and concern over the status of the marine environment in all tropical oceans has intensified. There are currently a number of efforts world wide (Reefcheck, Global Coral Reef Monitoring Network (GCRMN) and Coral Reef Degradation in the Indian Ocean (CORDIO)) which aim not only to investigate and assess the impacts of this event on the environment (i.e. reef recovery, reef community population dynamics and ecosystem restructuring), but also to evaluate what socio-economic impact may be inflicted upon the coastal communities and countries whose livelihoods and economies depend, directly or indirectly, on the availability of marine resources and a healthy reef environment.

The scale and pervasive nature of current levels of bleaching related coral mortality is the most geographically widespread and most severe since records of this kind have been kept (Wilkinson, 1998). Coral bleaching, widely accepted as a stress response in corals, can be described as the whitening of corals resulting from the degeneration and/or loss of symbiotic algae, the zooxanthellae, and/or the loss of cells containing zooxanthellae from coral tissues (Brown and Ogden 1993; Brown 1997). Bleaching can be elicited by a number of causative agents working individually or in concert with each other from both natural and anthropogenic sources. These include elevated sea temperatures, high solar irradiance at UV wavelengths, sedimentation, disease, abnormal salinity and pollution. The deviation from what are considered to be normal levels of the physical and biological parameters of the system, and the duration of the perturbation will determine the ability of the coral to recover from such stress events. Part of the explanation of bleaching susceptibility is probably due to interaction with fluctuating zooxanthellae populations (Rowan et al., 1997; Fagoonee et al., 1999). In addition, however, this biological variability must itself interact with variations in the key physical controls of sea surface temperature (SST) and solar irradiance (Spencer et al., in press). In the case of the 1998 bleaching event anomalous sea temperatures were documented in all of the areas where bleaching occurred. Impacts appear to have been the product of two factors: the extreme nature of the positive temperature anomaly and the duration of the lethal temperatures. This was evident in a number of locations in the WIO. For example, water temperatures exceeded a greater than +1ºC anomaly for more than 4 months (Spencer et al., in press).

The timing of inception, duration and magnitude of ocean warming showed strong regional variations across the Indian Ocean. It is clear from a range of reports that the extent of coral bleaching and mortality during this event (Wilkinson, 1998; Lindén and Sporrong, 1999; Spencer et al., in press) displayed both regional and local variations at continental and island coral reef sites. Such dramatic alterations to the climatic and oceanographic environment at such large scales are thought to be a result of an exceptional warming event. In this instance it may be related to the 1997-98 El Niño Southern Oscillation Event (ENSO), widely described as one of this centuries strongest (Slingo, 1998; McPhaden, 1999). Recent studies of the inter-annual variability of Indian Ocean SSTs have suggested a periodic ENSO signal which is either in phase with the peak El Niño warm phase off the west coast of South America, or lags some six to nine months behind it (Tourre and White, 1995, 1997; Nicholson, 1997). However, other research (i.e. Webster et al., 1999; Saji et al., 1999) has argued that the oscillations SSTs, precipitation and winds between the eastern and the western Indian Ocean are the result of internal ocean - atmosphere dynamics and not a direct response to ENSO events. Regardless of the source of the warming event in the Indian Ocean its impacts and widespread nature highlights not only the interconnectedness of the marine environment in the Indian Ocean, but also demonstrates that impacts on coral reefs occur irrespective of political boundaries. These transboundary issues require that impacts on reef systems must be monitored and assessed at variable spatial scales to establish the intensity and variability of the impact itself.

At the regional level impacts to the marine environment by naturally occurring events will vary spatially. It is important not only to document this variability, but also to understand the source of this variability throughout the marine ecosystem. Following a natural disturbance, with resulting impacts to reef systems, concern is directed towards the recovery dynamics of that reef. However, in areas where the reef is already stressed from anthropogenic sources the recovery process becomes complicated and may take much longer as a result of the synergistic effect of perturbations. Difficulty then arises when trying to assess the rate of recovery without being able to separate the level of anthropogenic stress, from the stress resulting from the natural disturbance, which may be hindering the recovery process. Therefore, it is important to establish benchmark reef locations, which are remote from centres of human activity and free from anthropogenic disturbances, against which anthropogenic impacts elsewhere can be assessed and rates of recovery evaluated. Aldabra Atoll, Southern Seychelles, is an ideal non-anthropogenically disturbed location in which to study reefs and adjacent ecosystems. It has further significance with it being in the middle of a region which has been classified as having a number of reefs at high risk (Bryant et al., 1998).

Aside from acting as a regional benchmark there are a number of practical reasons why Aldabra provides a key component to a research agenda in the region not the least of which is monitoring the effects and long term impacts of the bleaching event. Many studies of coral bleaching have concentrated upon documenting the degradation of structural reefs into algal-dominated systems. Yet the reverse set of processes are likely to be of considerable importance: the ability of a coral reef to replenish lost coral populations, reinstate framework growth and recover reef structural complexity. The recovery of these oceanic reefs from high bleaching related coral mortality, such as those around Aldabra, is of much regional interest. The establishment of a systematic monitoring programme of the Aldabra reef environment will provide a greater understanding of the natural reef processes being played out locally, with implications to understanding reef dynamics elsewhere in the region.

