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An Assessment of Damage to Maldivian Coral Reefs and Baitfish Populations from the Indian Ocean Tsunami

Prepared by an Australian Government Mission
and the Maldives Marine Research Centre

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CONTRIBUTORS

Australian Team

John Gunn	CSIRO Marine Research
David Milton	CSIRO Marine Research
Hugh Sweatman	Australian Institute of Marine Science
Angus Thompson	Australian Institute of Marine Science
Mary Wakeford	Australian Institute of Marine Science
David Wachenfeld	Great Barrier Reef Marine Park Authority
Kevin Parnell	James Cook University
Geoff Dews	Independent consultant
Laurie Engel	AusAID
Vittorio Brando	CSIRO Land and Water
Arnold Dekker	CSIRO Land and Water

Maldives Marine Research Centre Team

Abdulla Naseer
Mohammed Shiham Adam
Zaha Waheed
Hussain Zahir
Ismail Haleem
Ismail Abid
Yousef Shafiu
Ibrahim Naeem
Ahmed Najeeb
Sofi Ahsan Adnan
Saamee Mohammed Rasheed

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Cover image: The Maldives consists of 1,190 islands stretching over 800kms in the Indian Ocean.

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1 Executive summary

IN RESPONSE TO A REQUEST FROM PRESIDENT GAYOOM OF THE MALDIVES, THE AUSTRALIAN PRIME MINISTER MR HOWARD COMMITTED A TEAM OF AUSTRALIAN MARINE SCIENTISTS TO ASSIST IN THE ASSESSMENT OF DAMAGE TO THE CORAL REEFS OF THE MALDIVES FOLLOWING THE 26 DECEMBER 2004 TSUNAMI.

The team was formed by scientists from Australia's leading marine science agencies (CSIRO, Australian Institute of Marine Science, Great Barrier Reef Marine Park Authority and James Cook University), and included expertise in coral and coral reef fish ecology, reef health assessment, reef management, reef and island geomorphology and baitfish assessment. AusAID provided co-ordination and funding for the team's mission, and an AusAID officer accompanied the team to the Maldives.

The Australian team joined with scientists from the Maldivian Marine Research Centre in a 17 day mission with the following major objectives:

1. Conduct a rapid assessment of coral reef health, including the nature and extent of any damage to corals and associated reef ecosystems caused by the tsunami,
2. Examine the geomorphology of islands and associated reef systems to determine the nature and extent of any structural damage or changes resulting from the tsunami,
3. Examine the impacts of the tsunami on baitfish populations resident in atoll and coral reef lagoons,
4. Develop recommendations for work to be conducted following the mission's rapid assessment where this is required to fully understand the impacts of the tsunami on Maldivian coral reef systems.

CORAL AND CORAL REEF HEALTH

One hundred and twenty four reef sites were surveyed in seven atolls, covering about 170 km of reef margin, with additional information from 65 tourism dive sites. Although there was damage to coral and movement of sediments in all regions these perturbations varied in extent and intensity. Even so, surveys generally indicated that direct damage to reefs from the tsunami was minor. However, the reefs of the Maldives are in the early stages of recovery from the massive bleaching in 1998 and the most significant consequence of the tsunami may be to hamper this process. Many survey sites had a light coating of sand. Small coral recruits are most vulnerable to smothering by sand and rubble and even a light coating of sand may make reef surfaces unsuitable for future settlement. In general little is known of the biodiversity or prior ecosystem status and past changes on coral reefs of the Maldives. This complicated the assessment of the effects of the tsunami and, given the economic importance of coral reefs to the nation, this is a gap.

The mission was hampered by a lack of adequate historical data on the biodiversity and ecosystem status of, and past changes to, coral reefs of the Maldives. Given the economic importance of coral reefs to the nation, this is a critical gap. Our strong view is that the biodiversity and resilience of coral reef ecosystems needs to be safeguarded through a network of protected areas, and there is a need to increase national capacity in coral reef science so as to continue and extend existing monitoring programs for reef resources.

REEF AND ISLAND GEOMORPHOLOGY

An assessment of the geomorphology of reef flats, shorelines and islands of 19 inhabited and uninhabited islands of Laamu and Thaa Atoll was undertaken. The tsunami approached islands from the outside of the atoll, including on the western side. Despite significant damage to buildings, the tsunami had less impact on the reef flats, islands and beaches than was expected:

> Reef flats on the outside of atolls were minimally impacted.

> Beaches exposed to the tsunami experienced limited erosion, and some toppling of vegetation that may increase the likelihood of further seasonal erosion.

> The ends of islands suffered more extensive erosion.

> The island surface and soil structures of the islands remained relatively intact, and there were no major accumulations of reef sand or shingle.

> On the beaches on the lagoon side of the atolls, scour pit formation caused significant erosion and deposition of sediment on the adjacent reef flats, except on islands where the water did flow right across the island.

> One case of an island breaching was documented.

The importance of shoreline vegetation for erosion prevention was significant in all environments.

Much of the building damage was caused by scour under and around structures, and by physical damage by debris. On coral walls without rendering, water entering cracks led to rapid collapse of walls. Increased groundwater pressures probably caused some lifting of solid floors. Huraa on North Malé Atoll was visited where one area of collapse of the ground was probably assisted by the tsunami, but a cavity or area of loose sand beneath a cemented layer, which led to the collapse, is not unusual.

BAIT AND FISHERIES ASSESSMENT

To assess the impact of the tsunami on reef-associated fisheries (bait and reef fisheries) surveys of the perceptions of fishers active in Laamu, Thaa and Baa atolls and at Malé fish market were undertaken. Islands in Laamu and Thaa Atolls were highly impacted by the tsunami, whereas Baa atoll was only moderately and Malé only lightly impacted.

The study found that fishers in the pole-and-line fishery in the southern atolls (Laamu and Thaa) noticed few effects. Most had returned to fishing and their income was similar to that before the tsunami. In Baa Atoll, fewer fishers had returned to fishing and more were still involved in the reconstruction of their islands. Reef fisheries in Baa Atoll and in Malé had reduced effort as nearby resorts had low occupancy and thus demand was low.

A high proportion of pole-and-line tuna fishers landing in Malé felt the bait fishery was poor and had declined since the tsunami. However, these fishers believed that poor bait fish catch rates were due to seasonal fluctuations rather than tsunami effects.

It was impossible to assess the accuracy of fisher perceptions due to a lack of fishery data on their catch, effort and species composition. While surveys are useful in obtaining a rapid early assessment of major impacts, it will not detect more subtle or longer term effects of the tsunami on fishery productivity.

KEY RECOMMENDATIONS

The existing Maldives coral reef monitoring program needs to be expanded to cover more reefs and allow detailed examination of the impacts of the tsunami on fragile coral populations and associated ecosystems currently rebuilding after the massive coral bleaching event of 1998.

To facilitate increased monitoring of reef resources, there is a critical need to increase national capacity in coral reef science (including fisheries).

The biodiversity and resilience of coral reef ecosystems needs to be safeguarded through a network of protected areas.

More detailed examination of the geomorphic effects of the tsunami on a small number of islands should be undertaken as soon as possible.

A simple monitoring program of island shorelines at selected sites should be implemented, in order to better understand seasonal and long term trends, as well as the effect of major events such as a tsunami.

The important live bait fishery and the valuable reef fish fisheries need to be incorporated in the national fishery data collection system in order to be able to detect the effects of major environmental perturbations or excessive catch.

2 Introduction and background

THE MALDIVES TSUNAMI

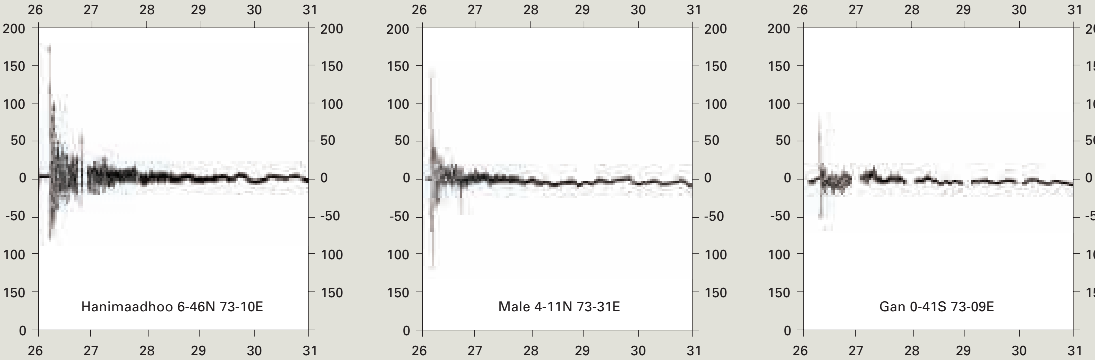
The Maldivian archipelago extends approximately 900 km from 7° 06'N to 00°45'S, and 130 km from 72° 33' E to 73° 47' E in the north central Indian Ocean[1]. It comprises 16 atolls, five oceanic faros (ring-shaped reefs exposed to the open ocean), and four oceanic platform reefs (reefs lacking lagoons which are exposed to the open ocean). Scattered around and through the atolls, faros and platforms are a total of 2,041±10 distinct coral reef structures larger than 0.01 km2[2]. One thousand, one hundred and ninety islands scattered throughout the archipelago occupy 5.1% of the total reef area.

At 9.20 am on 26 December 2004, islands throughout the Maldivian archipelago were hit by the first of a series of tsunami waves caused by an earthquake centred west of the Indonesian island of Sumatra in the NE Indian Ocean. In the Maldives, tsunami waves caused rapid surges of water across the reefs and islands rather than the large waves experienced in Thailand and Sumatra.

Tide gauges at Hanimaadhoo Is (6°46'N, 73°10'E), Male Is (4°11'E, 73°31'E) and Gan Is (0°41'S, 73°09'E) measured the amplitude and period of tsunami surges (Figure 2.1).

Although amplitude varied significantly among the three sites, in all cases the first surge was the largest and this lasted in the order of 20 minutes. Each surge was followed by a draw-down of water, with the amplitude of draw downs generally being less than the preceding surge. The largest initial surge recorded was at Hanimaadhoo Is (Figure 2.2), where it reached 180 cm

FIGURE 2.1: Tide gauge data for three sites in the Maldivian archipelago for the period 26–31 December 2004. Data are residuals of the tidal signal.



Sourced from: University of Hawaii Sea Level Center http://uhslc.soest.hawaii.edu.

above expected sea level (tide level subtracted). Although this level can not be taken as an accurate estimate of absolute sea height (http://uhslc.soest.hawaii.edu/), the magnitude of the surge exceeds the maximum elevation of any island in the Maldivian archipelago.

Reports from island residents suggest that water levels and the extent of island inundation varied significantly throughout the archipelago. At this stage the degree of variation remains unquantified, and the reasons for apparent variation in surge heights remains unknown. The Maldives Government Ministry for Planning and National Development, as part of the National Tsunami Task Force efforts developed a data base and GIS plots of flood severity and inundation derived from resident polls (Figure 2.3).

Eighty-two Maldivians were killed by the tsunami surges and in early February, 26 remain missing. The financial cost to the Maldives in loss of buildings, fishing vessels, personal belongings, agricultural production, reduced tourism etc is estimated to be between US $480–1000 million.

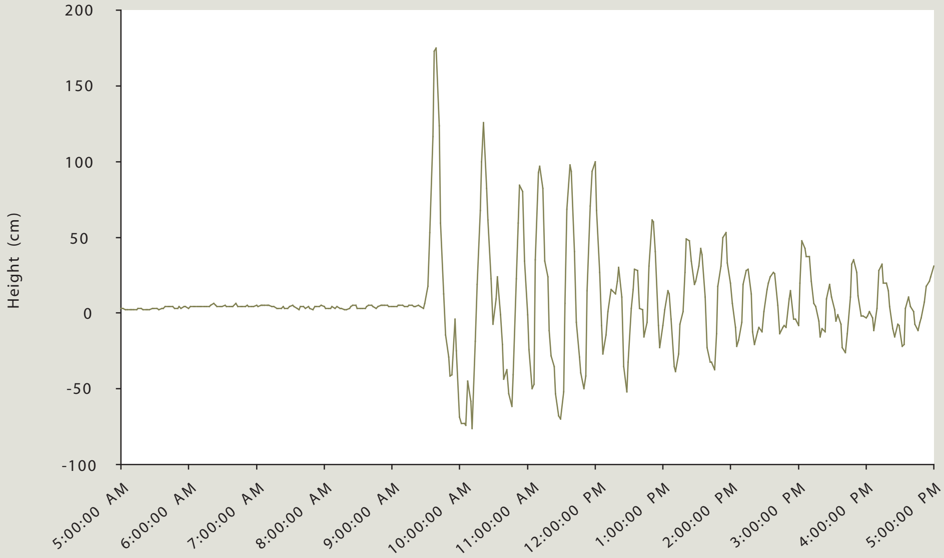
The Maldives archipelago is serviced by a network of modern communications technology, which allowed the impacts of the tsunami on the island populations and infrastructure to become obvious to the Government of the Maldives shortly after the event. However, the impacts on the Maldivian coral reefs and associated ecosystems remained largely un-observed and thus undetermined.

A United Nations Flash Appeal document written in early January 2005 claimed that the "preliminary findings indicate that the tsunami most likely led to extensive damage of the fragile reef systems". It is not clear how the UN reached these conclusions. However, with over 50% of the Maldivian GDP derived from coral reef and island-based tourism, and a further 12% from fisheries which depend on baitfish resources dwelling in atoll lagoons, it is understandable that there was concern in the Maldives that the tsunami had adversely affected the coral and baitfish populations.

AUSTRALIAN MISSION TO ASSESS TSUNAMI DAMAGE TO CORAL REEFS AND BAITFISH POPULATIONS

On 6 January, 2005 leaders of countries affected by the Indian Ocean tsunami met with their counterparts from across the region, Europe, North America and international organizations. On the margins of the meeting, the president of the Maldives, President Gayoom met with the Prime Minister of Australia, the Hon. Mr. John Howard to discuss areas where

FIGURE 2.2: An expanded view of the residuals of tide height data collected at Hanimaadhoo Is on 26 December 2004 showing the period and amplitude of surges and draw-downs.



Australia might provide assistance to the Maldives as part of their immediate post-tsunami relief efforts. On 7 January Mr Howard committed (among a range of initiatives) to provide a team of Australian marine scientists to conduct an assessment of the damage caused by the tsunami to coral reef systems of the Maldives.

A team of eight scientists was formed from CSIRO Marine Research, the Australian Institute of Marine Science, the Great Barrier Reef Marine Park Authority, James Cook University and an independent consultant. The team had expertise (in some cases based on previous work in the Maldives) in coral and coral reef fish ecology, reef health assessment, reef management, reef geomorphology and baitfish resource assessment. CSIRO Land and Water staff supported the team with high resolution optical satellite imagery of Maldivian reef systems before and after the tsunami.

The team arrived in the Maldives on 23 January 2004 for a 17 day mission.

