ALDABRA: MONITORING THE PATH TO RECOVERY

Ben Stobart, Raymond Buckley, Larry LeClair, Kristian Teleki, Nigel Downing , David Souter and Martin Callow

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Phase II

February 2001

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Introduction

Aldabra Atoll: A Natural Science Laboratory

Aldabra Atoll (9°24' S, 46°20' E), Southern Seychelles Islands Group, is one of the world's largest raised coral atolls (34 km long, maximum 14.5 km wide, area 155 km^2). It is located 1150 km southwest of the capital of the Republic of Seychelles, Mahé, and 420 km north of Madagascar (Figures 1 and 2). Late Quaternary raised reef limestones, averaging two km in width and up to 8 m above sea level, rim a shallow, central lagoon (190 km^2). The lagoon is on average 2 - 3 m deep at low tide. The coastline consists mainly of deeply undercut limestone cliffs and a broad intertidal reef flat (200 – 500 m). 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) air temperatures of 31°C and 22°C respectively (Stoddart and Mole 1977). The climate is semi-arid, with an annual rainfall of 1100 mm (Stoddart 1983; Viles *et al*. 2000). Northwest monsoon winds from November to March bring the heaviest rainfall, with SE trades blowing throughout the remainder of the year. The tidal range is 2 - 3 m and results in large-scale hydrodynamic exchanges between the lagoon and the ocean through the channels. The main channel alone drains approximately 60% of the lagoon (Stoddart 1971).

Aldabra Atoll has been characterised as "one of the wonders of the world" and "one of the world's greatest surviving natural treasures" (Attenborough 1995). The isolation of Aldabra in a remote area of the Indian Ocean has helped preserve this large atoll in a relatively natural state. Although increasing levels of stress from human activities are contributing to the decline of the world's coral reefs (Bryant *et al.* 1998; Hodgson 1999; Wilkinson 2000) the marine environment of Aldabra with its coastal reefs and expansive lagoon has remained untainted. Aldabra is surrounded by a region which has a number of coral reef systems at high risk from activities ranging from coastal development and destructive fishing practices, to the overexploitation of resources, marine pollution, and runoff from inland deforestation and farming (Bryant *et al.* 1998). Aldabra is an ideal natural laboratory for studying tropical marine ecosystems and related environments (i.e. seagrass and mangroves).