THE ALDABRA MARINE PROGRAMME (AMP)

In light of the 1998 coral bleaching event and the regional importance of the Aldabra marine communities, the main objectives of this project were to:

- establish a permanent system for the long term monitoring of benthic and reef fish communities;
- conduct an assessment of the diversity and abundance of corals and fishes;
- quantify bleaching impacts on corals;
- establish a system for assessing larval supply of coral species to the lagoon and reef slope;
- resurvey the Drew (1977) transect adjacent to the settlement on Ile Picard.

GEOGRAPHY OF THE SEYCHELLES

The Seychelles consist of 115 islands (41 granitic and 74 coralline) comprising a total land area of 455 km^2 with an Exclusive Economic Zone (EEZ) of 1 374 000 km^2 (Shah, 1998) (Figure 1). The Seychelles themselves support reefs which can be classified into three groups: fringing reefs (typical of the high granitic islands of the Seychelles Bank); platform reefs and atolls (primarily of the Providence, Farquhar and Aldabra island groups) (Stoddart, 1984; Salm et al., 1996). Coral reefs of the Seychelles are among the most extensive in the world, representing an estimated 5% of the 36 000km^2 of coral reefs in the Indian Ocean (Spalding and Grenfell, 1997).

The Seychelles government has long recognised the need to promote efforts which preserve the marine environment as this is intrinsically linked to its tourist and fishing based economy and cultural history (Herminie, 1999). However, the reefs have been described, in a pre-bleaching environment, as already under stress from anthropogenic activities. It has been argued that an environmental upset could lead to ecological collapse (Shah, 1994). With the strong effects of the bleaching event on the corals of the inshore waters of the Granitic islands it appears that a shift in the ecosystem structure has occurred and may have difficulty recovering in an already stressed environment.

Fishing in the Seychelles

Fishing activities are vital to the Seychelles economy and the local cultural landscape. Fish resources constitute 83% of the export earnings (UNEP, 1999) and the Seychellois are one of the largest consumers of fish, averaging 75kg/person annually (Shah, 1994). Fish targeted by fishing activities are typically coral reef species. The majority of the catches consist of snappers (Lutjanidae – 52%), groupers (Serranidae – 18%), and emperors (Lethrinidae – 13%). The semi-pelagic jack (Carangidae) also frequently make up a significant percentage of the catch as they feed in coral and sandy areas (Shah, 1994; Jennings et al., in press).

Diversification of the fishing industry has occurred in recent years with the cultivation of prawns (Black Tiger Prawn - *Penaeus monodon*) on the outer island of Cöetivy; a live fin fish and holothurian (sea cucumber) fishery on Farquhar (taking advantage of the lucrative Asian market); and a steadily increasing tuna industry, with the Seychelles maintaining the largest tuna processing and shipping facilities in the Indian Ocean (IOTC, 1998). Since the establishment of the Seychelles EEZ in 1972, a fleet composed of foreign vessels has been licensed to fish in these waters. With the inability to patrol and monitor all fishing activities in the EEZ, there is concern over the pirate drift netters which represent a significant threat to fishing resources and by catch species in the Seychelles. At regular intervals GPS (Global Positioning System) locator beacons from drift nets wash ashore on a number of the remote outer islands, including Aldabra (pers. obs., 1998). Neither the direct nor the indirect effects of large-scale industrial fishing on other species is well understood in the waters of the WIO (UNEP, 1999).

The inshore waters of the Granitic Seychelles and the Seychelles Bank are believed to be fully fished or overexploited and clear changes in fish communities are evident in intensively fished areas (Jennings et al, in press). As a result of the continued over-exploitation of their inshore waters, it is likely that new areas within the vast Seychelles EEZ, particularly in the remote Southern Seychelles, will be increasingly targeted by fishing operations to maintain yields (UNEP, 1999; Jennings et al., in press). The outer islands have traditionally played a major role in the Seychellois economy aside from fishing by supplying natural resources which included oysters and shells, sea bird eggs, guano and coconuts (Shah, 1995). Increasing demands on the marine resources of the southern Seychelles highlight the importance of initiating monitoring programs in this area to trace the impact, if any, of these increased activities and to provide the impetus for long term resource management planning.

There are considerable gaps in information regarding the status of many fish species in the Seychelles. This is a barrier to making precautionary fisheries resource management decisions for the sustainable use of this resource (Shah, 1997). The status of fishing in the Seychelles is likely to be complicated further with the changes in available fish habitat resulting from coral bleaching related mortality experienced throughout the region.

Tourism

The importance of tourism to the Seychelles economy cannot be overstated. It contributed 15% to the country's GDP in 1996, generating between 70-75% of the foreign exchange and employing 20% of the labour force (UNEP, 1999). The Seychelles government recognises the intrinsic linkages between the environment and tourism, but acknowledges that there are likely to be conflicts between efforts to preserve the natural environment and increased tourist arrivals which place higher demands on all natural resources (UNDP, 1997). Tourist arrivals to the Seychelles were estimated to be 150 000 in 1999, twice its national population of 76 000. It is expected this number will reach 250 000 by the year 2007 (UNEP, 1999). In 1971 tourist arrivals only numbered 3175 (Shah, 1998), a striking comparison.

Currently tourism is primarily a beach-orientated industry on the islands of the Seychelles bank. However, with increasing emphasis on ecotourism in the last decade there are clear indications that remote areas of the Southern Seychelles are being considered for the development of exclusive tourist facilities to meet projected demand. Alphonse, at the southern extent of the Amirantes, 415 km south of Mahé, has been developed with full hotel, recreation and staff facilities which were completed in December 1999. Further south, Farquhar and Assumption (30 km southeast of Aldabra) have potential to be developed in the near future, the latter having implications for the natural environment of Aldabra. Aldabra has been described as the potential 'sleeping giant' of ecotourism in the Seychelles (Shah, 1995) and, though regulated, an increased anthropogenic presence in the area and arrivals on Aldabra can be expected. Both terrestrial and marine environments will require close observation and monitoring should the situation arise.