MISSION OBJECTIVES AND CONSULTATION WITH MALDIVES GOVERNMENT MINISTRIES

The Australian team worked with senior staff at the Maldives Marine Research Centre (MRC) to develop the following broad objectives for the mission:

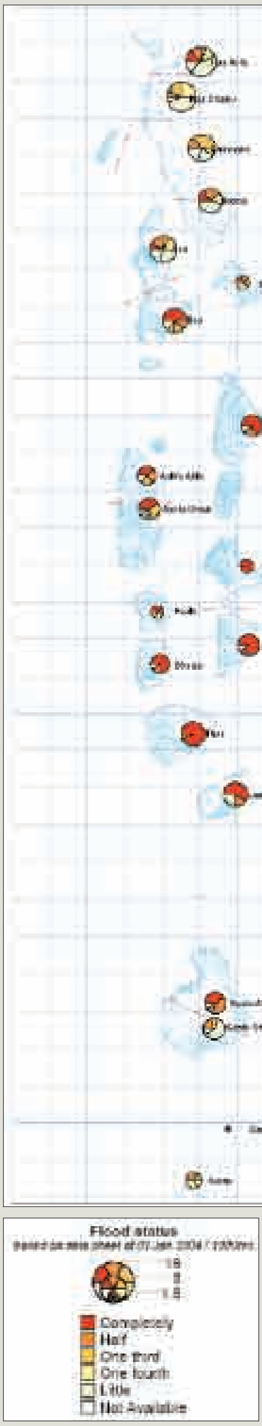
1. Conduct a rapid assessment of coral reef health, including the nature and extent of any damage to corals and associated reef ecosystems caused by the tsunami;
2. Examine the geomorphology of islands and associated reef systems to determine the nature and extent of any structural damages or changes resulting from the tsunami;
3. Examine the impacts of the tsunami on baitfish populations resident in atoll and coral reef lagoons;
4. Develop recommendations for work to be conducted following the mission's rapid assessment where this is required to fully understand the impacts of the tsunami on Maldivian coral reef systems.

It was agreed that all work towards these objectives would be conducted by a joint Australian/MRC team, and that this team would produce a joint report to the Governments of Australian and the Maldives following the mission.

Following arrival in the Maldives on 23 January, team members met with senior officials and ministers of a number of relevant ministries – Environment and Construction; Fisheries, Agriculture and Marine Resources; Tourism; Atolls Development;

FIGURE 2.3: Maldives Ministry of Planning and National Development estimates of the extent of flooding to islands in each atoll.

Pie charts show the extent to which islands were flooded during the tsunami based on categorized values for each island. The size of the pie represents the sample size of the respective atoll.



Planning and National Development – to discuss the mission's objectives and ensure that these met the Maldivian Government needs. These meetings confirmed the requirement for a rapid and synoptic assessment of damage to the reefs throughout the archipelago. However, many government officials requested that field efforts concentrate in areas where a) there had been significant damage to inhabited islands and tourist resorts and b) fisheries relying on baitfish were focused. Given the limited time available to the Australian team for the rapid assessments, government officials also requested that survey designs and methods used by the team should be suitable for use in government and NGO monitoring after the Australian team left the Maldives. As a result of the discussions, the team focused field work on atolls where islands had been flooded – 12 of the 25 worst affected islands were surveyed – and methods used are based on standards recently adopted by the ICRI/ISRS(2005).

Team members also met with representatives of environmental NGOs and dive operators interested in the state of Maldivian reefs. In some cases these groups had already conducted *ad hoc* post-tsunami surveys of reefs they had dived for many years, on the basis of which they had made conclusions regarding the nature and extent of damage. Their suggestions and observations were incorporated into the team's survey designs and data analyses.

MALDIVIAN CORAL REEF SYSTEMS BEFORE THE TSUNAMI

The reefs of the Maldives grew upwards during the post-glacial sea level transgression. The period 6000-3000 years BP were dominated by vertical reef growth as the reefs caught up with the rising sea-level. Islands have formed from 3000 years BP to present.[3] The islands are sand dominated with coral shingle and boulder deposits being relatively uncommon, the result of the relatively few storms that the Maldives experience. Many islands are stabilized by the presence of beachrock, but seasonal adjustments which are the result of the north-east and south-west monsoons are common. These adjustments frequently take the form of spits that accumulate at the ends of islands.[4]

The coral reefs of the Maldives support a high diversity of reef animals, with about 250 species of hard corals and 1,200 reef and reef associated fish species reported in the literature.[2]

Most of the coral reef habitat of the Maldives has not been regularly monitored. Therefore, measures of coral cover are available from only a few sites. Studies prior to 1998 from coral reef sites on seven different atolls showed live hard coral cover ranging from between 28% and 58%.[5]

Between March and June 1998, the monthly mean sea surface temperature (SST) in the Maldives was significantly above the 1950–1999 average, with the warmest month, May, being 2.1°C over the average.[6]

This unusually warm water caused severe stress to the corals of the Maldives, leading to a condition known as coral bleaching and, for the vast majority of corals, death. By the end of the bleaching event, live hard coral cover had fallen to between 0% and 5%, representing a mortality rate of between 90% and 95% at most locations. There were some small areas of reef habitat that showed better survival from the bleaching event. Most notably, Addu atoll, particularly deep locations, showed good survival, with surveys in 2002 measuring between 41% and 54%.[5]

The bleaching event did not affect all families of corals equally, with corals in the families Poritidae, Faviidae and Agariciidae generally surviving better than those in the families Acroporidae and Pocilloporidae. Thus the bleaching event not only greatly reduced the overall amount of hard coral, it also changed the community structure. For example, one study of corals on artificial reefs found that the community structure changed from 95% branching corals and 5% massive corals before the bleaching to 3% branching and 97% massive afterwards.[5,6]

Since the 1998 coral bleaching event, several studies have looked at recovery of hard coral communities[5,6,7,8,9]. Generally speaking, all sites that have been studied indicate some level of recovery through the presence of new coral recruits and regeneration of tissue on massive coral colonies that were partially killed.[5,7] However, so far coral recovery has been slow with only a 3% increase recorded between 1998 and 20026. In 2002, the highest hard coral cover measured on five sites on five different atolls was approximately 10%, with the average being approximately 6%.[5]

3 Coral reef assessment

THREE DIFFERENT METHODS WERE USED TO ASSESS THE STATUS OF CORAL REEFS: BROAD-SCALE SURVEYS, LINE INTERCEPT TRANSECTS AND DIVE OPERATOR SURVEYS. METHODS OF SURVEY USED IN EACH ATOLL ARE PRESENTED IN TABLE 3.1. A FULL LIST OF SURVEY SITES ASSESSED USING BROAD-SCALE SURVEYS IS PRESENTED IN APPENDIX 3.1.

TABLE 3.1: Summary of survey methods used at each atoll.

Atoll	Broad-scale surveys	Line intercept transects	Dive operator surveys
Raa	✔		
Baa	✔		✔
Aari			✔
North Malé			✔
South Malé	✔		✔
Vaavu	✔	✔	✔
Vattaru	✔	✔	
Meemu	✔		
Thaa	✔		
Laamu	✔		
Addu			✔

Broad Scale Survey

Site selection

Atolls were selected for survey based on information provided by the National Disaster Management Centre and represent those atolls where impact on island communities and infrastructure was greatest. Within atolls, an effort was made to replicate sampling based on broad reef zones. The Maldives form a twin chain of atolls oriented along the edges of a North-South plateau lying across the tsunami's path. Atolls on both the eastern and western edges of the plateau were surveyed. Within each atoll, the a priori sampling design included replicate surveys of the major reef zones as determined by their position on an atoll and their aspect relative to the east to west propagation of the tsunami. This generated eight different reef zones, detailed in Table 3.2.

Logistical and time constraints meant that at each atoll not all zones were surveyed equally. A full list of survey sites is included in Appendix 3.1. Within zones, site selection was haphazard and often dictated by the availability and accessibility of sections of contiguous sections of reef.

TABLE 3.2: The eight different coral reef zones sampled in the broad scale survey, as dictated by position on atoll and aspect in relation to tsunami.

Position on atoll	Aspect in relation to tsunami
East	East
	Channel
	West
Central	East
	West
West	East
	Channel
	West

Rapid assessment technique

Tsunami damage was assessed using a technique based closely on the rapid assessment technique suggested by ICRI/ISRS (2005). To maximise the area of reef surveyed in the short time available, the primary method of assessment was manta tow surveys (English et al. 1997). This technique involves a snorkeller being towed along the reef edge behind a small boat for two minute periods, covering approximately 200m. The boat then stops briefly to allow observations to be recorded. These surveys concentrated on upper reef slopes in depths of 1-6m. Five manta tows of two minutes duration were made at each site and observations were recorded into the categories listed in Appendix 3.2. In order to increase depth coverage at a subset of the manta tow sites, the same categories were recorded in sets of five SCUBA swims, each swim being five minutes duration. For logistical reasons, upper reef slope surveys at the two Southern atolls were conducted using five minute snorkel swims instead of manta tows.

Observations of damage on shallower reef crests and reef flats were made to assess areas of reef not covered by broad-scale surveys. These observations entailed a swim from a GPS mark on the reef slope, up over the reef crest and into the reef flat area. These transverse transects were not quantitative; they aimed simply to describe any obvious patterns of tsunami damage from the slope to reef flat. Sites were selected that were of interest to the survey in terms of impacts and where possible were adjacent to sand cays and vegetated islands.

Photo Documentation

An extensive collection of digital photographs document examples of damage to coral reef communities observed during the surveys. These images have been labelled and copies retained by AIMS and MRC.

Data management and archiving

Data was transferred from field sheets on a daily basis into either Excel spreadsheets and then complied into a single Access database at the completion of field work. Copies of this database reside at both AIMS and MRC.

Line Intercept Transects

Three long-term monitoring sites (established in 1998) were re-surveyed. At each site there were 3 x 50m transects on the reef crest and 3 x 20m transects in 7-10m of water. Data were recorded using standard line intercept transect protocols (see English et al. 1997 for methods). At one site on Vattaru Atoll, the substrate was altered to such a degree that site markers could not be found and random transects at the same location and depths were used instead.

Dive operator survey

In order to obtain a snapshot of the impacts to the reefs and marine environment the Ministry of Tourism and the Marine Research Centre devised a questionnaire for distribution to all the resorts and dive operators in the Maldives. The aim of the survey was to obtain information on the visual impacts to the reef from the tsunami as seen by the tourism dive industry. Participation in the survey was voluntary.

The assessment covered a range of environments in the main tourism atolls and three sites in Addu Atoll. Although the questionnaire covered a broad range of impacts it was expected that the main focus of the survey would give an indication as to impacts on the house reefs of the resorts, protected dive sites and other favoured sites that are of special interest to the recreational diver.

The questionnaire covered: the timing of the tsunami event; impacts; photographic records; the number of visitations to the site after the tsunami; impacts as a result of sedimentation; damage to live corals and reef structures; changes to fish abundance and community composition; debris; shoreline changes; and saltwater intrusions. The questionnaire also provided an opportunity to express personal suggestions and recommendations for remediation action.

Participants were asked to assess various levels of impacts using five categories of severity; no change, very little change, little change, moderate change, high change and very high change. Surveys were returned for 65 dive sites from six atolls (see Table 3.1).

RESULTS

Results from the three different methods are presented as a general synthesis followed by detailed descriptions from each of the survey groups. The data from broad-scale surveys are summarised in Appendix 3.3.

Synthesis

Atoll wide coral cover was typically low, ranging from approximately 5% to 15% (Figure 3.1).

At the scale of the entire Maldives or any single atoll, the impact from the tsunami on coral reefs and associated marine systems was only slight (Figures 3.2 and 3.3). Damaged coral and altered substrate (disturbed, deposited or excavated) were observed on all atolls studied but for each atoll only a small proportion of the overall system was affected. This pattern is supported by the results from all three survey methods: the broad-scale survey, the line intercept transects and the dive school survey.

Quite strong differences between atolls were observed. For example, a greater proportion of sites surveyed on Thaa and Laamu atolls showed damage than on Raa and Baa. Accounts of each individual atoll are given in the results and Figures 3.4 to 3.10.

FIGURE 3.1: Mean hard coral cover on all atolls from the broad scale surveys. Means are from all transects across all reef zones.

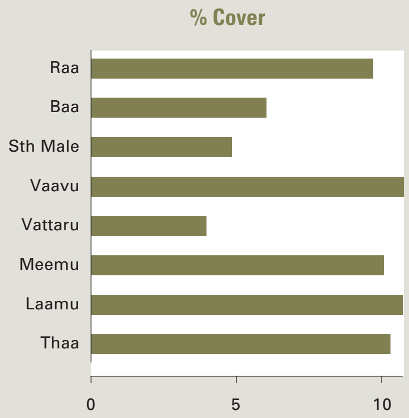


FIGURE 3.2: Damage to live hard coral on all atolls from the broad scale surveys. Figures are from all transects across all reef zones.

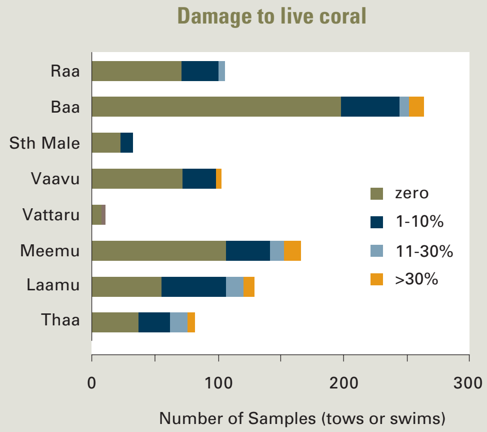
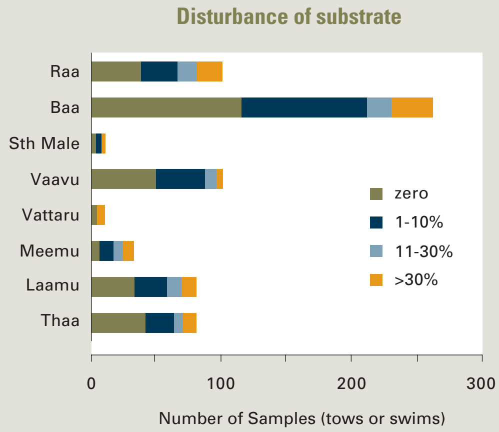


FIGURE 3.3: Disturbance of substrate on all atolls from the broad scale surveys. Figures are from all transects across all reef zones.



Within each atoll, different habitats surveyed (see Table 3.2 above) showed markedly different coral communities and degrees of damage.

The outside of atolls (whether on the east or west) were generally least affected. Occasional alteration of substrate and damage to corals (toppling or breakage) were observed, but usually few transects and only to a small degree. The exception to this was reefs on the western side of Baa Atoll where high levels of sediment had been deposited onto the outer rim (Figure 3.5).

Most channels on atolls south of Malé showed at least some damage. The worst damage observed comprised banks of rubble and coral block in shallow water, sometimes forming slides of material down the reef slope into deep (over 30m) water. Banks and slides of rubble and block had toppled some living corals and smothered others. Areas of lesser damage were typically dustings of fine sand down the reef slope. Most corals had cleared themselves of sand since the tsunami, with only small numbers of corals showing tissue death from smothering. Generally speaking, channels showed the greatest deposition of and disturbance to rubble, block and sand at the point where the channel was narrowest. Presumably these were the areas of fastest water flow and greatest energy during the tsunami.

The inside of the atoll rim was very variable in the damage sustained. Areas of reef sheltered behind islands (on the eastern side of atolls) generally experienced least damage, although debris of human origin was observed behind some inhabited islands. Areas of reef not sheltered by islands typically had more damage, although most reef areas were still little affected. The most severe impacts documented were areas where significant amount of sand, rubble and coral block were disturbed and/or excavated and/or deposited. In such areas, it is likely that hard corals and other reef animals were completely buried, leaving no trace to be detected in surveys. At Baa Atoll the most severe disturbances were observed on reefs inside the atoll rim on the western side of the island were areas of deeply excavated reef slope were observed.

Reefs in the centres of atolls (known as patch reefs) generally showed little damage in the southern solid rimmed atolls with damage patchy within the more open structured Baa Atoll.