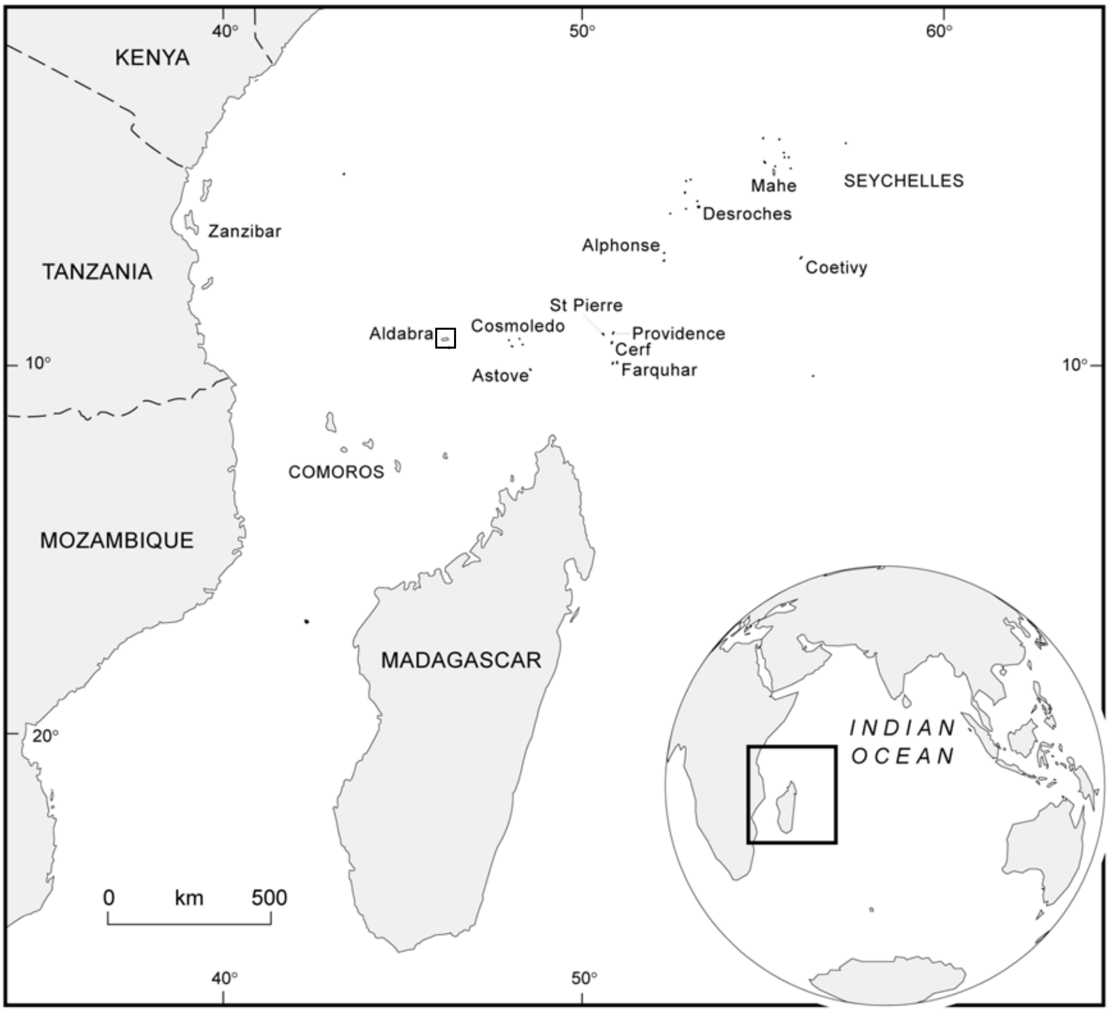


Figure 1. Location of Aldabra Atoll, Seychelles in the Western Indian Ocean.

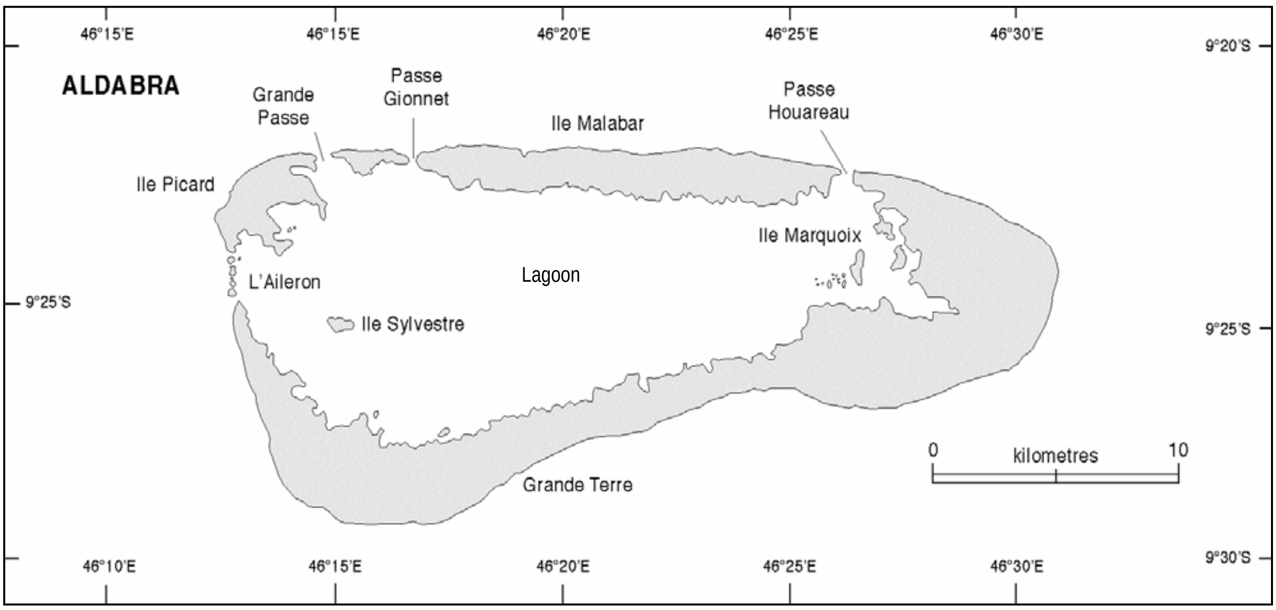


Figure 2. Aldabra Atoll.

UNESCO World Heritage Site

In the 1960's Aldabra Atoll was under the threat of military development. Through the efforts of concerned scientists and the Royal Society this threat was staved off. Instead a unique and intensive research campaign was initiated to fully study this exceptional environment. Aldabra was eventually handed over to the Seychelles Island Foundation (SIF), established in 1979, for the management and protection of Aldabra in perpetuity to protect the atoll's significance and importance to natural science. Aldabra Atoll was designated a UNESCO World Heritage Site in 1982 as further recognition of the atoll's environmental importance. A recent global study by Conservation International has included Aldabra in one of the areas identified as a *marine biodiversity hotspot* (Roberts, *et al.*, in press). High endemism and species richness are used to identify priority sites for marine conservation worldwide. The Conservation International study demonstrates the present critical importance of the marine environments of Aldabra for ecological studies that have global significance.

Marine Research

Studies of the marine environment of Aldabra have been conducted since the late 1800s, but the majority of the work on the atoll has been in the terrestrial environment. The paucity of marine research on Aldabra, and the dramatic decline of dedicated study in the last three decades, can largely be attributed to the logistical and financial constraints of undertaking a comprehensive marine monitoring programme at this remote location. To date, 23% of all published scientific works at Aldabra concern the marine environment (studies of corals and reef fishes amounting to 11%), and of these 5% have been published in the last decade (Teleki *et al.* 2000; Stoddart 1997). The majority of marine related research on Aldabra since the benchmark work of Barnes *et al.* (1971) has been a series of individual and unrelated studies, with the exception of the on going monitoring of turtle populations (i.e. Mortimer 1988; 1997).