The direct impact of the coral bleaching event on tourist arrival numbers, and monetary value is not yet known. It is currently being assessed as part of the CORDIO programme.

Marine Pollution

In the granitic Seychelles, marine pollution is related to coastal development, shipping and reclamation projects. Though the shallow marine environments of the southern Seychelles are not currently stressed in an analogous manner, they are not immune from sources of pollution (i.e. plastics). They are susceptible to a wide range of pollution from some of the busy shipping lanes which traverse the region, including oily waste from ships and discharge of ballast water which may harbour exotic species, pests, pathogens, or diseases. Thirty percent of the world's oil, or an estimated 470 million tonnes, is annually being transported through the WIO region, yet the countries of the WIO do not currently have the capability to respond to oil spill related emergencies (Salm, 1996; COI, 1998). At the coastal/island level, spill risks are due to trans-shipping and bunkering (COI, 1998). With uninhabited remote islands in the Seychelles there may well be means to generate income through oil bunkering related activities. The effects of these activities would have dramatic negative impacts in islands in the vicinity and marine ecosystems downstream, thus providing further rationale and cause for documenting the marine resources of Aldabra, and neighbouring islands.

ALDABRA ATOLL

Aldabra Atoll (9°24' S, 46°20' E) is a large (34 km long, maximum 14.5 km wide , area 155 km^2) raised atoll. It is situated 1150 km southwest of Mahé and 420 km north of Madagascar (Figure 1 and 2). Late Quaternary raised reef limestones, averaging 2 km in width and up to 8 m above sea level, rim a shallow central lagoon. The lagoon is linked to the ocean by two major and one smaller channel and by several smaller reef passages (Stoddart, 1984). Aldabra has monthly mean maximum (December) and minimum (August) temperatures of 31ºC and 22ºC respectively (Stoddart and Mole, 1977). Average rainfall, with Aldabra located in the relatively dry zone of the southwest Indian Ocean, is 1100 mm annually (Stoddart, 1983; Viles et al., 2000). The climate is heavily influenced by NW monsoon winds from November to March bringing the heaviest rainfall, with SE trades blowing throughout the remainder of the year. Tidal range is 2 to 3 m and results in large-scale hydrodynamic exchanges between the lagoon and open ocean through the channels. The main channel alone drains approximately 60% of the lagoon (Stoddart, 1971).

The scientific history of Aldabra encompasses almost 100 years of both terrestrial and marine based investigations. Early contributions regarding the flora and fauna, and indeed geomorphological structure, of Aldabra made it in 1910 one of the better known Indian Ocean reef islands (Stoddart, 1968). In the mid 1960s Aldabra was thrust into the international spotlight, being considered by the British Government as a possible air-staging outpost, with the threat of the construction of an airstrip and support facility. However, within a few months of what was referred to as the beginning of the "Aldabra affair" (Stoddart, 1968), and the start of a scientific campaign, the British Government abandoned the proposed development of Aldabra. The plans, which had been made by the Royal Society of London, for making a full inventory of as many of the terrestrial and marine features of the atoll as possible before development began (Stoddart, 1979) were, however, able to continue. Between 1967 and 1979 nearly 50 years of human effort were expended on scientific research of the atoll.

The tenure of the Royal Society on Aldabra concluded in 1979 when the management of the island and surrounding environs was handed back to the Seychelles Government under the auspices of the Seychelles Island Foundation (SIF). As further recognition of its natural environmental importance, Aldabra was afforded designation as a UNESCO World Heritage site in 1982. Further international support has been provided by the Global Environmental Facility (GEF) of the World Bank which not only funded a complete renovation of the research station, but also, in 1996, provided the resources for a complete Management, Science and Conservation plan for Aldabra. Although scientific investigations have continued since the Royal Society hand over and throughout the ensuing years, these have been primarily limited to the terrestrial environment, focussing on the avian, giant tortoise and invertebrate communities (Stoddart, 1997). These research areas comprise a little over half of all published research.

By contrast, very few recent scientific investigations have been undertaken to examine the marine communities at Aldabra Atoll. To date, only 25% of all published scientific works concern the marine environment (studies of corals and reef fishes amounting to 11%) and of these only 5% have been published in the last decade.