Incidence of disease in coral communities is a growing concern. Various workers have suggested links between increased infection rates and disturbance events, presumably resulting from reduced resistance due to physical or environmental stress and possible suspension of pathogens from the sediment. Incidence of coral disease was extremely low in these surveys. While physically damaged colonies or fragments could have been expected to die from secondary infection, this was not the case. The vast majority of coral fragments were healthy and several had begun to reattach to the substrate. Broken corals also showed rapid healing of lesions; an example being colonies of digitate *Acropora* spp. on the reef crest that had re-established the apical polyp on the broken stubs of digits.

Results for Individual Atolls

Raa and Baa Atolls (refer to Figures 3.4 and 3.5)

In contrast to the atolls surveyed to the south, both Raa and Baa atolls lie on the western side of the double chain of atolls making up the central Maldives. In addition to geographic differences, the reefs making up the atoll margin are far smaller and more widely spaced than their southern counterparts. This setback from the eastern margin of the Maldivian plateau and broken nature of the rim may to contribute explaining why reported damage to inhabited islands was lower than for southern atolls.

The level of direct tsunami impact on the upper reef slope coral communities was typically minor. Of the 218 manta tow transects completed only 27 (12%) recorded damage to the coral community with only nine (4%) showing damage to more than 10% of the corals present. Corals on fore-reefs and channel margins along the Eastern atoll rim off Baa Atoll showed limited evidence of tsunami damage to corals. Tumbling of a very few colonies and occasional breakage of coral branch tips due to movement of small to medium sized coral blocks was the extent of damage observed. This damage was generally restricted to the upper reef slope and crest in depths less than 2m. This limit to damage was confirmed with observations taken along transverse snorkel swims on three eastern rim reefs. In each case damage was not noted on the manta towed portion of the slope (3–6m) rather present as narrow bands of small, long dead, coral blocks (10–70cm diameter) that had accumulated just before the algal ridge. The movement of these blocks had caused breakage of many of the small digitate and sub-massive corals present though no whole colony mortality was observed. The contorted growth form of many colonies suggested that this type of breakage was not unusual within this zone. A further interesting observation was that almost without exception damaged corals were healing rapidly with partial mortality observed on a very few individuals colonies. Beyond the reef crest, evidence of impact declined though slight shifting of sand, rubble and coral fragments was evident.

The spectacular exception to the general very low tsunami impact on reef communities was the finding of a few large sections of upper reef slope that had been deeply excavated. This excavation was only observed at sites with an easterly aspect on Maahuruvalhi, the next reef south, Maa Faru, and the reef directly east, Boatu Urunu Faru, all on the western side of Baa Atoll (Figure 3.5) and on just one transect on Tilin Faru adjacent the evacuated township of Kandholhudhoo (Figure 3.4). The most severely affected site was Maahuruvalhi with the entire length of the survey (some 1km stretch of reef slope) severely excavated. At this site, it appeared that the loose rubble and sand component of the reef framework had been washed away leaving the larger blocks to collapse. In places, this erosion left pits up to 3m deep. The excavated section was from the reef crest down to approximately 5m with the excavated rubble deposited down the slope in a very loose jumble below this depth. Interestingly, only a few metres onto the reef flat and no evidence of disturbance was discernable. Obviously all corals that had been on this section of excavation had been removed, with many now at least partially buried and tumbled down the slope. SCUBA swims of this area observed this rubble deposit and buried corals down to at least 20m.

The only other area with a notable impact to the coral community was along the western fore reefs on the western atoll rims. The substrate here was a very shallow sloping spur and groove formation with grooves only 1–2m deep. The coral community was very sparse <5% and dominated by small *Pocillopora*, digitate *Acropora* and massive Faviidae colonies, though this community gave way to larger tabulate *Acropora* below 5m. The gullies held fine sediment deposits that were in a state of re-suspension. Some small massive corals in the base of these gullies were smothered.

SCUBA surveys at 7m and 10m recorded generally higher levels of impact than the shallow manta tows, with 45% of transects noting damage to some portion of the coral community. Smothering of corals was the most common impact (43% of transects noted at least minor incidence) and with the exception of the severely excavated sites mentioned above consisted of small pockets of sand and fine sediment accumulated on depressions in colony surfaces. Toppling and breakage of colonies was also evident on a number of transects (22% and 17% respectively) though again, with the exception of the highly excavated site at Maahuruvalhi, was limited to a small portion of the community.

Alteration to the substrate was more common than obvious damage to the coral community with 52% of transects having some form of observed alteration. The most extensive effect observed was a light "dusting" of the substrate with very fine sediment or in situ turning of rubble and small coral blocks. Dusting was most prevalent on sections of reef either in or facing the atoll lagoon. The eastern slope of Borangali was the most severely dusted site visited with fine white sediment from the crest to a depth of at least 25m. The depth of sediment ranged from a very thin (few mm) layer to several cm. The corals on dusted sections of reef were generally free from sediment with the exception of some deeper depressions in the surface of individual colonies. Turning of rubble was patchily distributed and mostly limited to sites protected from high swell energy where these finer substrate components could persist under normal hydrodynamic conditions. While neither of these disturbances had an observable impact on the coral colonies observable during manta tow surveys it is likely that small newly recruited colonies would have been killed. Further, should the fine sediments associated with "dusting" persist success of future recruitment periods may be compromised.

Of particular note was that severe impact to Kandholhudhoo was not evident in assessments of reef communities on the reefs immediately to the north and south. The coral communities adjacent Kandholhudhoo and on Vaffushi reef in particular were undisturbed despite the dominance of fragile *Acropora* spp. and *Porites rus*, along with a loosely compiled substrate.
A transverse swim over the reef flat of the adjacent Badaveri reef also found no evidence of damage to the reef community.

South Malé Atoll (refer to Figure 3.6)

Eastern sites

Surveys in South Malé atoll were limited by time and weather.

One east-facing reef at Finolhu fahlu had a broad gentle slope to about 8m then dropped away more steeply. The shallow slope had limited cover of massive, submassive and encrusting corals as well as some mobile boulders in gullies. Some detached partially dead *Porites* boulders in the gullies were the only possible damage from the tsunami.

East-facing channels at Guraidhoo, Gulhi and Embudhoo had steep sides with more rubble on the shallow areas and large areas of sand and rubble on the slopes. Corals were mainly massive *Porites* spp and robust *Pocillopora* spp. There were variable amounts of recently deposited sand and rubble down the slopes.

Vaavu and Vattaru Atolls (refer to Figure 3.7)

Eastern sites

Sites were surveyed in four regions on the eastern side of Vaavu Atoll: at Vattaru Atoll in the south, near Foththeyo in the extreme East, near Keyodhoo in the centre and near Devana Kandu to the north.

East-facing reefs in each region had a narrow, gentle sloping shelf to about 6m then dropped away steeply. The shallow slope had standing remains of *Acropora* spp. that had probably been killed by bleaching in 1998, as well as some mobile boulders in gullies and low cover of small colonies, mostly massive *Porites* spp and robust *Pocillopora* spp. There was minimal evidence of damage from the tsunami.

East-facing channels near Foththeyo and Keyodhoo and the Devana Kandu had a profile similar to the reef fronts but there was more rubble on the shallow areas and large areas of sand and rubble on the slopes. Corals were mainly massive *Porites* spp and robust *Pocillopora* spp. with some *Porites rus*. The west-facing wall of the channel at Vattaru ran along the side of the island which has a sandspit on the north side. There was extensive deposition of sand, rubble and some boulders, including living *Porites* colonies down the slope into the channel from the sandspit.

The North-West-facing reef edge at Vattaru had an interrupted rim of reef dominated by Massive colonies and digitate *Acropora* spp. There was considerable deposition of sand and rubble down the slope from the back reef and an unknown amount of smothering of parts of the reef rim. Divers from the MRC reported that there was considerable build-up of sediment on the back reef and much smothered coral at 10m. West facing reef edges at Foththeyo had the highest coral cover recorded at this atoll, averaging more than 30% and mainly composed of massive *Porites*, sub-massives and digitate *Acropora* spp. There was some deposition of sand and rubble down the reef slope.

Western sites

Sites were surveyed at Mas Araa Falhu in the north-east of Vaavu Atoll and in Raiyganduhulhamgu Kandu. West-facing site on Mas Araa Falhu had a gentle slope to 6m with a limited cover of massive, submassive and encrusting corals, then a steep drop. There was no evidence of damage from the tsunami.

In the channel south of Mas Araa Fahlu there was modest cover of massive and encrusting species on the steep walls. There was some deposition of sand and fine sediment. In Raiyganduhulhamgu Kandu, the West facing wall had a gentle slope to 6m that was dominated by massive coral species. The wall then sloped away at a greater angle. A considerable amount of sediment and rubble was deposited down the slopes, but no smothering was evident.

On the East-facing reef edge of Mas Araa Fahlu there was a continuous rim of reef along a gently sloping sand slope to about 10m. Delicate tabulate and digitate *Acropora* spp dominated. There was some deposition of sand and rubble down the slope, but a number of rubble chutes included living corals in growth position so smothering seemed limited. There was a fine layer of clean sediment over much of the slope.

Vaavu and Vattaru are the only atolls for which before/after tsunami data are available (Figure 3.11). While data from two of the three sites indicate no impact from the tsunami and ongoing recovery of coral populations from the 1998 bleaching event, data from one site (on Vattaru Atoll) show significant mortality to corals, caused by deposition of sediment by the tsunami. This is a good example of what has happened at sites where the tsunami did have a significant impact. Fortunately, the broad scale surveys indicate that such sites are relatively few and far between.

Meemu Atoll (refer to Figure 3.8)

Eastern sites

Sites were surveyed in three regions on the eastern side of Meemu Atoll: near Kolhuvaariyaafushi in the south, near Muli in the centre and near Dhiggaru in the north.

East-facing reefs in each region had a gentle slope to about 6m then dropped away more steeply. The shallow slope had standing remains of tabulate *Acropora* spp. that had probably been killed by bleaching in 1998, as well as some mobile boulders in gullies and low cover of small colonies, mostly massive *Porites* spp and robust *Pocillopora* spp.

East-facing channels at Muli and Dhiggaru had a profile similar to the reef fronts but there was more rubble on the shallow areas and large areas of sand and rubble on the slopes. Corals were mainly massive *Porites* spp and robust *Pocillopora* spp. with some *Porites* rus.

West-facing reef edges near Kolhuvaariyaafushi and Muli were of two types. When they were west of an island, there was a reef edge and a sandy slope to a depth of more than 10m. Low points in the reef edge were broken by sand and rubble chutes. The coral community was mainly made up of digitate *Acropora* spp. and massive *Porites* spp. There were sometimes palm fronds and tree branches, but most evidence of tsunami damage was fresh rubble in the chutes and some deposition of fine sand on the corals. Much of the reef edge was similar in sites away from cays, but near Naalaafushi there were a few sites where rubble had been deposited in long narrow tongues stretching 5-10m off the reef and one area where a large hole several metres long and up to 2m deep, had been excavated, undermining some large *Porites* colonies that had then toppled in. In a stretch on reef on the west side of the gap between two islands near Kolhuvaariyaafushi, the back reef consisted of a large area of rubble and boulders (including large living *Porites* heads) that had been recently deposited over the rim and down the slope.

Western sites

Sites were surveyed in two regions on the eastern side of Meemu Atoll: near Kolhuvaariyaafushi in the south and near Thuvaru in the centre. West-facing reefs near Thuvaru had a gentle slope to about 6m then dropped away, but less steeply that the reefs on the Eastern side. The shallow slope had standing remains of digitate and branching *Acropora* spp. that had probably been killed by bleaching in 1998, and low cover of small living colonies, mostly massive *Porites* spp and robust *Pocillopora* spp. and some tabulate *Acropora* spp. No tsunami damage was recorded.

West-facing channels differed. At Kurali Kandu in the south, the West facing wall had a gentle slope to 12m that was dominated by massive coral species, with more tabulate *Acropora* spp near the mouth and more sub-massive *Pocillopora* spp inside. A channel near Thuvaru in the centre had a profile similar to the west-facing reef fronts but there was more rubble on the shallow areas and some sand and rubble on the slopes. Corals were mainly massive *Porites* spp and robust *Pocillopora* spp. and tabulate *Acropora* spp. No tsunami damage was recorded.

One east-facing reef edge near Thuvaru was very discontinuous and irregular along a gently sloping sand slope to about 10m. Delicate tabulate and digitate Acropora spp dominated and a very few of these had been toppled, possibly by the tsunami, but were not buried.

Thaa and Laamu Atolls (refer to Figures 3.9 and 3.10)

Located towards the southern end of the Maldives, both atolls reported high damage to villages as a result of the tsunami. The direction of the tsunami was from the east/north-east, and villages on the eastern rim of both atolls reported the highest damage.

On the eastern rim the direction of the waves was from the east, whereas western rim villages reported waves from the west, the east and west, and sometimes a rising of the sea level in all directions. It is likely that the enclosed nature of both Laamu and Thaa Atoll (i.e. few channels breaking the reef edge) caused much of the tsunami energy to be refracted around the outside of the atoll as well as some traveling through the centre.

Our surveys focused on the eastern rim of both atolls and included reefs surrounding the highest impacted villages. The western rim was surveyed less intensively, as were patch reefs in the centre of atolls. In general the tsunami did not cause great damage to the coral reef ecosystem, and impacts observed were patchy and consistent with damage associated with storms.

On Laamu Attol 29 surveys were conducted: 21 on the eastern rim, 6 on the west and 2 patch reefs in the centre of the atoll. Thaa Atoll had 17 surveys: 14 on the east rim and 3 on the west.

Disturbance varied depending on the habitat surveyed. Within habitats across both atolls, the same general patterns in disturbance emerged. High energy, outer-rim reefs (i.e. reefs on the outside of the atoll) generally showed very limited damage due to the existing robust nature of this area. Channels showed the highest amount of disturbance to the reef substrate and some degree of damage to hard coral caused by the deposition of sand, and or toppling of rubble or small block down the slope. Inner-rim reefs had the highest overall damage to hard coral. This was largely due to the less robust nature of coral growth forms and greater relative abundance. Disturbance to substrate also occurred in this habitat and was the cause of most coral damage. The following paragraphs summarize the damage in more detail for each habitat.

Outer-rim reefs consistently showed little or no damage to the hard coral and substrate (<1%). They were characterized by a gentle slope that extended about 80m from the crest, and then dropped away more steeply. Spur and groove formations were usual near the crest with a few large blocks of rubble. Below this a flat pavement extended towards and down the drop-off becoming increasingly covered by dead standing coral (probably killed by the 1998 bleaching). Hard coral cover was usually below 10% and dominated by massive *Porites* spp., robust *Pocillopora* spp. and *Favid* spp. On a few sites *Acropora palifera* and digitate *Acropora* spp. (20cm diameter) became the most dominant growth forms. The only damage evident in this habitat was minor breakage to branch tips, and of these corals many already showed re-growth.

Channels (especially narrow channels) had disturbance to the substrate (~20%) and some degree of damage to the coral (~8%). Impacts were typically highest at the point where the channel narrowed and where the slope to the drop off became truncated. At this point and along the channel towards the inner rim, rubble and blocks from the shallows were pushed to the edge of the slope. They formed either rubble banks ending abruptly at the drop off (up to 1m high), or piles of rubble and block precariously lodged down the slope and stopped from toppling further by permanent blocks or massive *Porites* spp. A dusting of white sand was often seen further down the drop off. Damaged corals were smashed by tumbling blocks, toppled down the slope or smothered by rubble and sand. On the eastern rim adjacent to badly damaged villages, channel slopes were littered with human clothing, rubbish and tree parts.