Coral Studies

Barnes *et al.* (1971) and Drew (1977) conducted the first coral reef studies of Aldabra Atoll. The western reefs are characterised by a reef flat 460 m wide, 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 depth is characterised by massive, often vertically-sided, 'reef bastions' separated by sand-filled 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. On the southern, less exposed shore the reef flat is present but is 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 at 0 – 6 m depth, followed by a dominance of soft corals (6 – 14 m), massive corals, particularly favids, 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 depth and massive corals in over 30 m. (Barnes *et al.* 1971).

Fish Studies

There is a long history of Aldabra reef fish studies extending back over 100 years (e.g. 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 (Polunin 1984). However, there were substantial variations in species and abundance between habitats (reef-slope – 228 species, back-reef – 146 species; Polunin 1984). 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 reef fishes and sharks.

The 1998 El Niño Event in the Seychelles

The 1997-98 ENSO (El Niño Southern Oscillation) was described as the largest El Niño for the last 100 years (Slingo 1998; McPhaden 1999)**.** This event increased the magnitude of ocean warming in the tropical Pacific, Atlantic and Indian Oceans. In the western Indian Ocean this led to extensive and pervasive coral bleaching in this region, including the southern Seychelles. In early 1998, the waters of the Seychelles experienced high sea temperatures ranging from 29 - 34°C, and exceptionally reaching 37°C in some lagoons (Teleki *et al.* 1998). High sea surface temperature (SST) excursions for the Seychelles were prolonged in early 1998. Temperatures in excess of 30°C persisted for approximately four months. Previous studies have shown that small temperature and short duration excursions above the mean monthly summer maximum result in partial and complete recovery of bleached coral colonies (Brown *et al.* 1996; Brown 1997; Davies *et al.* 1997). Larger temperature changes that were maintained for prolonged periods, as was the case in 1997-98, lead to the mass mortality of affected corals. SST archives for the southern Seychelles suggest that a bleaching event of this magnitude had not been witnessed within the last three decades (Spencer *et al*. 2000).

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 (Spencer *et al*. 2000). In Aldabra, bleaching was generally worse in shallower waters, 10 m or less (Teleki *et al.* 1998). Areas which were impacted least were those influenced by cooler currents and localised upwelling, and in lagoonal channels where water fluxes are high. Furthermore, corals subjected to frequent high temperatures, such as in the lagoon of Aldabra faired well suggesting local adaptation of corals to periodic high sea temperatures.

Records for Aldabra also indicate that SSTs for 1998 were the highest of the previous three and a half decades (Figure 3). Anomalous temperatures began with a rapid increase in SSTs from November 1997 to a +1°C SST anomaly by January 1998. The peak SST of 30.7°C was reached in March, representing a +1.3°C anomaly above the long term monthly mean maximum SST. This +1°C anomaly persisted until April 1998, a duration of almost four months (Figure 4). All temperatures recorded for the period leading up to the bleaching event, and those following, ranged from +0.5ºC to + 1ºC higher than the long term average of the monthly mean maximum temperatures for 1961 to 1996 (Figure 4).