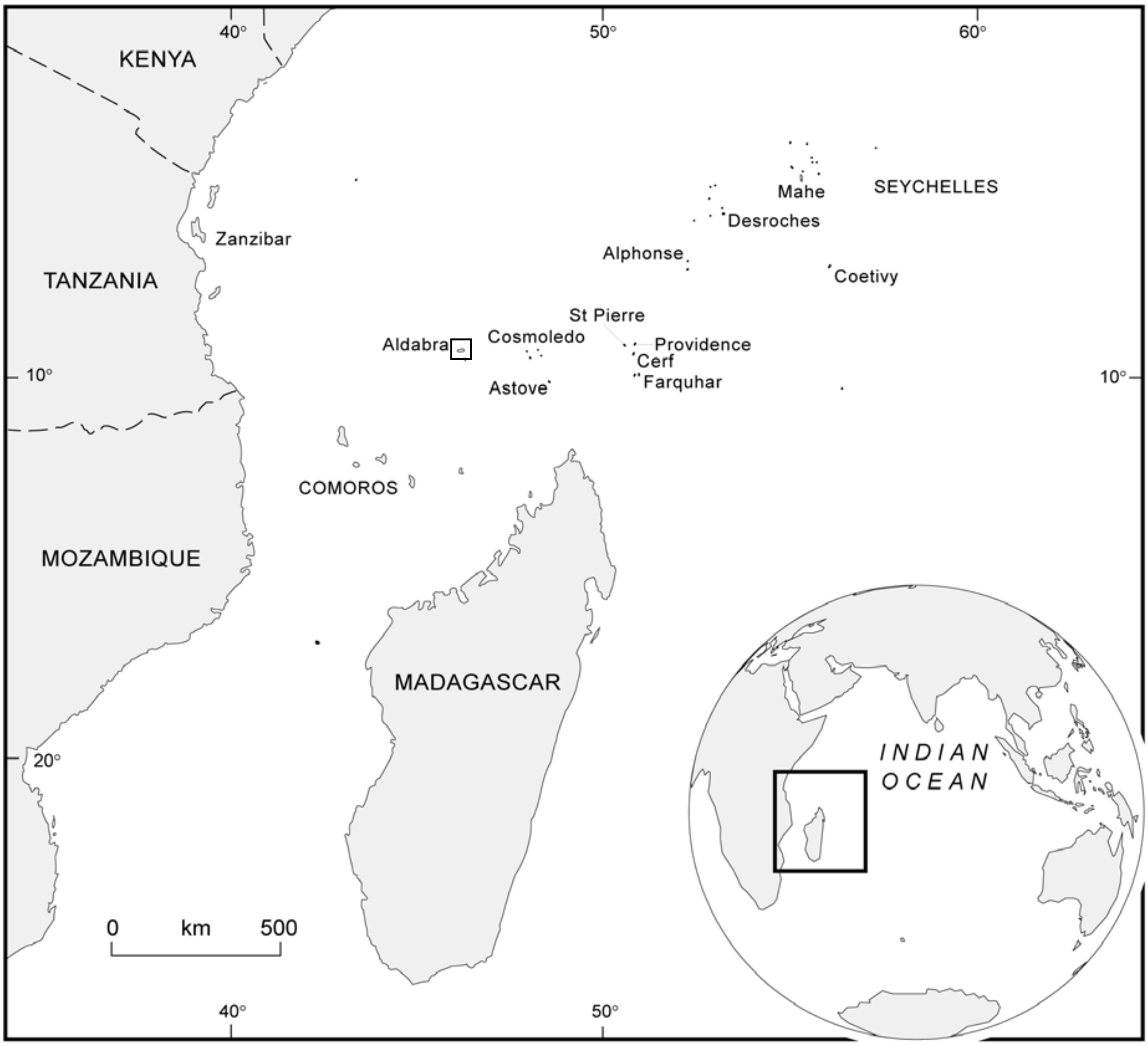

Figure 1. Map of the Western Indian Ocean with islands of the Granitic and Southern Seychelles.

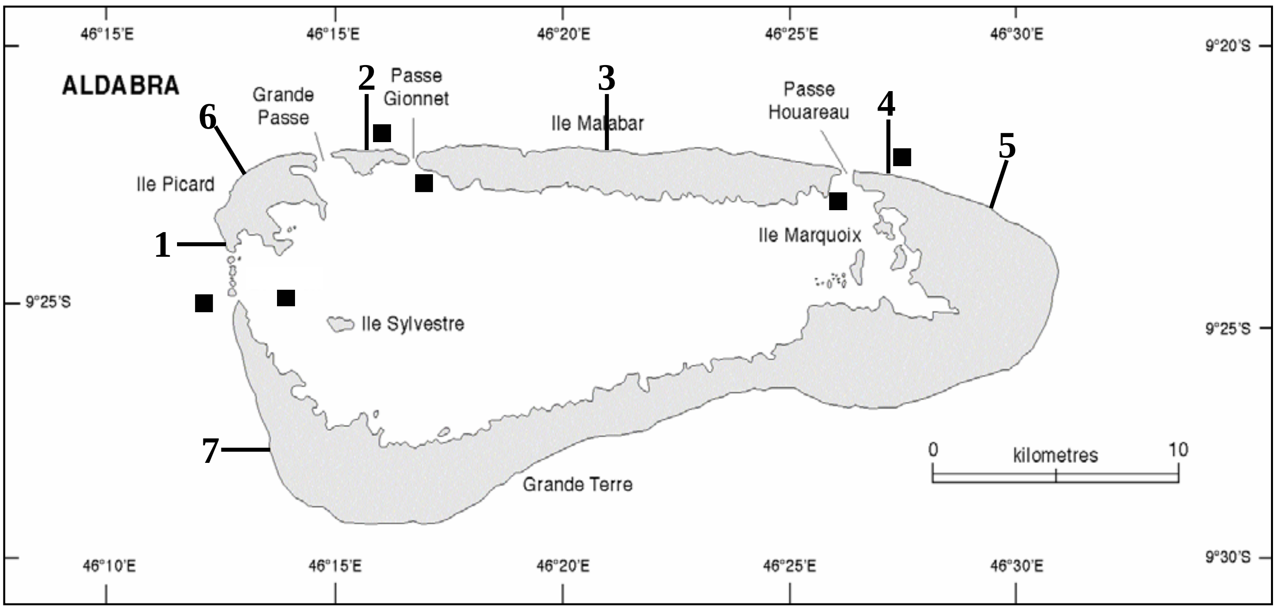

Figure 2. Map of Aldabra Atoll with the locations of the seven permanent coral reef transects and six settlement plates sites (■) established by the Aldabra Marine Programme (AMP) 1999.