Reefs on the inner-rim had the second highest damage to substrate (19%) after channels and the highest damage of all habitats to coral (14%). Reefs located directly behind islands typically had less disturbance than those located in gaps between islands. This implied islands provided some degree of protection from the full force of the wave. Reefs located in gaps between islands had patchy disturbance to both the substrate and corals. In some stretches tens of metres wide, large deposits of coral rubble and blocks had been pushed to the back of the reef slope. At one site (Laamu, site 8 see Fig. 3.10) there were a few excavations in the sand up to 3m deep and behind Vilifushi (Thaa, site 9 see Fig. 3.9) the seagrass meadow had been torn away along the back edge as well as small sections within (see geomorphology section). Coral damage occurred due to colonies being toppled, smothering by sand, or smashed by moving rubble/blocks. The surveys were conducted 4 weeks after the tsunami and loose sediment, which was high in this habitat, either continued to smother and kill the coral or had largely been removed (by falling through branches, prevailing currents or shed along with layers of coral mucus). It was evident that some corals had been partially smothered but many had managed to become sediment free. Broken corals showed signs of recovery (through growth of new tips) with no evidence of disease. The fate of toppled corals and coral fragments depended on final resting position. Those landing on solid substrates showed good potential for re-attachment and growth.

Patch reefs in the middle of atolls were only surveyed at Laamu Atoll. No damage was observed to the substrate or coral. Although this habitat was characterised by a lot of dead standing coral (probably due to the 1998 bleaching) there was some good recruitment of *Acroporid digitate* and table corals post 1998 bleaching.

In summary, where disturbance to the substrate occurred in close proximity to hard coral, some mortality was observed. However it is important to note that although corals were damaged, very few were completely killed and those that were damaged generally showed signs of recovery. Although there had been some large excavations and movement of rubble, this usually occurred in channels or where there was little live coral to be damaged.

Note: Absence of baseline data for most areas surveyed made it hard in some instances to determine whether significant deposition had occurred, and whether deep below the deposition live coral had been smothered.

Diver operator surveys

The results from the dive operator survey supported the conclusions from the broad scale survey. At the time of compiling this report only preliminary analysis has been carried out on the 65 returned surveys. The analysis did not separate the data into the various habitat types nor did it take into account the different levels of prior knowledge of the participants. A summary of results are presented in Table 3.3.

TABLE 3.3: Dive operator surveys. Impact was categorised into 4 types and the percentage of surveys reporting damage is shown. Of the 45% reporting smothering, only 4 reported high or very high smothering. Of the sites recording broken live coral, most had little damage with only two sites having high or very high damage.

Smothering of large areas of live coral	Broken live coral	Dead rock detachment	Change of abundance in marine species
45%	52%	36%	3%

The survey assessed the amount of debris on the reef and the type of debris, including vegetation and household waste. Table 3.4 shows the level of debris assessed at each site.

TABLE 3.4: Assessment of debris reported at tourism sites.

	Nil	Very little	Little	Moderate	High	Very high
Debris observed	56	7	0	1	1	0

The questionnaire asked participants to record any observations of new sand or rubble deposition post tsunami. Results indicate a low level of visible impacts to the reef flat from accumulation of sediments or rubble as seen in Table 3.5.

TABLE 3.5: Assessment of new deposits on the reef or lagoon from 65 reported tourism sites.

	Nil	Very little	Little	Moderate	High	Very high
Assessment of deposits	54	9	1	1	0	0

RECOMMENDATIONS

Immediate response

Recommendation: As the clean up after the tsunami progresses, disposal of refuse and debris should be conducted in a way that minimises entry of debris, particularly plastics, clothes, ropes, nets and other flexible man-made materials into the marine environment.

Justification: Human debris, particularly plastics, clothes, ropes, nets and other flexible materials can cause significant damage to marine life including corals, fish, whales, dolphins, turtles, and seabirds. A great deal of this type of debris has been generated by the tsunami and is still on islands, particularly on beaches. Further clean up to minimise entry of this material to the marine environment would help minimise further damage to the marine environment from the tsunami.

Recommendation: As reconstruction of Maldivian towns progresses, the Government should maintain its highly important stand on a prohibition of mining coral rock.

Justification: The physical structure of Maldivian coral reefs is an important element in protection of Maldivian societies from wave damage (storms, tsunamis etc). Given the very high mortality of corals experienced during the coral bleaching event of 1998, the current growth of Maldivian coral reefs has been greatly reduced. Every effort must be made to protect existing reef structures.

Long term response

Recommendation: Existing initiatives to protect biodiversity through marine protected areas and manage fisheries for sustainability should be maintained and strengthened.

Justification: In 1998, the ecosystem of the Maldives' coral reefs and related marine ecosystems received a significant impact from coral bleaching. Long term monitoring and surveys after the tsunami indicate that there has been some recovery of reef systems in all locations, but that this recovery has been slow in most places. Almost certainly, this slow rate of recovery is due to a limitation of larvae as very few mature corals remained after the bleaching event. In order for the ecosystem of the Maldives to remain healthy and continue its progress on the road to recovery, it requires that other, further impacts be kept within sustainable limits. A system of marine protected areas, such as the one recently declared at Addu Atoll, replicated on other atolls, would greatly enhance the health and resilience of the Maldives' marine ecosystems. A system of marine protected areas should be designed based on the best available information about patterns of biodiversity distribution and larval connectivity within and between atolls.

Capacity building

Recommendation: The Maldives would benefit from more personnel trained in coral reef and fisheries ecology to undertake assessment and monitoring of natural resources.

Justification: The Maldivian economy is strongly dependent on natural resources, particularly through the tourism and fisheries industries. Capacity to assess and monitor these resources is essential if they are to be managed for sustainable use, so they can provide an ongoing economic resource for generations to come.

Environmental Monitoring

Recommendation: Post tsunami surveys should be conducted as soon as possible at Marine Research Centre long term monitoring sites.

Justification: Three of the long term monitoring sites of the Marine Research Centre have already been surveyed post tsunami. These data provide the only available before/after tsunami comparison. The remaining long term monitoring sites that have not yet been surveyed since the tsunami should be re-surveyed as soon as possible to provide a more complete before/after comparison data set.

Recommendation: The Government should continue to allocate resources for existing long term marine monitoring programmes and serious consideration should be given to expansion of such programmes.

Justification: Existing long term marine monitoring programmes provided the only capacity to make before/after tsunami comparisons. This has provided the most definite assessment of tsunami effects. For similar purposes and to inform management of the Maldives' natural resources, such monitoring programmes are essential.

Recommendation: A collaborative monitoring programme between the Marine Research Centre and the tourism industry should be established to monitor the health of the marine environment at and around significant dive sites.

Justification: The Maldives has an enormous area of coral reefs. By collaborating with the tourism industry, the Government will be able to more efficiently and completely monitor this vast resource.

FIGURE 3.4: Results of broad scale surveys from Raa Atoll.
Histograms indicate live hard coral cover.

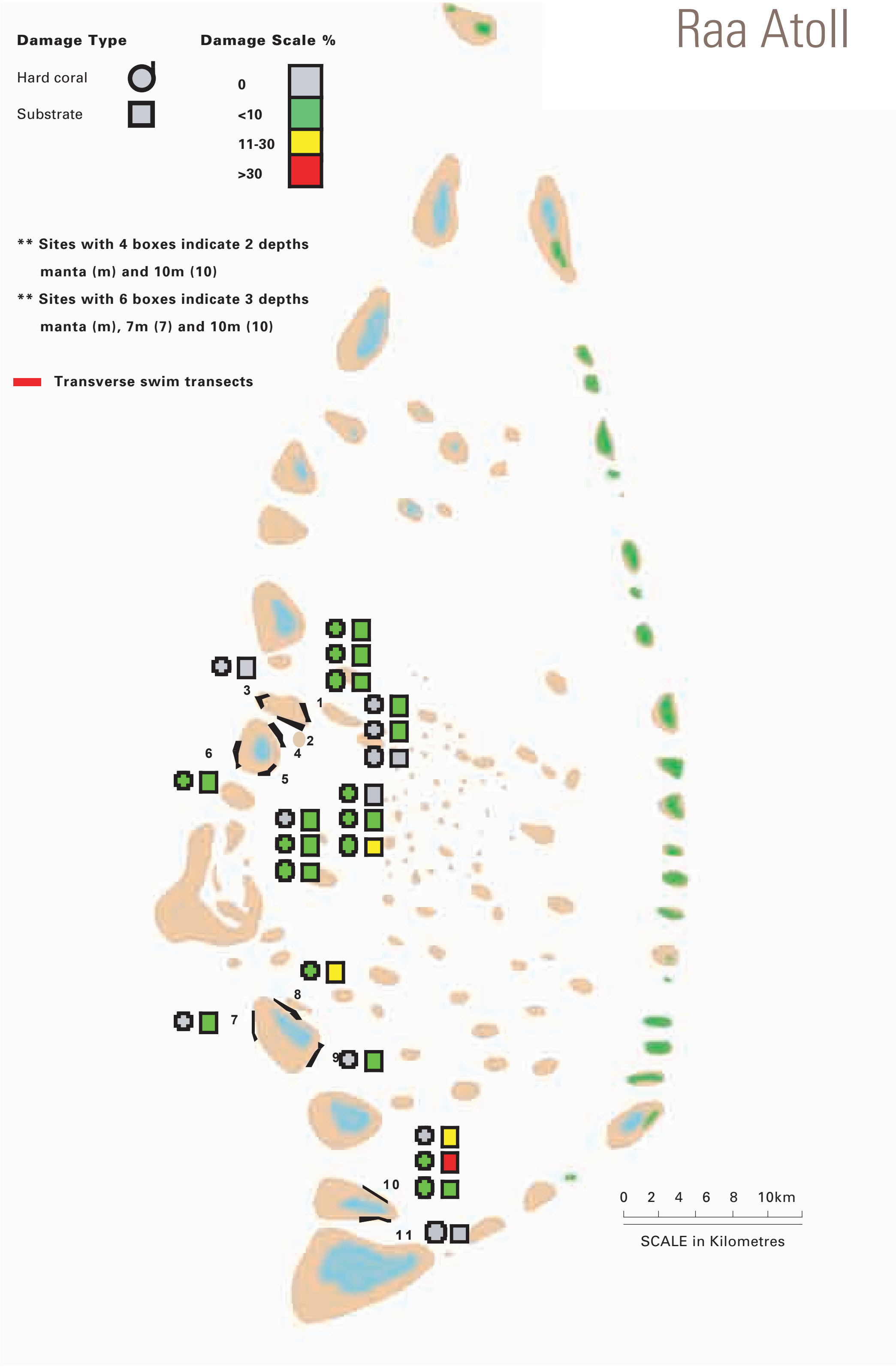


FIGURE 3.5: Results of broad scale surveys from Baa Atoll.

Histograms indicate live hard coral cover.

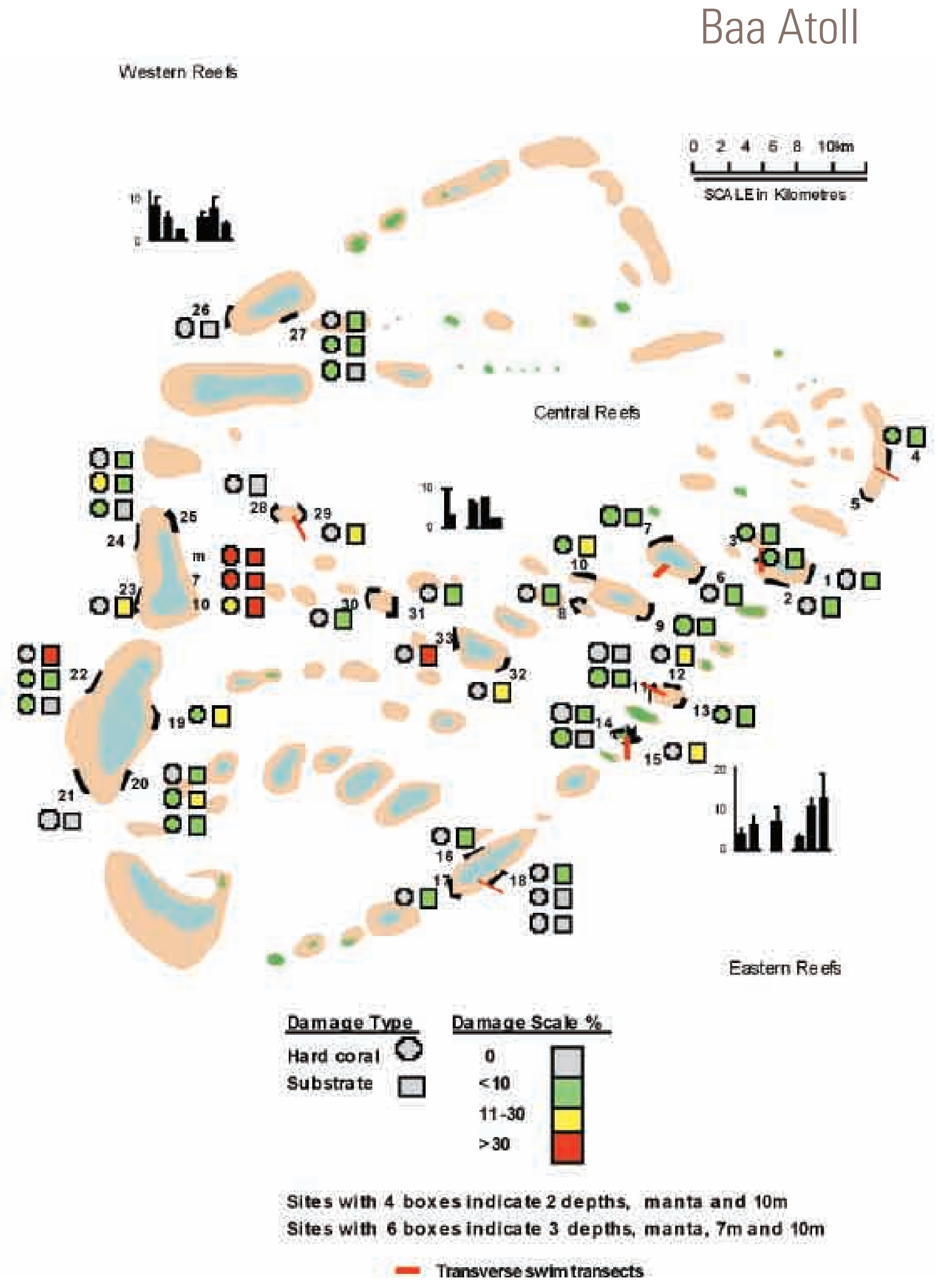


FIGURE 3.6: Results of broad scale surveys from South Malé Atoll.

Histograms indicate live hard coral cover.

FIGURE 3.7: Results of broad scale surveys from Vaavu and Vattaru Atolls.
Histograms indicate live hard coral cover.