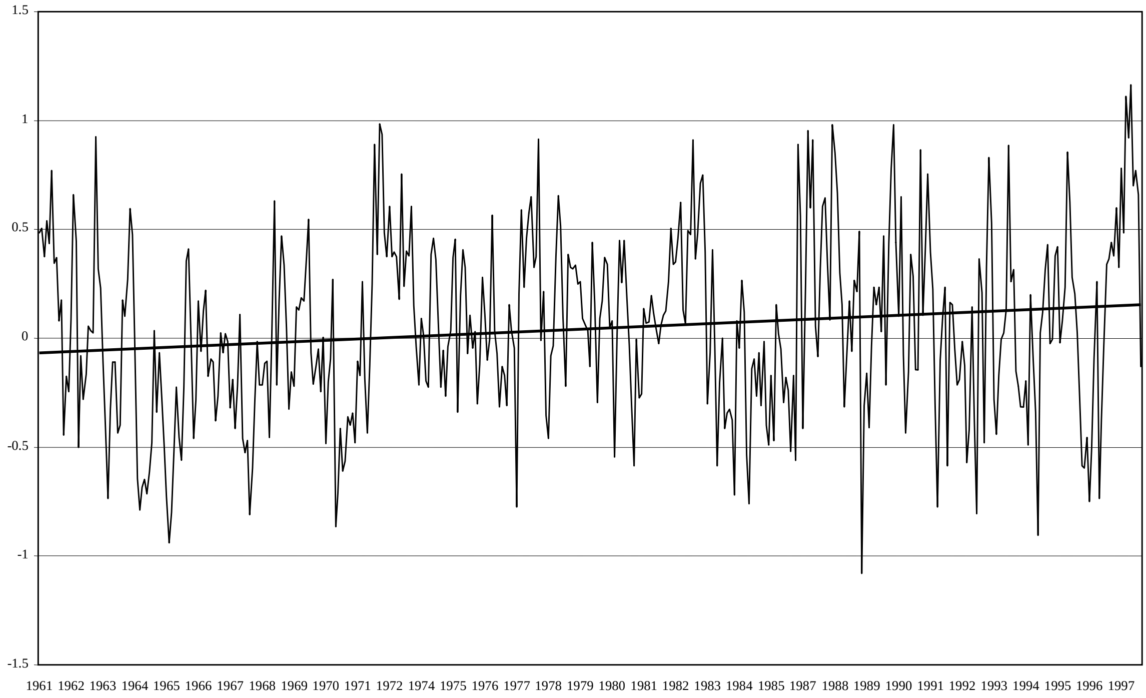


Figure 3. Monthly sea surface temperature (SST) anomalies (i.e. when mean temperatures are above or below the long term mean) for Aldabra Atoll using 1961-1990 baseline. Note the 1997 anomaly (Teleki *et al.* 1999).

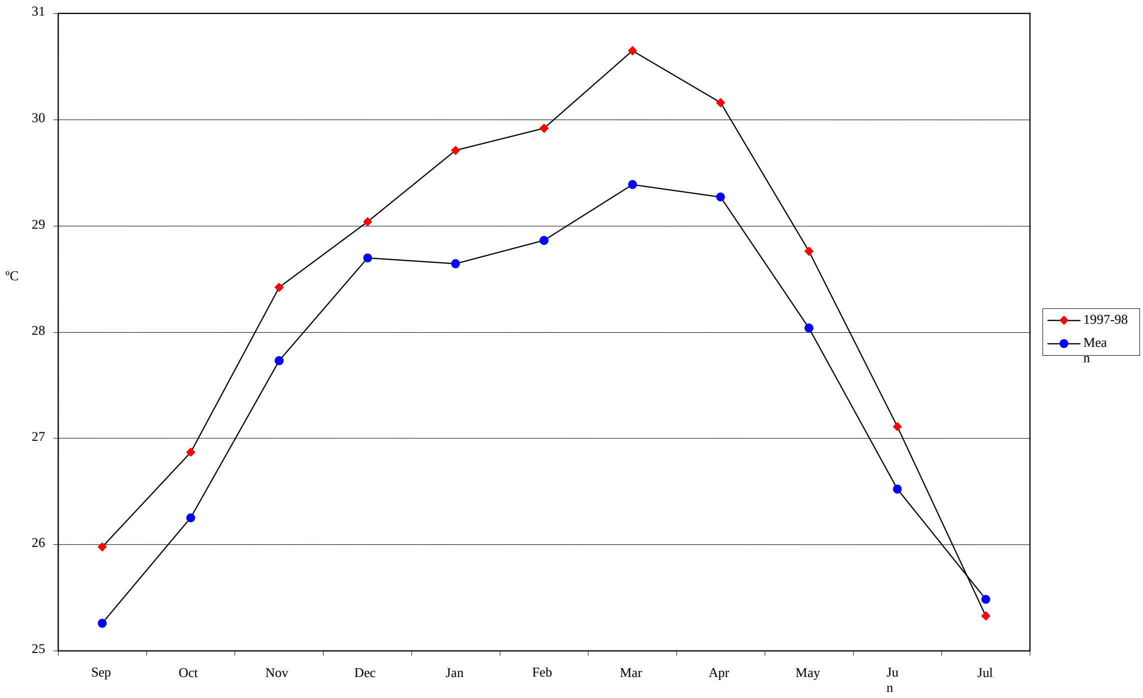


Figure 4. Monthly mean maximum sea surface temperatures for Aldabra Atoll from September 1997 to July 1998, in comparison to the average monthly mean maximum sea surface temperatures for the period September to July 1961-1996 (Teleki *et al.* 1999).

Results of the 1998 Southern Seychelles Atoll Research Programme

In April 1998, at the peak of the coral bleaching event, a Cambridge Coastal Research Unit (CCRU) research team, the Southern Seychelles Atoll Research Programme (SSARP), found that widespread bleaching and mortality was common on the outer reef slopes (3 – 25 m) surveyed from the western to northeastern sides of Aldabra Atoll. Coral coverage was 37%, with 41% of those bleached or recently dead. The intensity of the coral bleaching in Aldabra was not as high as in other areas of the southern Seychelles because peak warming was 0.5ºC lower (Spencer *et al.* 2000). Bleaching and related mortality was primarily seen in the branching and tabular species of coral (e.g. *Pocillopora* spp. and *Acropora* spp.), and was partial to patchy in most massive species (e.g. *Porites* spp. and *Pavona* spp.). Bleaching was in some areas confined to a single side of the coral colony. A high proportion of the massive species of corals displayed signs of previous mortality indicated by a thick overgrowth of algae and the presence of encrusting and boring invertebrates. As in other areas, soft corals had high levels of bleaching and mortality.