The Coral Reefscape of Aldabra

Coral reef studies of Aldabra were made by Barnes et al. (1971) and Drew (1977) as part of the Royal Society campaign. These studies proposed that the reef front areas of Aldabra Atoll could be classified into six morphological categories, based on exposure to wave and storm action in the shallower depths, and on light attenuation in the deeper reef zones. The western reefs are characterised by a 460 m - wide reef flat, a reef ridge margin and reef front slopes of 20 to 45°. The northern reefs support a narrower reef flat and reef front slopes of 30 to 45° whose margin at approximately 25 m is characterised by massive, often vertically-sided, 'reef bastions' separated by sand- and rubble-filled channels. The east and southeast coasts are the most severely exposed and have neither a reef flat nor a reef ridge. No hermatypic corals are present. Finally, on the southern, less exposed shore the reef flat is present but not delimited by a prominent ridge. The reef front itself is characterised by large areas of dead coral which vary greatly in extent. On the basis of a photo-transect (Drew, 1977), western coasts are typified by branching and columnar corals in 0 – 6 m water depth, followed by a dominance of soft corals (6 – 14 m), massive corals, particularly faviids, and *Halimeda* (14 – 28 m), and finally encrusting corals and gorgonians (28 – 42 m). On the more exposed coasts, these zones are translated downwards, with branching and columnar corals reaching 20 m and massive corals over 30 m water depth (Barnes et al., 1971).

There is a long history of Aldabra reef fish studies extending back over 100 years (i.e. Jatzow and Lenz, 1899; Regan, 1912; Arnoult et al., 1958). The fishes of Aldabra were included in a description of 820 marine fish of the Seychelles (Smith and Smith, 1969). This list was expanded and revised by numerous studies during the period 1969-1979 to 883 species in the region (Polunin, 1984). Specific studies of the fishes at Aldabra found a high diversity, with 185 species recorded in a 300 m^2 section of reef habitat in 1973. However, there were substantial variations in species and abundance between habitats (reef-slope – 228 species, back-reef – 146 species; Polunin, 1984). Quantified baseline studies for determining spatial and temporal changes in the reef fish communities at Aldabra have not been conducted. Several site-specific and species-specific investigations in recent years (i.e. Potts, 1973; Shapiro, 1977; Robertson et al., 1979; Stevens, 1984) provided valuable information on the behaviour, diversity, and ecology of several fishes. Fish surveys conducted at Aldabra Atoll in April-May 1998 noted 287 species from 35 families (M. Spalding, University of Cambridge, unpublished).

The 1998 Coral Bleaching Event in the Southern Seychelles

The coral bleaching event widely noted in the granitic Seychelles, and reported throughout the WIO (Maldives, Mayotte/Mozambique Channel, East African coast and La Reunion) (Wilkinson, 1998; Lindén and Sporrong, 1999), was extensive on all the southern Seychelles reefs in 1998 (Spencer et al., in press).

In early 1998, the waters of the Seychelles experienced unseasonably high sea temperatures ranging from 29 to 34°C and exceptionally reaching 37°C in some lagoons (Teleki et al., 1998). High sea surface temperatures for the Seychelles were unusually prolonged with temperatures in excess of 30°C persistent for approximately four months in early 1998 (pers. obs., 1998; Dawson-Sheppard, pers. comm. 1998). This was later confirmed with satellite derived SST data for the region obtained through the Hadley Centre – UK Meteorological Office.

Bleaching was not exclusive to hermatypic corals. Incidences of bleaching were widespread in alcyonaceans, non-scleractinian coelenterates (*Stichodactyla* spp. and *Heteractis* spp.) and bivalves

(*Tridacna* spp.). Additionally, initial reports described that there had been widespread coral mortality (50 to over 90%) and recorded observations of recent algal overgrowth on these corals. Some alcyonaceans, which were also completely bleached (*Lobophytum* spp. and *Sinularia* spp.), had evidence of recent mortality with subsequent necrosis and disintegration of their growth form in an advanced state. The cause of the die back was initially suspected, and later confirmed (see Spencer et al., in press), to be related to the unusually high sea surface temperatures which were recorded throughout the WIO between January and May 1998

Observations made by the Southern Seychelles Atoll Research Programme (SSARP: Desroches, Alphonse, St. Pierre, Providence – Cerf Bank, Farquhar and Aldabra (Figure 1), February – May 1998) and by the Thalassi/Shoals Expedition (Cöetivy, St. Pierre and Alphonse (Figure 1), February – March 1999) indicated that mortality was particularly high in the branching corals - *Acropora* spp., *Pocillopora* spp., *Millepora* spp. (fire coral) and *Heliopora* spp. (blue coral). Death in the massive or boulder corals such as *Porites* spp., *Favia* spp., *Pavona* spp. and *Diploastrea* spp. was in most cases partial and spatially patchy. In the outer islands (Alphonse to Aldabra), bleaching was generally worse in shallower waters (10m or less). Areas which were least impacted were those influenced by cooler currents (upwellings – windward side of St. Pierre and Alphonse) and those coral colonies which are found within lagoonal channels where water fluxes are high. Furthermore, coral subjected to frequent high temperatures, such as in lagoons, faired well. Thus many of the corals survived in the Alphonse Lagoon, suggesting an adaptation of corals there to periodic inundation by high sea temperatures.