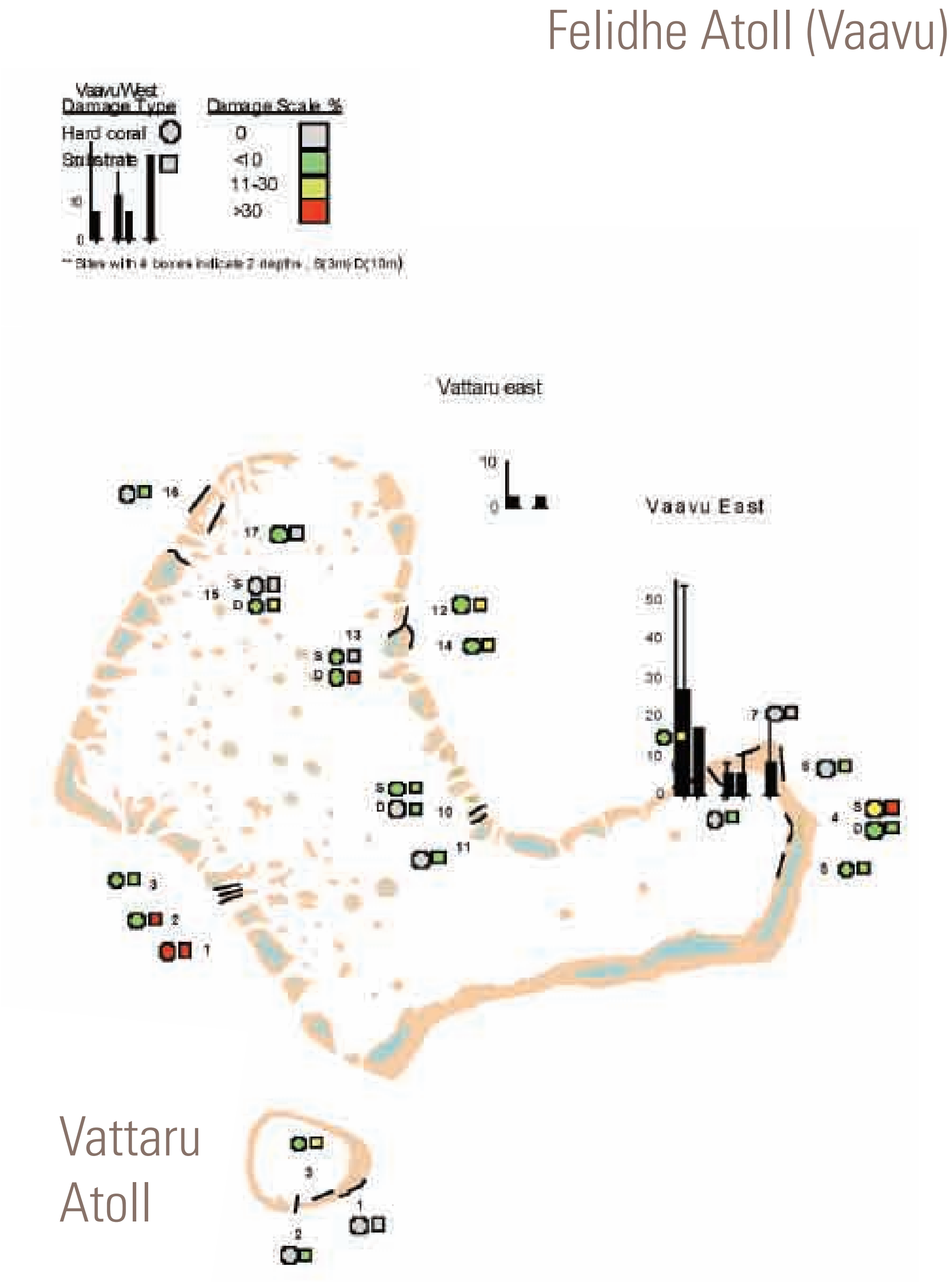


FIGURE 3.8: Results of broad scale surveys from Meemu Atoll.

Histograms indicate live hard coral cover.

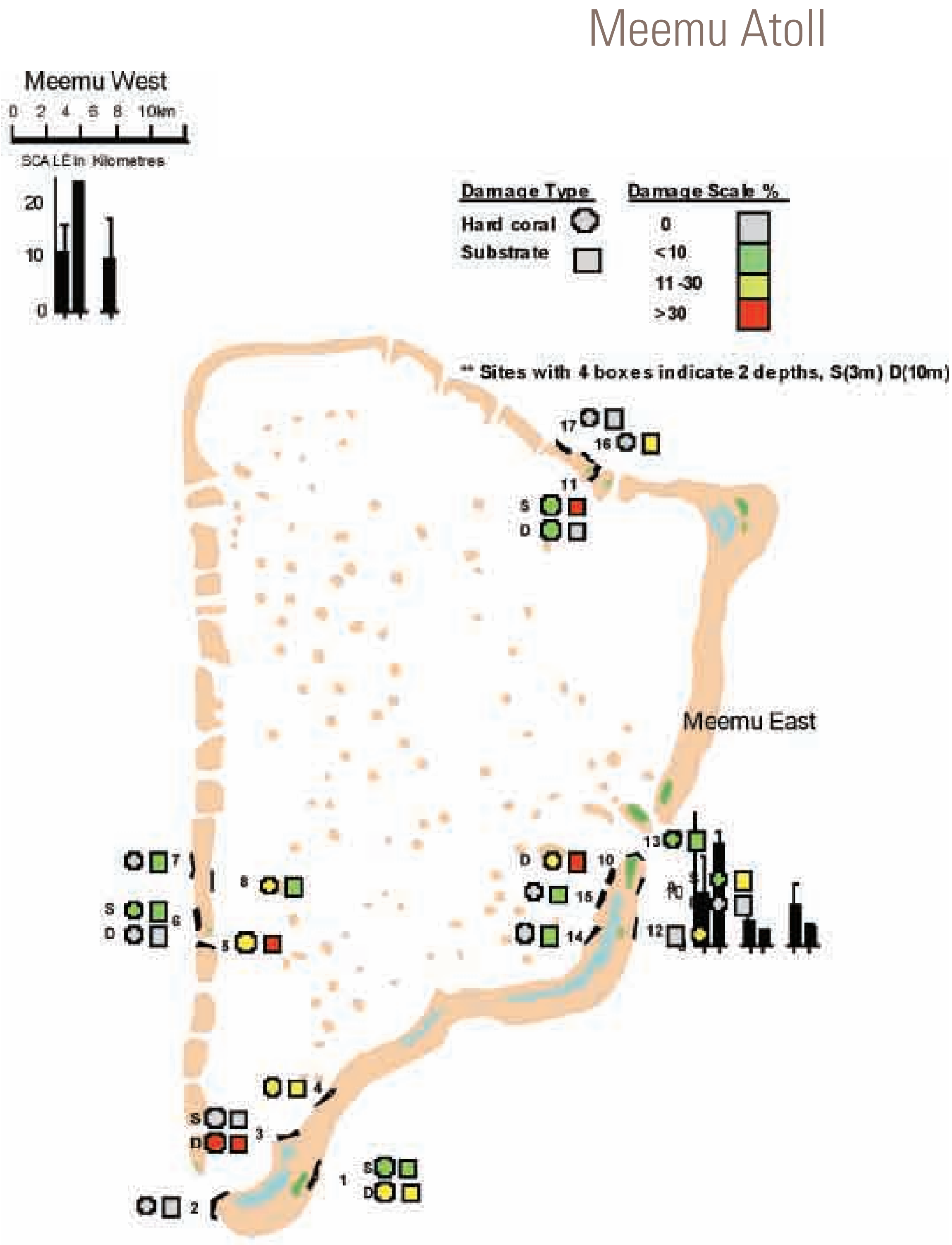


FIGURE 3.9: Results of broad scale surveys from Thaa Atoll.
Histograms indicate live hard coral cover.

Kolhumandulu Atoll
(Thaa)

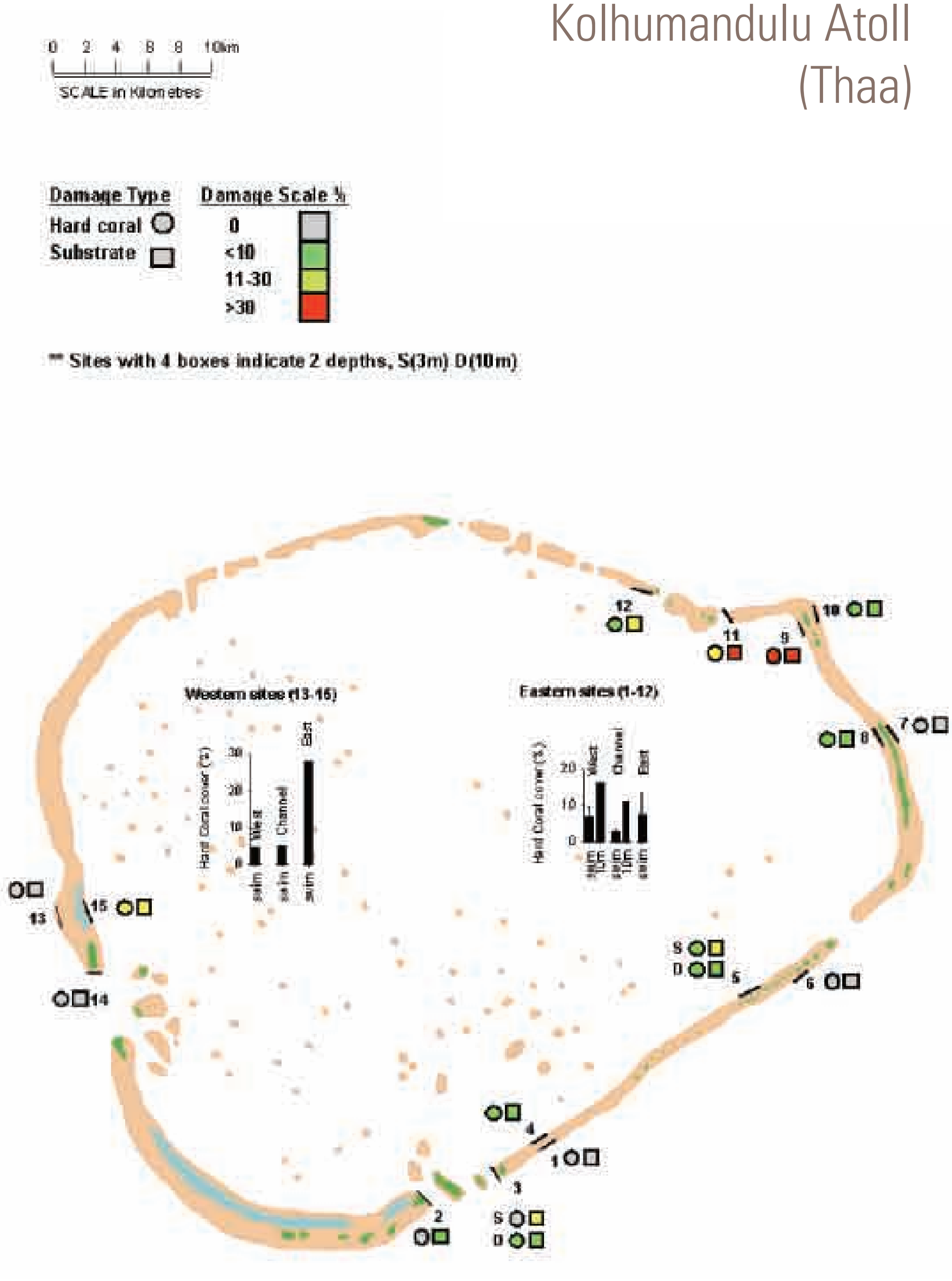


FIGURE 3.10: Results of broad scale surveys from Laamu Atoll.
Histograms indicate live hard coral cover.

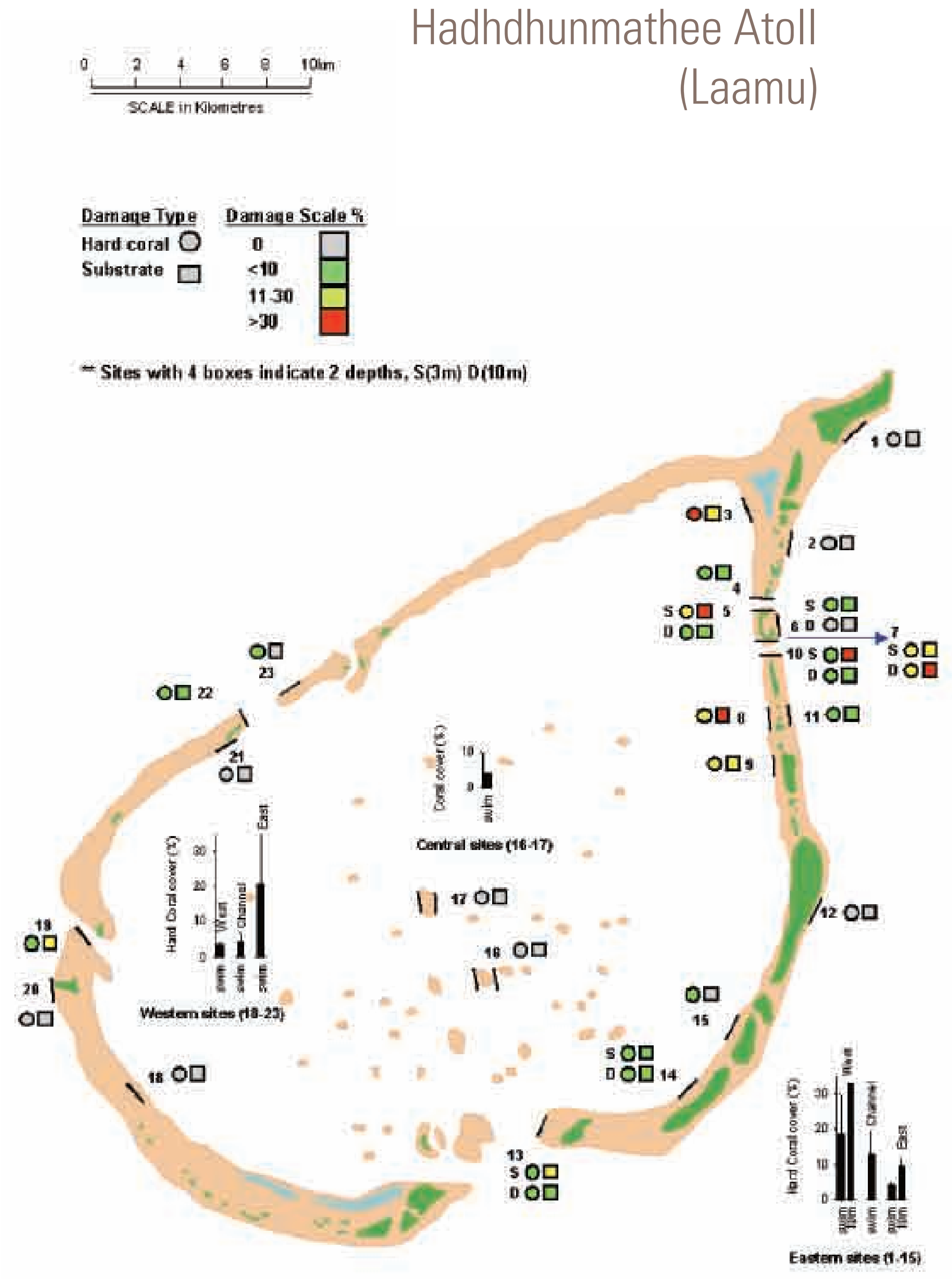


FIGURE 3.11: Results of line intercept transects from two depths at each of three sites, two on Vaavu Atoll and one on Vattaru Atoll, from 1998 to 2005 (post tsunami). Error bars are standard errors.

4 Reef and island geomorphology

AN ASSESSMENT OF THE GEOMORPHOLOGY OF REEF FLATS, SHORELINES AND ISLANDS OF SOME INHABITED AND UNINHABITED ISLANDS OF LAAMU AND THAA ATOLL WAS UNDERTAKEN.

INTRODUCTION

The necessity to work in proximity to other members of the reef assessment team, and the small size of the geomorphology team, meant that mapping of changes and detailed assessment of processes associated with the tsunami was not possible. The assessment is therefore, primarily descriptive.

Ten inhabited and nine uninhabited islands on Laamu and Thaa were visited (Table 4.1, Figures 4.1 and 4.2). On one, the shoreline was observed from the water only as landing was not possible. In addition, Huraa on North Malé atoll was visited. On inhabited islands, the island office was visited, and the island chief contacted when available. Guides were arranged and sites around the island perimeter were visited, concentrating on areas where the tsunami caused changes. Sites in the village where particular effects were noted were also targeted, as were sites where the height of the wave was recorded by water lines on walls. Guides and other residents were questioned particularly with reference to the characteristics of the tsunami waves, any unusual effects that were observed, the effect on groundwater and its recovery, and any changes that were noted to the surface of the island. On uninhabited islands, the island perimeter (or as much of it as possible) and sections of the interior were walked, and signs of the tsunami wave and associated deposits were described and photographed.