Although no quantitative data were gathered for the reef communities in the lagoon at Aldabra, extensive observations were made in all the channels and in the western half of the lagoon. Most coral species found in the channels, with the exception of isolated incidences of branching corals, were alive and displaying no obvious signs of stress. Normally deep water corals (e.g. *Tubastrea micrantha*) were found in the channels, most likely adapted to shallow waters because of channel hydrodynamic activity mimicking conditions of the deep water environment. This may also explain the high survivorship of massive and branching coral colonies in the channels. In the lagoon, patch reefs and individual colonies of massive coral species showed limited bleaching. Distinctive species such as *Galaxea*, *Seriatopora*, *Acropora* and *Pocillopora* were completely bleached, most often with increased distance from the flux of water from the channel.

The CCRU expedition to Aldabra also conducted surveys of fish communities on the reefs at four locations along the western and northeastern shorelines. The species of fish were recorded by abundance categories that ranged from <1 fish per transect, to 50+ fish per transect. A summary of the abundance of reef fish revealed 287 species from 35 families (Spalding 1998).

The Aldabra Marine Programme

The Aldabra Marine Programme (AMP) was formed to address the growing concern throughout the coral reef scientific community that this important marine ecosystem was being altered at increasing and unprecedented levels. Coral reefs are the planet's most diverse marine ecosystem, with the highest standing biomass, and the most species of fishes (Birkeland 1997; Sale 1991). Coral reefs are crucial to tropical ocean functions and to the human populations utilising the natural resources in these regions (Hodgson 1999; Johannes 1981; Russ 1991). Yet many of these complex ecosystems are threatened by impacts ranging from losses of essential habitats (Bohnsack 1995; Bohnsack and Ault 1996), to extinction risks for marine species (Roberts *et al.* 1999; Glynn and Deweerdt 1991). Further, the long-term effects of anthropogenic impacts, including global climate change (Bryant *et al*. 1998; Hodgson 1999; Pomerance 1999; Wilkinson 1998; Wilkinson and Buddemeier 1994; Chadwick 1999) exacerbate these stresses to the marine environment. The degradation of coral reef communities and their subsequent rates of recovery are important early-warning indicators of local and global marine ecosystem health. The need for long-term monitoring of coral reefs in a relatively natural state, to establish benchmarks for measuring changes and recovery in impacted reef systems, has been recognised (Wilkinson and Buddemeier 1994), but there are few anthropogenically unaltered sites to study (Roberts *et al*. 1999; Steneck 1998).

The Aldabra Marine Programme was established following the discovery of the extensive damage to the coral reef ecosystem at Aldabra Atoll. Determining the recovery dynamics of coral reefs altered by natural disturbances is a long-term process. It can be complicated, prolonged, or rendered impossible, in systems already stressed by anthropogenic sources. Studies at Aldabra provide benchmarks in the recovery process free from these disturbances, against which anthropogenic impacts in other coral reef systems could be assessed, and rates of recovery evaluated.

The primary goal of AMP was to establish the first permanent underwater survey sites for long-term, quantitative studies. These would determine the ability of coral reef systems to replenish lost coral populations, reinstate framework growth, and to recover reef habitat structural complexity and its fish communities.

The second AMP goal was to provide information for the development of a marine conservation programme for Aldabra to enhance the protection and preservation of the atoll's marine resources. AMP studies are conducted to fulfil the marine management priorities of the Seychelles Islands (as outlined in Beaver and Gerlach 1997). The research findings at Aldabra are disseminated to national, regional, and global initiatives. The AMP studies also contribute to a growing and valuable information database on global climate change and the environment.

The 1999 Aldabra Marine Programme Phase I

Objectives

Phase I of the Aldabra Marine Programme took place 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 (1997) coral transect adjacent to the settlement at Ile Picard.

All these objectives were achieved (Teleki *et al*. 1999). Seven permanent survey sites were established on the outer reefs along the northern and western coasts of Aldabra. The survey sites were located to give an even geographic distribution around the atoll, and to coincide with previous transects by Barnes *et al.* (1971) and Drew (1977). At each survey site, permanent 50 m transects were located along the 10 m and 20 m depth contours, with the exception of one site where the transects were located at the 5 m and 15 m contours due to limited coral cover at depth. Surveys on each transect assessed the diversity and abundance of corals and fishes, and quantified the impacts of the 1998 bleaching event. During this first phase the corals on the Drew (1977) transect were resurveyed and it was concluded that the corals were beginning to recover.

Coral Surveys

Overall there had been high coral mortality in water shallower than 5 m. Coral vitality increased with depth. Live coral coverage ranged from 3 - 21% in shallow water (0 – 10 m) and 0.5 - 34% in deep water (>10 m). Most of the live branching corals were dominated by *Pocillopora* spp. and *Porites* spp., which represented 20% of the coral cover. Massive species formed 63% of total live coral coverage on deep transects, compared to 45% on shallow transects. *Physogyra* spp. formed 65% of the live, massive coral coverage on the deep transects, but only 3% on the shallow transects. The foliose *Echinopora* spp., *Pachyseris* spp., and *Turbinaria* spp., and the encrusting *Montipora* spp., were common live corals at all sites, but the foliose genera were almost exclusively found on the deep transects.