Detailed, quantitative descriptions of reef fish communities suggest that in 1998 (SSARP) there was no major impact of the bleaching and related coral mortality on fish communities. Fish communities may be more robust than the coral communities but results from the *Thalassi/Shoals* expedition (Teleki et al., 1999) and Aldabra Marine Programme (AMP: November 1999) should improve the diagnosis of fish population dynamics following the 1998 bleaching event.

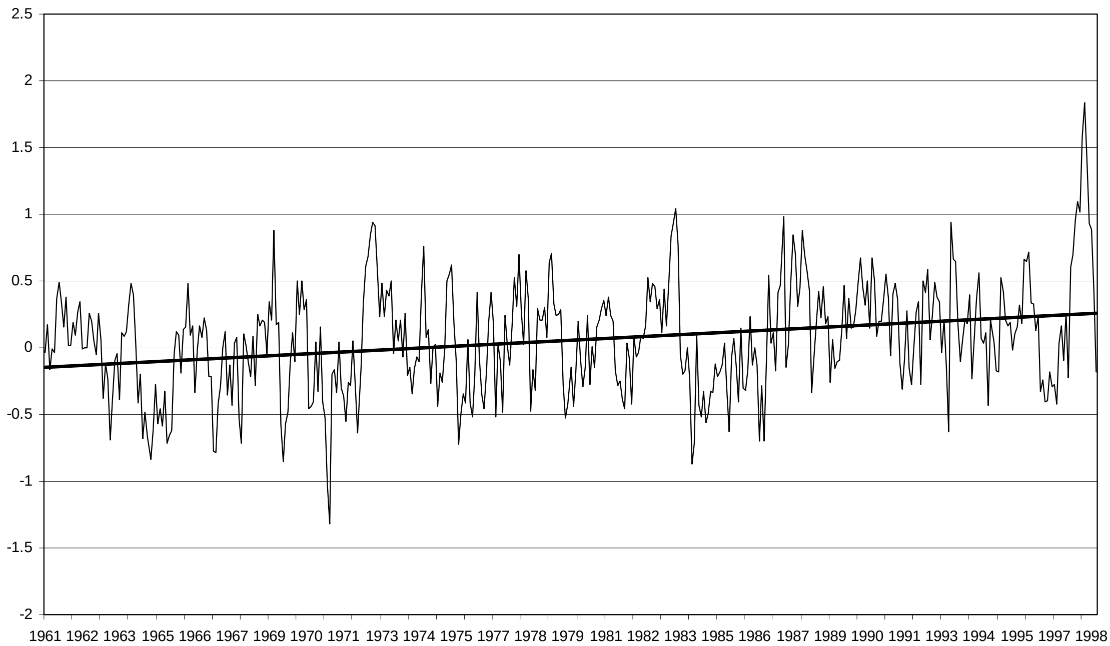

Figure 3. Monthly SST anomalies (ºC) for the southern Seychelles (6-10ºS 45-54ºE), using 1961-1990 baseline. Regression line indicates a warming trend of 0.108ºC per decade (Figure from Spencer et al., in press).

CORAL BLEACHING IN ALDABRA IN 1998

Study of sea surface temperature archives extracted for the Southern Seychelles suggests that a bleaching event of this magnitude has not been witnessed within the last three decades in this area (Figure 3). This is largely based on the assumption that the coral bleaching events occur following a >+1ºC increase above the mean maximum monthly SST (Goreau and Hayes, 1994).