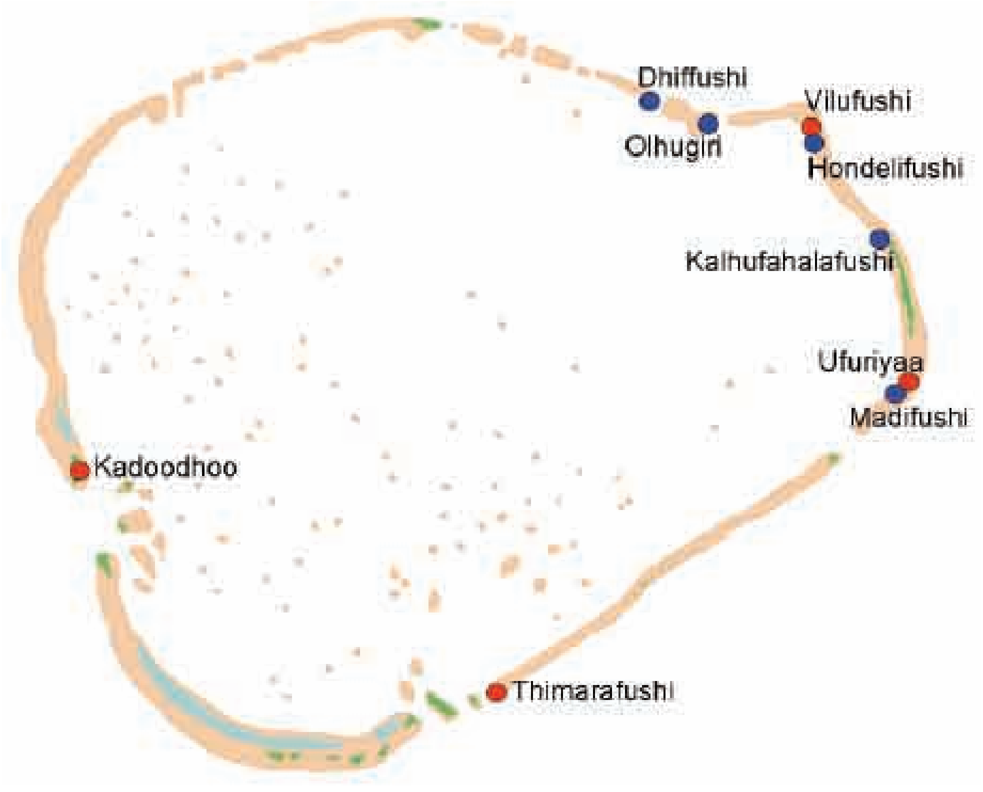
TABLE 4.1: Islands that were visited (L = Laamu Atoll; T = Thaa Atoll; K = Kaafu Atoll).

Inhabited	Uninhabited
Huraa [K]	Uvadhevifushi [L]
Isdhoo [L]	Ziyaaraiyfushi [L] (3)
Maabaidhoo [L]	Munnafushi [L]
Kalhaidhoo and Kudakalhaidhoo [L] (1)	Bodufinolhu [L]
Gan [L]	Ufuriyaa [T]
Fonadhoo [L]	Kalhufahalafushi [T] (4)
Maavah [L]	Hondelifushi [T]
Thimarafushi [T]	Olhugiri [T]
Madifushi [T]	Dhiffushi [T]
Vilufushi [T]	
Kadoodhoo [T] (2)	

(1) now joined by a causeway
(2) observed from the boat
(3) now 3 unvegetated sand cays
(4) also known as Rahfathi

FIGURE 4.1: Laamu atoll showing the islands that were visited (red = inhabited, blue = uninhabited).

FIGURE 4.2: Thaa Atoll showing the islands that were visited (red = inhabited, blue = uninhabited).



TSUNAMI WAVE CHARACTERISTICS

Reports and evidence from vegetation show the wave coming from the east or north-east on the eastern islands of the atolls. However, on Maavah, on the western side of Laamu, the eastern side of the island was not flooded. Reports of the wave coming from the west are supported by observations on nearby uninhabited islands. This feature of the tsunami may be the result of some wave refraction around the largely enclosed atolls.

As the tsunami waves approached all islands visited from the seaward (non-lagoon) side the atoll, it is reasonable to use the terminology "outside" and "inside" with respect to reefs, reef flats, beaches and islands. This terminology will be adopted.

Two people who were on the reef flat or beach reported a bubbling of water from the sand and the apparent mobilisation of organic matter from within the sediment as the first sign of the approaching event.

There are some reports that the water retreated before rising, although coming at a lower tide level, this may not have been noticed in many locations. Photographs taken by residents of Maabaidhoo (Photographer: Mohamed Meezaan) and Vilufushi (Photographer: Abdulla Nizar) show the initial sequence of events. The tsunami waves appeared on the islands as bores (waves with no backflow between them). The first wave was small, followed almost immediately by one or two higher waves (Figures 4.3 and 4.4). The presence of standing waves indicate a high water speed (Figure 4.5). In most places, no reverse flow was reported, with the water passing directly over the island. On wide islands where flooding did not reach the inside shore, or where a seaward ridge was not present, water drained back to the outside of the island. Flooding lasted between 5 and 15 minutes, although in low-lying areas the period of flooding was extended.

Wave height was variable, but always highest on the outside of the island. The maximum confirmed height on an outside wall was 2.8 m.

FIGURE 4.3: *The first tsunami wave on Maabaidhoo (Photographer: Mohamed Meezaan).*

FIGURE 4.4: *The first tsunami wave on Vilufushi (Photographer: Abdulla Nizar).*

FIGURE 4.5: *Standing waves in the tsunami on Maabaidhoo (Photographer: Mohamed Meezaan).*

REEF FLATS ON THE WAVE-APPROACH SIDE OF THE ISLAND

There were few signs of disturbance on reef flats on the outside of the island. A small number of reef flats were walked to the reef crest, and on others the inner section was observed from the island shoreline. Disturbance was limited to overturning of small coral colonies (mainly *Porites rus*) and recolonised bommies. Small and fragile colonies of *Acropora* species were undisturbed. There was one report of a reasonably large reef block on the reef top being moved a few metres. On the inner reef flat, some small beachrock blocks were overturned.

There was no indication of significant sediment movement from the reef front onto the reef flat or within the reef flat. There was some indication of a small amount of sediment movement from the beach onto the inner reef flat in some locations, although no evidence was found of smothering of microatolls or seagrass near the reef flat/beach interface (toe of beach).

BEACHES ON THE OUTSIDE OF THE ISLANDS

The beaches on the outside of the islands were relatively unaffected. In many places, the only indication that a significant event had occurred was the toppling of overhanging and shoreline vegetation. In most places, however, a small (less than 0.5m) erosion scarp was evident, but it is possible that in many cases, the scarp is a normal response to the north-east monsoon. The scarp may have formed as an erosion feature when the wave first hit, but many scarps are probably related to land drainage from the outside of the island rim following the passage of the waves. Roots of plants indicated erosion of up to 5m on the outside of islands, although the areas with high erosion tended to be adjacent to the ends of islands.

Areas where shoreline vegetation was sparse were more severely eroded than areas where there were overhanging trees, or where there were grasses or other low ground cover. In such cases, it was common for trees and shrubs to topple, either being pulled from the ground by the force of the wave or having roots exposed by erosion. Typical outside beach erosion is shown in Figure 4.6. On Kalhufahalafushi, photographs of the same or similar areas taken before and after the tsunami, show typical erosion in the order of 0–3m (Figure 4.7).

ENDS OF THE ISLANDS

Most islands visited were orientated parallel to the reef crest, and had relatively narrow sections at the distal ends. Many had beachrock outcrops extending from the ends, indicating that islands previously extended beyond their present limits. The ends of the islands were in many cases significantly impacted (Figure 4.8). Although most water flowed over the island, a significant amount would have been directed along the shore towards the ends of the islands resulting in significant water velocities. The actual extent of erosion was very difficult to determine, but in many cases would have been in the order of 10–20m, accompanied by some narrowing of the already narrow islands.

Sand spits extending from the ends of islands onto the inside reef flat were very common. Photographs taken before the tsunami in some locations show that these were present prior to the event, being permanent accumulations, or seasonal accumulations associated with the north-east monsoon. Some sand eroded from the ends of the islands would almost certainly have added to the accumulations, but we found no cases where there was conclusive evidence that new accumulations in the form of sub-aerial or intertidal spits were created.

FIGURE 4.6: *Typical beach erosion on the outside of islands, Hondelifushi.*

23 April 2004

3 Feb 2005

FIGURE 4.7: *The same site on Kalhufahanafushi, before (23 April 2004) and after (3 Feb 2005) the tsunami.*

FIGURE 4.8: *Typical erosion at the ends of islands.*

ISLAND SURFACES

Typically islands have an outside rim which is higher than the island interior. Normally there is also a lower inside rim. On inhabited islands, the natural morphology has been significantly altered, often with the removal of the rims. It was expected that large quantities of sand, rubble and beach rock would have been transported from the outside reef flat, and beach onto the outside rim and into the island interior. There were no examples of significant sand transport into the interior of the island. There were many examples of small reef rubble clasts being transported significant distances inland and deposited as thin sheets, but no major accumulations, such as rubble ridges, were observed. The largest material observed to have been transported onto the island were pieces of beach rock approximately 30cm x 20cm x 20cm, at the distal end of Kudakalhaidhoo.

Most island surfaces were barely disturbed. In some locations close to the edges of the islands, exposed roots (particularly of coconuts) indicated a few centimetres of the sandy soil had been stripped. However, most of the soils in the island interior appeared largely undisturbed. Grasses and other low vegetation had clearly been flattened by the water, but their root systems were largely undisturbed. Except at the outside beach, medium sized trees and shrubs were flattened or pushed over, but not ripped out. Larger trees (especially coconut palms) were not damaged, although some have clearly been affected by salt water. These observations were supported by island residents when specifically asked about loss of surface sediments. This finding was surprising, given the high water speeds shown in photographs, and as evidenced by the vegetation that had been pushed over. Clearly, the structure of the flow was such that shear stress at the boundary was relatively low.

A very good example illustrating the small impact at the island surface came from Kudakalhaidhoo, an island which in 1999 was joined to Kalhaidhoo by a causeway with material dredged from the harbour. Kudakalhaidhoo was being used for agriculture.
A number of pits, approximately 1m square and 1m deep had been dug, in which to plant bananas. The material removed from the hole had been placed beside the hole on the side from which the tsunami approached. Only a small amount of the sand from the pile was moved into the pits, and the piles of sand remained generally intact. This was despite evidence that the water level over the island was at least 1m, and despite this site being very close to the location where the largest beachrock clasts moved onto the island were observed (Figure 4.9).

There were isolated examples of scour pits on islands, associated with changes in surface morphology. Most examples were associated with features such as roads.

FIGURE 4.9: *Sediment transport into banana pits on Kudakalhaidhoo Island. The wave came from the top left corner.*

Significant scouring occurred along roads or pathways where flow was concentrated. Gully erosion associated with the water draining the land was concentrated along roads and tracks. In some cases, this gully erosion extended up to 50m inland (Figure 4.10).

INSIDE BEACHES OF THE ISLANDS

On wide islands, the water did not flow across the island to reach the inside beaches. However, on those that were completely flooded, the most significant changes to the morphology were on the inside beaches. The development of deep scour pits on inside beaches, accompanied by significant erosion, were the most common feature observed clearly associated with the tsunami. These were observed on almost every island that the water crossed completely.

Scour pits are widely reported features associated with tsunami. Examples are shown in Figures 4.11 and 4.12. They are caused by extreme turbulence and downward pressure from the water, normally associated with changes in topography. On the inside of islands, very large quantities of water drain from the island surface onto the beach as the wave passes over the island. At the island/beach interface, the water falls as in a waterfall, with considerable downward force, excavating a hole. An erosion scarp develops, and some of the water flows backward against the scarp. This water also contains coral pieces excavated from the hole, which assists the erosion of the scarp. The erosion scarp and scour pit moves inland, sometimes for a considerable distance. In some locations, up to 30m of erosion was indicated. In many cases, the scour pit has excavated reef framework and rubble, depositing material on the beach and adjacent reef flat. Significant accumulations of sand and rubble from the scour pits were found on the inside reef flats up to 50m from the beach.

The scour pits were variable in morphology, ranging from isolated examples normally associated with a track or area of shoreline with low vegetation cover, to extensive pits along the length of the inside shore. Many scour pits were a series of deep pools separated from each other by ridges, indicating areas of concentrated flow. The deepest scour pits were approximately 2m deep, although there was clear evidence of infilling since the tsunami, due to their steep sides. Figures 4.13 and 4.14 show profiles across scour pits on Maabaidhoo (adjacent to an uninhabited part of the island), and Kalhaidhoo (adjacent to the causeway to Kudakalhaidhoo).

FIGURE 4.10: *Gully erosion by return flow at the northern end of Gan.*

FIGURE 4.11: *Scour pits on Uvadhevifushi.*

FIGURE 4.12: *Scour pits on Maabaidhoo illustrating a common form that has ridges between discrete pools.*

FIGURE 4.13: Section across scour pits on the inside of Maabaidhoo.

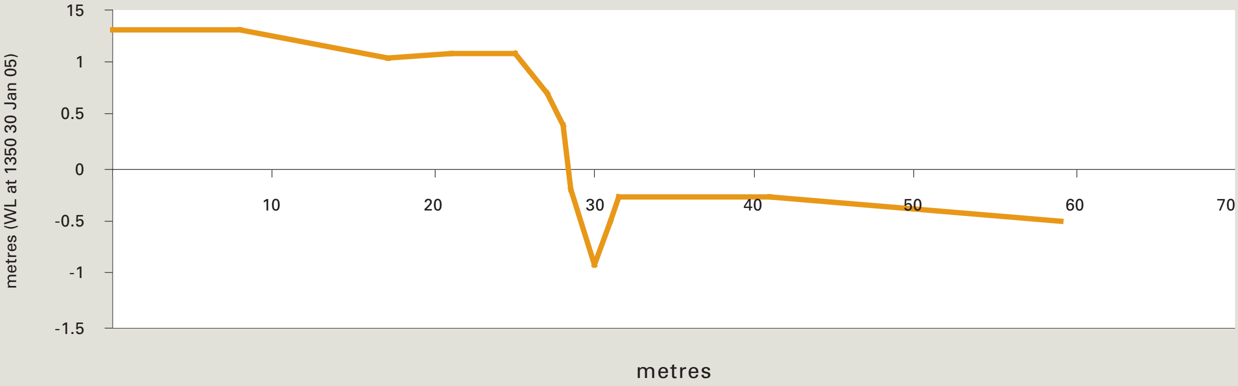
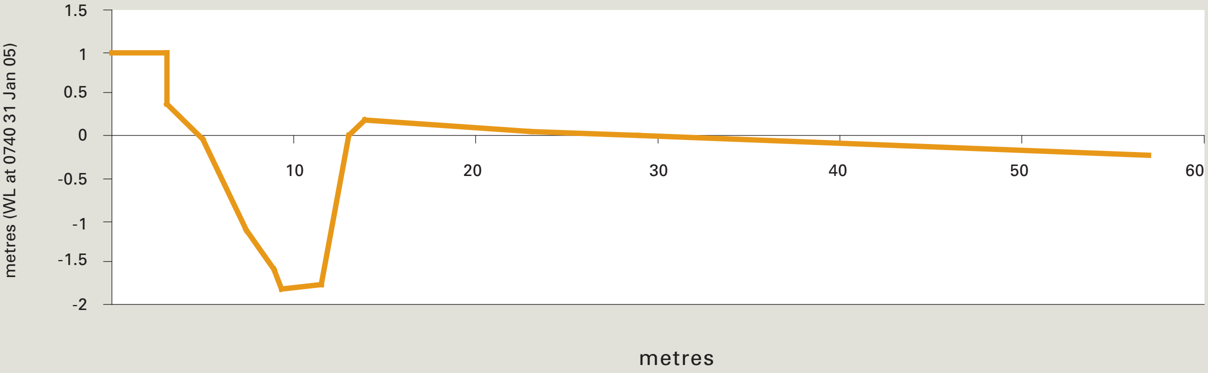


FIGURE 4.14: Section across scour pits adjacent to the causeway between Kalhaidhoo and Kudakalhaidhoo.