From west to east along the coastline of Aldabra there was a prominent gradient of decreased coral growth, related to levels of increasing hydrodynamic energy. There was evidence of widespread mortality in all coral growth forms with a high degree of spatial heterogeneity of tissue death within and between colonies. In massive corals it was most common to find surviving live tissue on the periphery and/or the underside of the colony. At locations where branching corals survived, often the colony had suffered only partial mortality. Plate and fine branching corals were not found at any of the locations surveyed, probably due to the relatively high hydrodynamic conditions at Aldabra. The onset of mortality in these growth forms would rapidly compromise their structural integrity. Overall, comparisons with coral coverage data collected in 1998 revealed that in shallow depths bleaching primarily led to mortality, while in deeper water bleached corals were more likely to recover.

Fish Surveys

The quantified fish surveys on the outer reefs at Aldabra found 165 species representing 27 families, and the qualitative (off-transect) surveys identified an additional 46 species and 6 families. The total of 211 species from 32 families found in November 1999 were generally in agreement with the 287 species from 35 families (Spalding 1998) reported by the CCRU expedition to Aldabra in April 1998.

The densities of fishes on the transects were often dominated by large schools of a few species from the families Serranidae (groupers and basslets), Apogonidae (cardinalfishes), Pomacentridae (damselfishes), and Caesionidae (fusiliers). The abundance of fishes in the smallest size category was caused primarily by large numbers of small sized species, and secondarily by juvenile life stages. Although there was a prominent gradient of decreased coral growth from west to east along the coast line of Aldabra, there was no correlation between either the number of species, or the density of fishes, and the corresponding west to east locations of the transects. However, there were positive correlations between the amount of live coral habitat, and the number of species, and the density of Chaetodontidae (butterflyfishes), Labridae (wrasses), and Serranidae. These families each have several species that are commonly associated with live corals and habitat structure formed by erect dead corals (Crosby and Reese 1996).

The 2001 Aldabra Marine Programme Phase II

Phase II of the Aldabra Marine Programme took place between 8th and 22nd February 2001.

The main objectives were to:

- Repeat the transects of corals and fishes at the seven permanent survey sites established in 1999;
- Establish additional permanent survey sites on the outer reef and conduct benchmark transects of corals and fishes at these sites;
- Establish permanent survey sites in the lagoon and conduct benchmark transects of corals at these sites;
- Conduct coral recruitment transects at selected locations on the outer reef and in the lagoon;
- Tag coral recruits at selected locations on the outer reef to monitor growth and survival;
- Deploy temperature data loggers at selected locations on the outer reef and in the lagoon.

The secondary objectives of this phase were to:

- Improve the ease of location of each permanent transect site;
- Establish a checklist- of fishes in off-transect areas at the outer reef and lagoon survey sites;
- Assess the status of *Echinometra* spp. and *Diadema* sp. (black-spined urchins) at selected locations on the outer reef;
- Conduct training exercises for Aldabra Station staff in the methods of assessing coral recruitment, surveying urchins, and monitoring the physical marine environment.

Honeycomb Moray Eel (*Gymnothorax favagineus*)

Methodology

Coral and Fish Transects

The procedures used in the 2001 AMP survey to locate and mark permanent survey sites, and the methods used to quantify corals and fishes on the transects, replicated those used in AMP Phase I (Teleki *et al*. 1999).

To establish new outer reef sites, a primary transect of varying length was extended from 20 m depth to the reef crest at 3 - 5 m depth, and two 50 m secondary transects were extended laterally from the primary transect along the 10 m and 20 m depth contours (Figure 5). Permanent survey sites in the lagoon were established in areas where there was abundant live coral habitat. At the lagoon sites a single 50 m transect extended along a depth contour appropriate to the habitat. All 50 m transects were permanently marked with steel stakes at the beginning and end, and each stake location was fixed using a Global Positioning System (GPS). Prior to each coral and fish survey, a tape or line was placed along the transects between the two stakes, following the appropriate depth contour.

Digital underwater videography was used to record the benthic habitat on both sides of the 50 m secondary transect lines, first along the shoreward side and then back along the off-shore side, with a pause every 25 m. All video footage was acquired at a slow swimming speed to maintain image quality, with the diver positioning the camera 40 cm above the substrate. The imagery from the secondary transects was later analysed using the AIMS 5-dot method (Osborne and Oxley 1997). Four still pictures were also taken around each stake in a clockwise direction with the stake always in the corner of the picture: lower right corner for first picture, lower left for second, top left for third and top right for fourth. These pictures were recorded approximately 1 m from the substrate. Below 20 m, reference footage was filmed to characterise the general habitat.