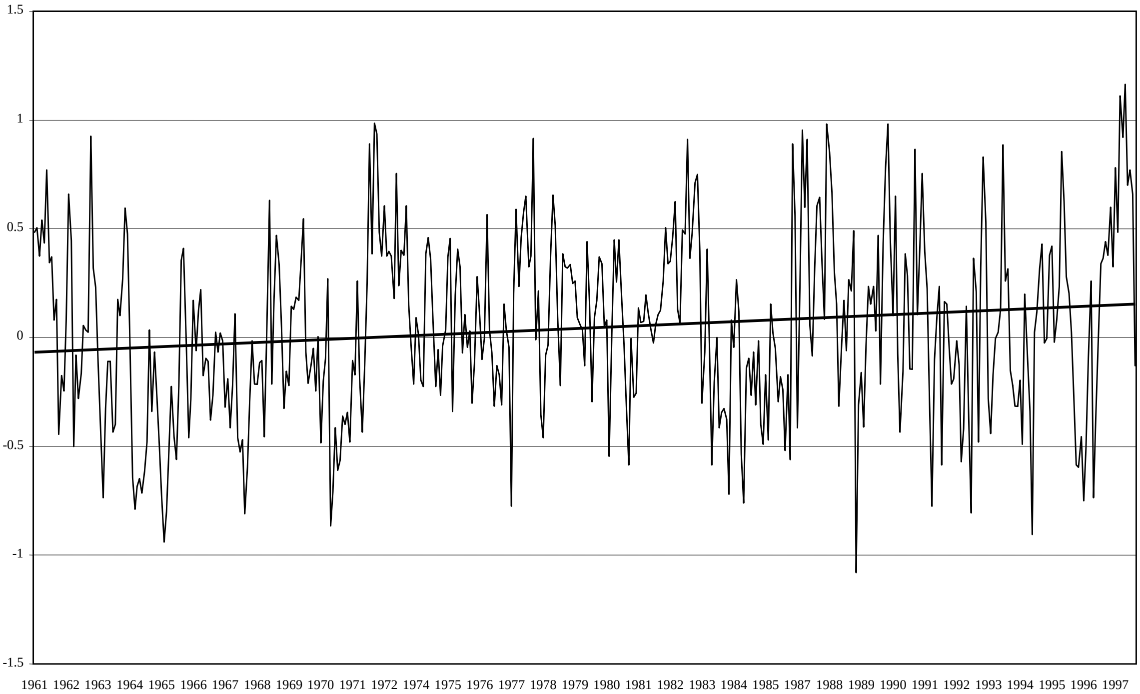

Figure 4. Monthly SST anomalies (ºC) for Aldabra (5-10ºS 45-50ºE), using 1961-1990 baseline.

Localised records for Aldabra also indicate that SSTs for 1998 were the highest of the previous three and a half decades (Figure 4). Anomalous temperatures began with a rapid increase in SSTs from November 1997 to a +1°C SST anomaly by January 1998. Peak SSTs (30.65°C) were reached in March, representing a +1.31°C anomaly above the longterm mean maximum SST for that month. The +1°C anomaly persisted until April 1998 indicating a duration of almost four months (Figure 5). All temperatures recorded for the period leading up to the bleaching event and those following ranged from +0.5 to +1ºC higher than the long term average of the monthly mean maximum temperatures (1961-1997) (Figure 5).

In April 1998, close to the peak of the coral bleaching event (Figure 5) a Cambridge Coastal Research Unit (CCRU) based research team (SSARP) found that widespread bleaching and mortality was common on the outer reef slopes surveyed (3-25 m) from the western to northeastern sides of Aldabra. 41% of corals (coral coverage = 37%) were bleached or displayed recent mortality. Bleaching intensity in Aldabra was not as high as other areas in the Southern Seychelles possibly because peak warming was 0.5ºC lower than other areas in the region (Spencer et al., in press). Bleaching and related mortality was primarily seen in the branching and tabular species of coral (i.e., *Pocillopora* and *Acropora*), and partial to patchy in most massive species (i.e. *Porites*, *Pavona*). Bleaching was in some areas confined to a single side of the coral colony. However, a high proportion of the massive species of corals displayed signs of previous mortality, as indicated by a thick of algal overgrowth and the presence of encrusting and boring invertebrates. As in other areas, soft corals showed high levels of bleaching and mortality. Although no quantitative data were gathered for the reef communities in the lagoon, extensive observations were made in all of the channels and in the western half of the lagoon. Most of the coral species found in the channels, with the exception of isolated incidences of branching corals, were observed to be alive and displaying no obvious signs of perturbation. Lagoonal patch reefs and individual heads of massive coral species displayed very limited bleaching. Distinctive species such as *Galaxea*, *Serioptera*, *Acropora* and *Pocillopora* were completely bleached, particularly with increased distance from the flux of water within the channels.

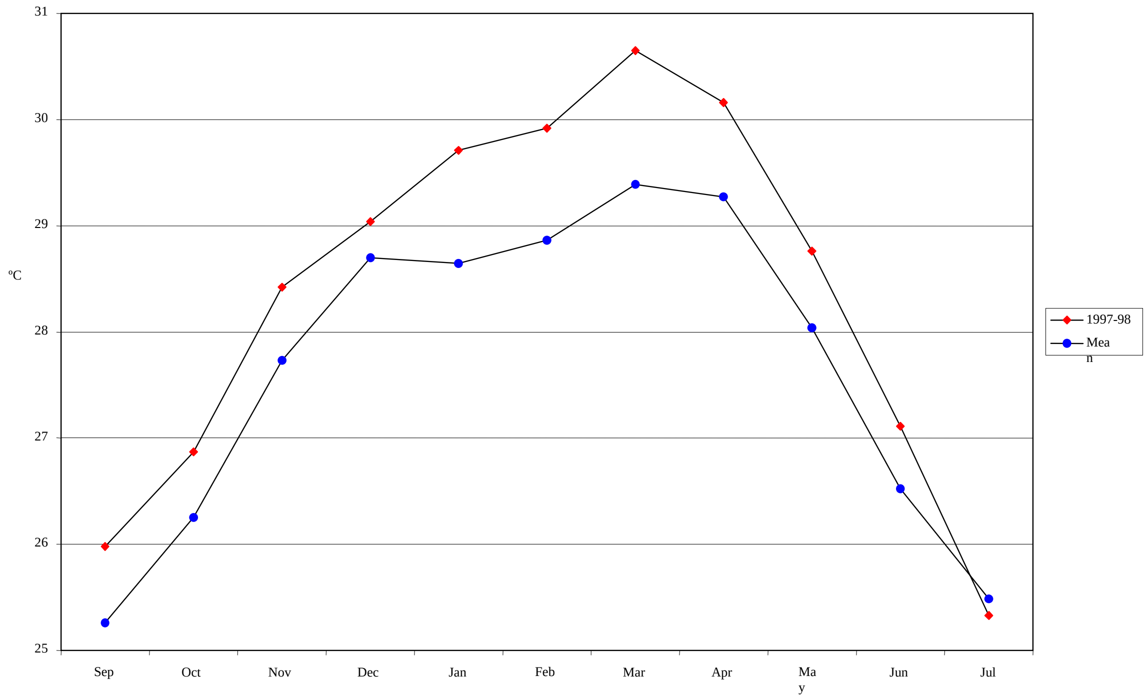

Figure 5. Monthly mean maximum sea surface temperatures for Aldabra (9-10ºS, 46-47ºE) from September 1997 to July 1998 in comparison to the average monthly mean maximum sea surface temperatures for the period September to July 1961-1996.