Large scour pits and significant erosion were found adjacent to unvegetated reclaimed areas, such as causeways and harbour frontages. The causeway linking Kaddhoo and Fonadhoo, for example, was extensively damaged, requiring extensive repairs (Figure 4.13).

INSIDE REEF FLATS

Where scour pits had been formed, inside reef flats had extensive accumulations of sand and rubble. There were some areas of accumulation of debris and rubble probably transported from the ends of the islands and shallow areas of channel on the inside of islands (Figure 4.16).

An extensive seagrass meadow grows on the inside reef/ sand flat at the southern end of Vilufushi. The beds would be almost exposed at low tide. There had clearly been a major perturbation to the seagrass bed with large channels scoured out, and holes up to 3m in diameter and having the appearance of scour pits (Figure 4.17). Pieces of matted seagrass roots and sand were found intact, but lying at various odd angles in close proximity. Some of the newly excavated sections had new, shallow rooted sea grass growing, presumably from old roots remaining.

The origin of these excavations is not certain, but a possible explanation is sub-aerial scour when water was drawn away by the tsunami prior to the wave hitting. The orientation of the steep side of the discrete and roughly circular scour pits indicated formation by water flowing from the inside of the atoll to the outside.

FIGURE 4.15: *The causeway between Kaddhoo and Fonadhoo showing extensive erosion on the inside (left) caused by the formation of scour pits.*

FIGURE 4.16: *Rubble on the inside reef flat, Uvadhevifushi.*

FIGURE 4.17: *Scour in seagrass beds on the inside of Vilufushi.*

ISLAND BREACH

Kalhufahalafushi is a narrow island approximately 8km long at the extreme east of Thaa atoll. The island is also known as Rahfathi meaning "chain of islands", indicating that it has not always been a continuous landform. The tsunami caused the island to breach approximately 550m from its northern end, at its narrowest point (Figures 4.18 and 4.19). Scour pits exist on the inside beach on both sides of the breach, and it is most likely that scour erosion from the inside through to the outside, by the process described on other islands caused the breach. Very large pieces of beachrock (approximately 2m x 2m x 50cm) were excavated and deposited on the adjacent inner reef flat (Figure 4.20). A large sand sheet extended approximately 100m onto the reef flat. A fast tidal stream occurs through the channels, and it is likely that the breach will widen in the near future, with remnant sections of island being removed (Figure 4.21).

BUILDING AND STRUCTURE DAMAGE

Despite the relatively minor impact of the tsunami on the island surface, many buildings were severely damaged or destroyed. The mechanisms of damage were varied. It was very clear that coral walls, particularly boundary walls with only shallow foundations, were the worst affected. Coral houses without surface rendering were also significantly affected. Concrete block structures without reinforcement with concrete or steel were also severely damaged. Modern structures, built with reinforcing, were rarely damaged.

Scouring around and under structures caused considerable damage and collapse. On coral walls without rendering, water entering fissures and cracks at considerable speed and pressure mobilized individual clasts and removed loose material, leading to rapid collapse. There were many examples where a very thin coat of mortar over coral walls prevented damage. Impact by floating debris was also likely to be a significant cause of damage, particularly to unsupported boundary walls.

A number of examples of tiles and cement being pushed up from floors were seen. These seemed to be unrelated to major structural damage to the buildings, and were probably the result of changes in water pressure within the island sediments. Although there is no data to support this conclusion, the rapid increase in water level on top of relatively porous island sediments will almost certainly result in the rapid elevation of the water table. Where this is constrained by an impervious surface, surface damage is quite possible.

We investigated an area described as subsidence or collapse on Huraa, in North Male Atoll (Figure 4.22). Approximately 3 days after the tsunami, a circular area of ground, approximately 2.5m in diameter subsided. The area had been covered by a pile of sand after the tsunami, providing the extra weight to finally force the collapse. The hole was approximately 0.5m deep, but was probably deeper due to sand infill from the sand that was on top. A loose, naturally cemented layer approximately 30cm below ground level capped a cavity around the perimeter of the hole, extending laterally up

FIGURE 4.18: *Kalhufahalafushi before the tsunami showing the very narrow area that was breached.*

FIGURE 4.19: *The breach in Kalhufahalafushi.*

FIGURE 4.20: *Beachrock excavated from the inside of Kalhufahalafushi. This rock is approximately 1.5m high and 2m across.*

FIGURE 4.21: *The tidal stream excavating seagrass beds on the outside of the breach on Kalhufahalafushi.*

FIGURE 4.22: *The slump on Huraa, North Male atoll.*

to 2m from the edge. The brackish groundwater was very high in relation to ground level, indicating that the island is quite low at this location.

Cavities confined by cemented layers are common within reefs and on reef islands. There are islands that have similar "pools". It is possible that water movement and pressure associated with the tsunami, combined with the high water table (with respect to ground level) assisted the process. In this particular location, it is also possible that this collapse is at a site of a long abandoned well. Wells were sometimes dug to a cemented layer, as this assists in keeping them open. Over time, erosion and settling of sediment around the lateral margins under the cemented layer occurs, extending the cavity.

No other collapses of this nature were found on other islands. It is likely that this is an uncommon event. However, it illustrates the importance of undertaking some site investigations for all major building projects.

Harbours and associated structures suffered significant damage in the tsunami (Figure 4.23). Collapse of walls was caused by scour and by pressure on the back of elevated cement structures. Some rubble basin and channel walls were also damaged, but these structures are often damaged by other high energy wave events.

GROUNDWATER

There were some reports of water overflowing wells immediately prior to the waves arriving. As discussed above, an increase in water level over porous sediments could cause this to happen. The tsunami undoubtedly caused salt water intrusion into the freshwater lens on all islands. Some island vegetation died as a result, although some apparently dead trees have recently started to shoot. On all inhabited islands, the status of the groundwater was said to be improving, with some reports that it was nearly back to normal, despite the period since the tsunami being relatively dry. Significant and fairly rapid recovery is likely after future rainfall events.

DISPOSAL OF DEBRIS AND RECLAMATION

Most inhabited islands have already cleared debris from the villages. The debris is generally placed at the shoreline, either at a nearby point, or in reclamation. The location and form of reclamations have almost certainly not been planned with knowledge of coastal processes that are operating. It may be that some of these structures may cause problems for adjacent island shorelines in the future. Debris cleared from islands comprises both rubble and general household rubbish. The amount of plastics, fabrics and other household rubbish being placed in or adjacent to the marine environment is a cause for concern, as these things can cause significant damage to marine ecosystems.

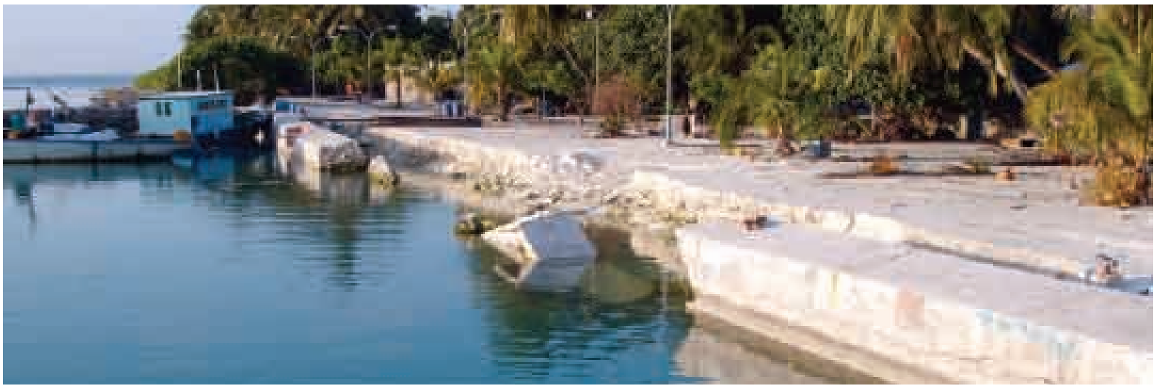


FIGURE 4.23: *Collapse of the harbour wall at Vilufushi.*

DISCUSSION AND CONCLUSIONS

The tsunami of 26 December 2004 has resulted in surprisingly little change to the reef flats, beaches and islands of Laamu and Thaa atolls. Some isolated cases of significant change to these environments were observed, and others are known to have occurred elsewhere. Clearly the damage to buildings on inhabited islands is very significant, and this needs to be addressed. However, except for some specific issues relating to the physical causes of damage, such consideration is beyond the scope of this report.

Reef flats on the outside of atolls were minimally impacted. Outside-atoll reef beaches had small (generally less than 5m) of erosion, and some scarping and toppling of shore vegetation. The ends of the islands were more significantly affected by erosion and narrowing. The island surfaces were minimally impacted, with only minor surface erosion, and limited deposition of sediment from the marine environment. Inside-atoll (lagoon) shorelines were most significantly affected, with the development of scour pits and significant erosion on the shores of all islands which were narrow enough to have water flowing right across. Some deposition of sediment on adjacent reef flats occurred, both from erosion of the shoreline, and from material transported from or around the ends of the islands. The importance of shoreline vegetation in reducing erosion on all shorelines is very clear. Areas with no vegetation suffered significantly more erosion than areas with vegetation.

Environmental perturbations frequently initiate changes that continue or have repercussions into the short to medium term future. In situations where major changes have occurred, such as the breach of Kalhufahalafushi, the altered morphology is likely to remain into the foreseeable future. In many cases, the change is likely to be reinforced by present processes. The toppling and loss of vegetation on shorelines will make shorelines more susceptible to erosion by normal wave processes over the next few years. Slumping of scarps and some further shoreline vegetation dieback is likely. The ends of islands that are orientated parallel to the reef have been destabilized and some morphological change in the future is expected. Some features, such as scour pits, will fill in over time, particularly once the southwest monsoon starts. Before then, however, they may promote erosion by providing deep water next to a scarped shoreline.

There will be calls for restoration of some environments. Processes that have been initiated will be difficult to overcome, and success without considerable financial input is not certain. On uninhabited islands, restoration is normally unnecessary. On some inhabited islands, restoration using clean material could be considered. We saw one case of a sea wall being built with material excavated from the reef flat nearby. This wall and excavation is unlikely to protect against future events, and may cause adverse effects by changing nearshore coastal processes.

Our knowledge of the evolution of the reef and island system of the Maldives is poor, and the tsunami has illustrated that we have very poor understanding of the short and long term processes that maintain these geomorphic systems. It may be that such events have played a role in the evolution of the Maldives that has been unrecognized or misdiagnosed. Understanding this event, and its impact on the geomorphology of reefs in general and the reefs of the Maldives in particular is essential, as it not only has local significance, but also significance for other reef systems of the Pacific which are also susceptible to tsunami.

RECOMMENDATIONS

Requirements for follow-up studies (in order of priority)

1. To provide a broad-scale analysis of perturbation by tsunami surges to island and reef systems, a thorough analysis of pre- and post-tsunami high resolution satellite imagery (Quickbird and ALI) should be undertaken.
2. Detailed examination of a small number of uninhabited islands should be undertaken as soon as possible. This would involve:
    - detailed mapping of the reef and shorelines and sediment deposits
    - sediment analysis
    - mapping of vegetation toppling directions and the extent and nature of vegetation damage
    - a thorough assessment of island surface changes
    - the establishment of vertically referenced profile monitoring sites to determine further change and recovery.

    From more focussed studies, a better indication of the characteristics of the wave (including boundary water velocities) could be obtained. This knowledge would be more generally applicable within the Maldives, and to other atoll environments that are vulnerable to tsunami (such as those in the Pacific). A team of three, working for three to four days would adequately cover a typical island.
3. A simple monitoring program of island shorelines at selected sites should be implemented, in order to better understand seasonal and long term trends, and to understand the role of major environmental perturbations and the recovery from them.
4. The provision of high resolution before and after satellite images for the areas visited would make the rapid observations made in this study much more meaningful. This data would enable significant further interpretation from the data already collected.
5. Little is known about the internal stratigraphy of islands of the Maldives. Some geomorphological and geotechnical research in order to better understand how islands evolved and their internal structure is important to assist development planning.

Suggested considerations for planning and redevelopment:

6. Vegetation along shorelines has provided considerable protection from erosion by the tsunami. Unnecessary clearance of vegetation along the shoreline should be discouraged.
7. The occupation of land near the ends of islands, and in the vicinity of seasonal spits, should be avoided.
8. It is not common for village buildings to be constructed right on the shoreline. The practice of leaving a shoreline buffer should be continued.
9. Restoration in areas of damage, and reclamations and other structures should be planned and undertaken with a knowledge of coastal processes operating on the reefs, reef flats and island shores of the Maldives.
10. People should be encouraged to find alternatives to shoreline disposal of household rubbish.

5 Rapid assessment of reef and lagoon fisher perceptions of tsunami damage to their fisheries

LIVE BAIT FISHERY IS THE MOST IMPORTANT REEF FISHERY IN THE MALDIVES AND IS ESSENTIAL FOR THE TUNA POLE-AND-LINE FISHING. THIS IS BECAUSE COPIOUS AMOUNTS OF LIVE BAIT ARE REQUIRED TO ATTRACT AND MAINTAIN TUNA SCHOOL DURING POLE-AND-LINE OPERATIONS.

Tuna fishing is the most important fisheries activity in the Maldives, providing employment, particularly to outer island economies, and a source of food for Maldivians. Tuna catches in 2003 were 138,751t representing 89.3% of the recorded national fish landings with an export value of about US$40 million US$. Thus, decline in bait availability would have enormous consequence to the tuna industry.

The major varieties of live bait used in the Maldives are sprats (*Spratelloides gracilis, S. delicatulus*) anchovies (*Encrasicholina heterolobus*), silversides (various species), cardinalfishes (various species) and fusiliers (various species). The average species composition of the Maldivian live bait is estimated by Anderson[10] and is summarized in Table 5.1.

The amount of live bait caught is not recorded as a requirement for the national fisheries statistics. However, the live bait catch has been estimated for 1978–81, 1985–87 and 1993 and more recently in 2004. Total catches have increased dramatically over the years concomitant with the tuna catch – the most recent estimate is between 35 000 and 80 000t per year. There are no assessments or detailed studies on population dynamics of the bait resource and so the sustainability of the current levels of catch is not known.

Other reef fisheries are the sharks, grouper, aquarium and the beche-de-mer, which are essentially export-oriented. The general reef fisheries exploit a variety of species including jacks, breams, scads, snappers, jobfishes and dog-tooth tuna. A large proportion of the reef fish catch is sold directly to the tourist resorts but some are either salt-dried or sold locally, particularly in the Malé fish market.

The official recorded catch of reef fish is about 16 000t in 2003. This is considered to be an under-estimate as most of the catch is believed to go unreported.

The status of the reef fisheries is not known. However, grouper and bech-de-mer fishery is considered to be in serious decline11 (+ MRC, unpublished data for grouper).