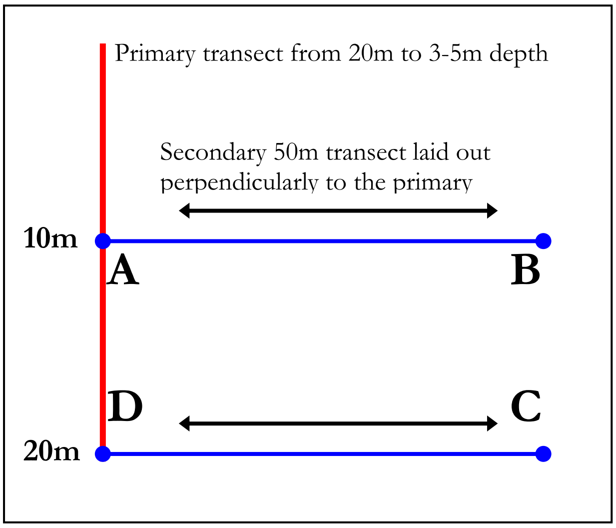


Figure 5. Diagram of transect layout.

The 1999 primary transect videography was not repeated in 2001, although it was filmed for the newly established site 8.

Fish transects were conducted using protocols developed for rapid visual assessments (Ginsberg *et al.* 1998; English *et al.* 1997). Two divers recorded the species, number, and sizes of fish in a 2 m corridor extending out from either side of the 50 m transect, and vertically to the surface. The sizes of the fish were recorded in six total length categories: 0 - 5 cm, 6 - 10 cm, 11 -20 cm, 21 - 30 cm, 31 - 40 cm, and > 40 cm. Transects were surveyed in 25 m sections, first for larger/conspicuous fishes, and then immediately re-surveyed for small/cryptic fishes. Only the first 25 m section of the transects at 20 m depth were surveyed. Thus, over 300 m^2 of benthic habitat was surveyed for fishes at each site. The fish transect data was analysed using Analysis of Variance (ANOVA) and regression statistical procedures (Zar 1984).

Qualitative surveys were conducted for species of fish off the transects on the outer reef, and at the lagoon survey sites, to develop a more complete inventory of fishes at Aldabra Atoll. On the outer reef, these surveys were done visually after a transect survey was completed, and concentrated on locating species not seen on the transect. In the lagoon, digital videography was used to record fishes near the permanent survey sites, and focussed on obtaining a video record of the many juvenile life-stages found in the shallow water.

New methods were used in February 2001 to facilitate locating the survey sites in following years, and to improve the repeatability of the coral and fish surveys. To make the stakes visible underwater floats were attached to each one.

To delineate the exact locations of the permanent transects for future surveys, the positions along the depth contour of five of the 50 m transect lines were marked by permanent lead-core line. This will allow the 50 m secondary transect tapes to be laid in exactly the same position on subsequent surveys. If this is successful, lead-core line will be placed along all 50 m transects on future expeditions.

Two underwater lasers were mounted on the video camera housing, and the beams set to cross each other (i.e. converge into a single spot of light) when the camera was 40 cm above the substrate. This provided the video camera operator with an accurate height reference above the substrate.

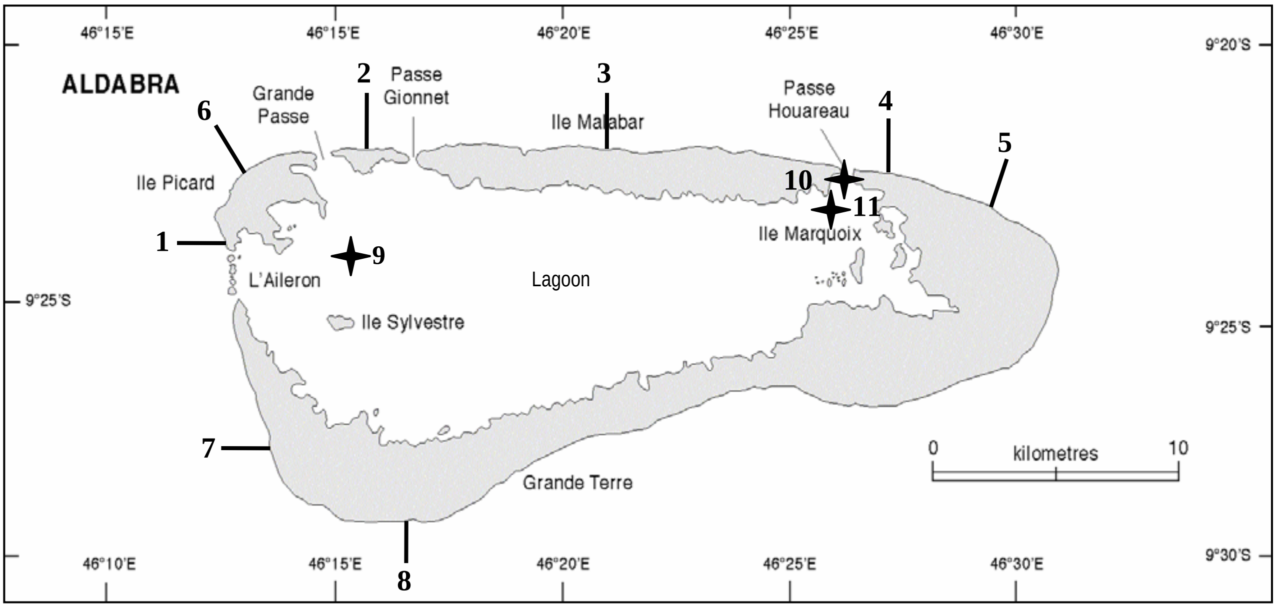
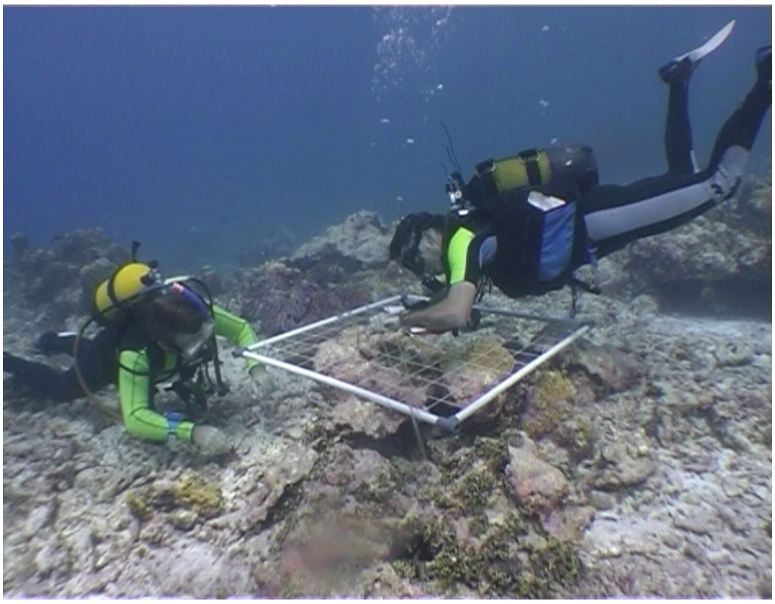