METHODOLOGY

Between the 12th and 24th of November 1999 a series of 7 permanent transects were established on the northern and western coasts of Aldabra Atoll (Figure 2). Transects were located for an even geographic distribution around the atoll and to coincide with previous transects by Barnes et al. (1971) and Drew (1977). Work was not carried out on the southern and eastern coasts due to high seas generated by the SE trade winds. At each site quantitative baseline surveys of the corals and reef fishes were conducted along each of the transects.

Primary transects were placed from a depth of 20 m to the reef crest at a depth of approximately 3-5 m. Secondary transects were laid at 20 m and 10 m following the depth contour (Figure 6). Depths were corrected to the mean lower spring tidal datum (Figure 6). At site 7 transect depths were 15 m and 5 m respectively, because the maximum depth of the coral reef was found to be 18 m. Secondary transects were permanently marked with a steel stake that was driven into the substrate at the beginning and end of the transect. The position of primary transects was fixed by the two stakes marking the beginning of each of the two secondary transects at 10 m and 20 m depths.

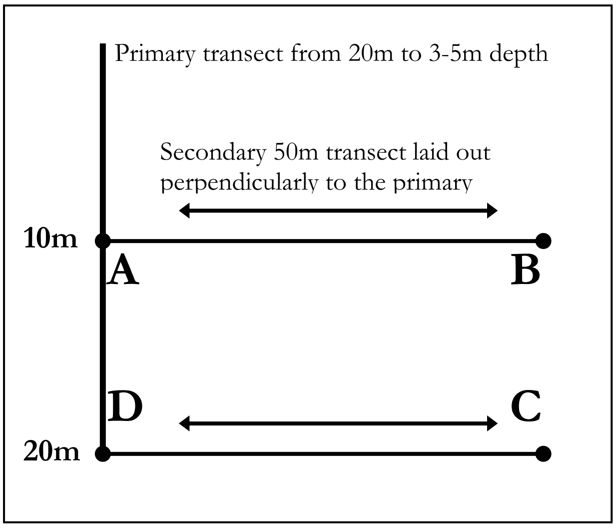

Figure 6. Permanent transect layout. Letters indicate points where permanent stakes were located.

The general position of the permanent transects was established both by using a hand-held GPS unit and taking compass bearings to prominent features of the shore and land-marks. Each of the four secondary transect stakes were temporarily marked with a taut-line-moored surface buoy to locate exact location (lat/long). Fixes were recorded clockwise as shown by the order of letters in Figure 6. In order to increase accuracy the boat was positioned exactly above the stakes by pulling on the rope until it was vertical in the water, at which point a GPS fix was taken. A bearing to notable landmarks was also taken from stake A.

The benthos at each site was surveyed using digital videography. The primary transect tape was surveyed with a single run, keeping the tape in the centre of the video image. The camera was held 1 m above the substrate, and depth was recorded at approximate 5 m intervals. Secondary transect footage was recorded 40 cm above the substrate on each side of the transect tape, keeping the tape on the edge of the video image. Thus, a run along the left side of the tape and back on the right side, with a pause every 25 m (Figure 6). All video footage was acquired at a slow swimming speed in order to maintain image quality. A general view of the reef was recorded in deeper water between 20 and 40m. Where time allowed, the coral species present at each site were noted, as well as topography and outstanding features.

Underwater videography along secondary 50m transect line.

Video imagery was analysed using the AIMS 5-dot method (English et al., 1997; Osborne and Oxley, 1997), recording live and dead, hard and soft coral growth forms (branching, tabular, massive, encrusting and foliose). The occurrence of coral genera within each of these growth form categories was also noted, as well as incidences of mushroom corals, *Heliopora* (blue coral) and *Millepora* (fire coral). Additional observations of the substrate were noted in predefined categories: sand, rubble, rock, turf, *Halimeda* and other macro algae.

Settlement plates were located at six sites, three on reefs around the outside of the atoll, and three within the atoll (Figure 2). At each site, six ceramic tiles were attached to the seabed using cable ties. Of the six tiles, two were oriented in the horizontal plane, two at approximately 45 degrees to the horizontal, and two in the vertical plane.

Fish surveys were conducted using protocols developed for rapid visual assessments (Ginsberg et al., 1999; English et al., 1997). Two divers swam simultaneously along either side of a 50 m secondary transect tape. Each diver recorded the species, number and size of fish in a 2m corridor extending out from either side of the tape, and vertically to the surface. Six total length categories were used: 0-5 cm, 6-10 cm, 11-20 cm, 21-30 cm, 31-40 cm and >40 cm. The 10 m depth transect was swum as two sections of 25m. Each section was first surveyed for larger/conspicuous fishes, and then immediately re-surveyed for small/cryptic fishes. The 20 m depth transect was swum as one 25 m section only, but otherwise treated in exactly the same way as the 10 m depth transect. Thus, the water column over 300 m^2 of benthic habitat was quantitatively surveyed for fishes at each of the locations around the atoll.

In addition, at the end of each dive, an inventory of species not seen within the transect limits was made.