Figure 6. Aldabra Atoll with the 11 permanent Aldabra Marine Programme monitoring sites for coral and reef fish studies on the outer reef and within the lagoon.

Coral Recruitment and Tagging

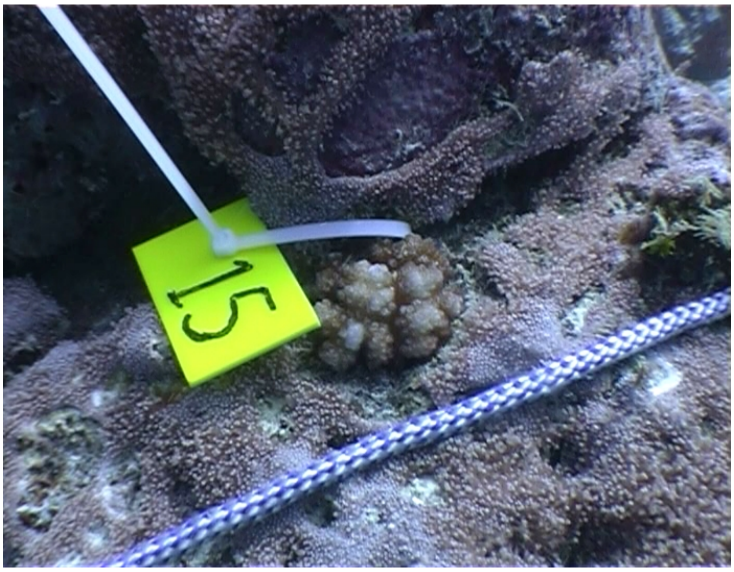
In February 2001 coral recruitment was assessed at all permanent survey sites on the outer reef and in the lagoon for the first time, using counts of recruits in 1 m^2 quadrats, with up to nine randomly positioned 4 m x 1 m quadrats, at each of the 6 m[1], 10 m, and 20 m survey depths. A maximum width of 5 cm was used as the upper limit for defining recruits (Engelhardt 2001). These criteria are based on *in-situ* coral growth rate observations of Wallace (1985), Wallace *et al*. (1986) and van Moorsel (1988). Fast growing *Acropora* corals have been shown to reach a maximum size, two years after settlement, of between 2 cm and 5 cm (Wallace 1985; Wallace 1999). At lagoon sites, counts were only made at the depth of the single transect. At most sites and depths 8 sets of 4 quadrats were surveyed to give a total area of 32 m^2. The recruits were measured across their greatest width and the width at 90 degrees to this. Recruit size was calculated by averaging the two widths. Where possible, recruits were identified to genus level. When the first quadrat in a set was completed, the quadrat frame was flipped over to give the next quadrat location, and so on.

[1] Heavy swell in some outer reef sites prevented the count at 6 m depth.



Divers measuring coral recruits in a quadrat

AMP Phase II initiated the first study of coral growth and survivorship at Aldabra. At four permanent survey sites (Sites 1, 3, 6, and 7) 20 coral recruits (<5 cm diameter at the greatest width) were measured in the same manner as above at both 10 m and 20 m depth. These recruits were then tagged by attaching numbered Perspex squares to the nearest available substrate with cable ties. A video image of each coral recruit was also taken to record the condition of the recruit, and to facilitate relocation and measurement of these recruits on future surveys.



Tagged coral recruit