The effect of tsunami on the bait and reef fisheries were investigated using a simple questionnaire. This was because there were no detailed assessments (biological or socio-economic studies) of the fisheries to compare with the situation after the tsunami. Also the time and resources available did not allow conducting visual assessment surveys or sampling of the catches at an appropriate scale. Thus, the objectives of this survey were (1) to undertake a rapid assessment of the status

TABLE 5.1: Average composition of the Maldivian livebait catch (after Anderson 1994).

Species / Family	Local name	Percentage
Spratelloides gracilis	Rehi	38 ±10%
Caesionidae	Muguraan	37 ± 9%
Apogonidae	Boadhi & Fatha	10 ± 3%
Engraulidae	Miyaren	7 ± 2%
Spratelloides delicatulus	Hondeli	5 ± 1%
Atherinidae	Thaavalha	1%
Pomacentridae	Buerki & Nilamehi	1%
Others	–	0.2%

of the fisheries that rely on coral reefs (bait and reef fisheries) in atolls known to have islands that were heavily affected and (2) identify potential issues or threats to these fisheries from the tsunami and make recommendations for future studies.

METHODS

A survey of fisher perceptions of the impacts of the tsunami on their fisheries was undertaken from 28 January to 3 February 2005 in three atolls with high (Laamu and Thaa) or medium (Baa) impacts. Active fishers from other atolls who were landing their catch in Malé market were also interviewed during periods between the other surveys. Both tuna fishers (pole-and-line and long-lining) and reef fishers were surveyed with a structured questionnaire (Appendix 3). The questionnaire was kept short and it was designed to have a fixed range of responses to avoid obtaining a large number of variable answers. Each interview took between five and 10 minutes to conduct, depending on the interviewer and the degree of probing required. Interviews were also designed to require a minimum of expertise by the interviewer. All interviews were conducted in Divehi and the Australian team member was available at all times for clarification on the classification of responses.

Interviews were always conducted in private to avoid outside influences on individual responses. Normally a maximum of three interviews were conducted of members of each fishing vessel. Owners, captains and crew were all interviewed during the survey and the choices were mostly random. Some fishers conducted both tuna and reef fish fishing depending on the season. For these fishers, both sections of the questionnaire were completed. Responses that were clearly different from the choices available on the questionnaire were also recorded in pencil on the survey form. These responses were later categorised during data entry. All data were entered into a database and data were also displayed in a GIS.

RESULTS FOR EACH ATOLL

General

A total of 281 interviews were conducted in three atolls (Laamu, Thaa and Baa) and in the Malé fish market (other atolls). The average ages and number of dependants of each fisher were similar for the most affected atolls surveyed (Table 5.2). The percentage of active fishers in the three survey atolls (Laamu, Thaa and Baa) varied, with about 65% actively fishing in Laamu and Thaa Atolls. In contrast, only 46% of fishers surveyed in Baa Atoll were currently fishing. Fisher households were large, averaging 7–8 per household. Most fishers were in their middle ages (between 30 and 50), with exceptional individuals in their 70s (Table 5.2).

FIGURE 5.1: *Zaha Waheed interviewing a fisher at a meeting on Thulhaadhoo, Baa Atoll.*

TABLE 5.2: The number of fishers from each atoll who were fishing and their average, maximum and minimum age along with the average and maximum number of dependents (n = number of interviews; Min = minimum; Max = Maximum; no. = number).

Atoll	Level of impact	Fishing	n	Min age	Max age	Average age	Average no. of dependents	Maximum no. dependents
Baa	Moderate	n	37	23	70	43.4	8.3	21
Baa	Moderate	y	31	21	59	42.1	8.6	18
Laamu	High	n	22	16	56	36.3	7.6	14
Laamu	High	y	38	20	66	41.0	7.1	15
Thaa	High	n	29	25	75	44.3	7.6	18
Thaa	High	y	57	22	80	40.7	6.2	30

Surveys of three impacted atolls

A total of 105 of the 126 active fishers interviewed in the three atolls were fishing by pole-and-line for tunas (Table 5.3). All fishers interviewed in the two southern atolls, Laamu and Thaa, were undertaking pole-and-line fishing except for two reef fish fishers in Thaa Atoll. The situation was quite different in Baa Atoll, where the fishers undertook a range of fishing activities. Pole-and-line tuna fishing was still the most important fishing activity, but reef fishing for fish, lobster and beche-de-mer were also undertaken.

TABLE 5.3: The number of fishers interviewed in the three atolls that were undertaking pole-and-line tuna, reef or a mixture of fishing activities (n = number of interviews).

Atoll	Type of fishing	n (%)
Baa	Pole-and-line	12 (39%)
	Reef	8 (26%)
	Both	8 (26%)
	Yellowfin tuna	3 (9%)
Laamu	Pole-and-line	38 (100%)
Thaa	Pole-and-line	55 (96%)
	Reef	2 (4%)

The number of days tuna fishers fished during the last week (21–28 January 2005) varied between atolls (Fig. 5.2), with fishers from Laamu being the most active. On Baa, the pattern showed that there were a group of part-time tuna fishers (1–2 days per week) and a second group that fished 5–7 days a week. This second group tended to fish for reef fish in the same season due to poor tuna fishing. The level of fishing effort in Thaa was intermediate between that in Laamu and Baa Atolls, with most fishing between 2–4 days last week.

The type of bait fishing conducted in each atoll varied (Table 5.3), with the pole-and-line tuna fishers in Baa taking bait almost exclusively during the day. In Laamu Atoll, there was an even spread of respondents who fished for bait at night with lights or used nets set overnight on reefs to catch their bait. The situation in Thaa Atoll appears to be more similar to Baa Atoll, with more day-time fishing for bait than those with lights at night.

Only five fishers responded to questions about the current status of the bait fishery by saying it was poor and worse than before the tsunami hit (Table 5.3). Four of these were from Baa Atoll and these fishers explained that the current poor conditions were a normal seasonal occurrence during the North-east monsoon. The other respondent was from Laamu Atoll and he thought there had been some loss of baitfish habitat on bait grounds adjacent to the eastern islands.

The majority of fishers from all atolls, especially Thaa Atoll, said that bait fishing was currently average or good and this condition was similar or better than during the period prior to the tsunami (Table 5.4).

FIGURE 5.2: Maps of islands visited in Baa, Thaa and Laamu Atolls and the number of interviews made at each island.

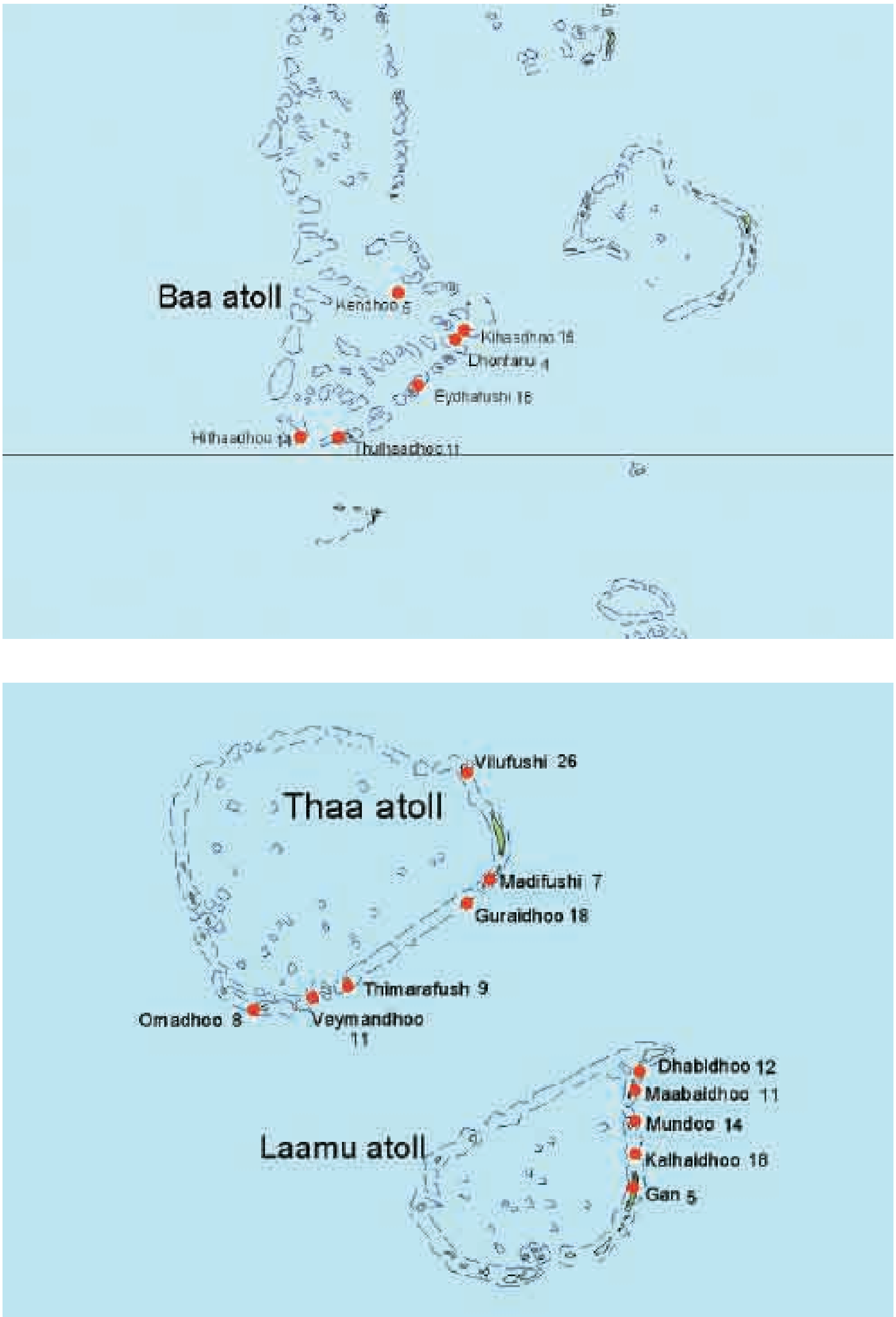


FIGURE 5.3: The percentage of tuna fishers that went fishing between one and seven days in the last week.

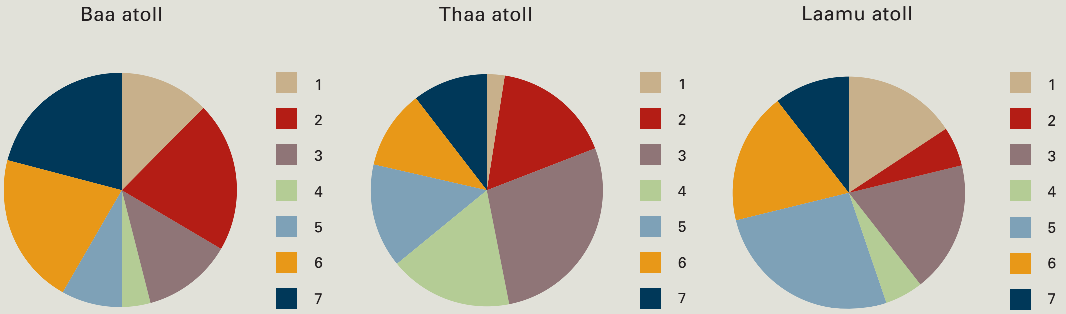


FIGURE 5.4: *Photograph of one of the Apogon species that fishers from Laamu call Boadhi.*

TABLE 5.4: The type of bait fishing practiced in each atoll and the fishers' perceptions of current bait fishing conditions and whether it is better or worse than before the tsunami. The responses where the fisher felt the bait fishing was currently poor and it was poorer than before the tsunami are bolded.

Atoll	Bait fishing method	Current bait fishing conditions	Comparison with before tsunami	Number of responses
Baa	Both	Average	Similar	1
		Good	Better	1
	Daytime	Average	Poorer	1
		Average	Similar	1
		Average	Similar	4
		Good	Poorer	1
		Good	Similar	12
		Poor	**Poorer**	**4**
		Poor	Similar	5
	Night-time	Poor	Similar	1
Laamu	Both	Average	Poorer	1
		Average	Similar	1
		Good	Better	3
		Good	Poorer	2
		Good	Similar	4
		Poor	Similar	1
	Daytime	Average	Poorer	2
		Average	Similar	7
		Good	Poorer	2
		Good	Similar	2
		Poor	**Poorer**	**1**
	Night-time	Average	Similar	1
		Average	Poorer	1
		Average	Similar	9
		Good	Similar	1
Thaa	Both	Average	Better	1
		Average	Similar	1
		Good	Better	12
		Good	Similar	4
		Poor	Better	1
		Poor	Did not know	1
		Poor	Similar	3
	Daytime	Average	Poorer	1
		Average	Similar	4
		Good	Better	8
		Good	Poorer	3
		Good	Similar	3
	Night-time	Average	Similar	5
		Good	Better	3
		Good	Poorer	1
		Good	Similar	5
		Poor	**Poorer**	**3**
		Poor	Similar	1

Rehi (*Spratelloides gracilis*) was the most important baitfish species identified by pole-and-line tuna fishers in Baa and Thaa Atolls (Table 5.5). This is consistent with the overall baitfish situation in the Maldives (Anderson 1997). This contrasted with the responses from Laamu, where the fishers were mostly catching *Apogon* species by draping the net over the reef during the night and collecting it before dawn. This bait fishing method is not commonly practiced in other atolls (MRC unpubl. data). Only five fishers recorded that they had had to move bait grounds from their regular sites since the tsunami. Three of these moved because of seasonally poor catches unrelated to the tsunami and another because of poor visibility affecting their catch rate. These changes in catch rates for Rehi are well known from fishery surveys by the Marine Research Centre (MRC unpubl. data) and are unlikely to be a direct consequence of the tsunami. These changes in bait grounds may have been due to sedimentation of reefs as these five were all targeting *Apogon* spp, species with a close affinity with coral reefs.

The level of income of fishers in the pole-and line fisheries in Laamu and Thaa Atolls was similar (Table 5.6). In Baa Atoll, they appear to have lower income than in other atolls. This is consistent with their assertions that the tuna catches during the northeastern monsoon were poor, rather than a lack of baitfish to undertake fishing. The reef fishers in Baa Atoll had similar income to the pole-and-line fishers in the other atolls (Table 5.6). These fishers catch fish for the resorts and rely on their operation for income. In most cases, active fishers appear to be maintaining their income since the tsunami and the quoted incomes in the last week were similar or higher than those quoted during the previous month.

Malé market

The distribution of fishers who land their catch in Malé market is quite wide (Fig. 5.3). Fishers from as far north as Lhaviyani and Noonu Atolls to as far south as southern Kaafu Atoll were interviewed while landing catch in Malé. Of the 68 interviews taken in Malé, most were from Kaafu Atoll, near to Malé (Table 5.7). Their age distribution was similar to that found in the more affected atolls, except that there were probably a higher proportion of younger fishers interviewed. Family sizes were also similar to those found elsewhere in the study (Table 5.7).

Most (41 of 59 active: 69%) were full-time fishers and went fishing 6–7 days each week. The least active fisher interviewed still fished three days each week. These were mostly tuna fishers (53/59 active fishers: 90%) despite our efforts to interview the reef fish fishers that land their catch in the mornings.

The perceptions of current bait fishing and how it

TABLE 5.5: The most abundant baitfish species identified by each respondent and whether they have changed bait fishing grounds since the tsunami.

Atoll	Ground Same ?	Most common bait species	Scientific name	Number of responses
Baa	n	Rehi	*S. gracilis*	1
Baa	y	Muguraan	Caesionids	8
Baa	y	Mushimas	*Selaroides* spp	3
Baa	y	Rehi	*S. gracilis*	19
Laamu	n	Boadhi	*Apogon* sp	5
Laamu	y	Muguraan	Caesionids	1
Laamu	y	Boadhi	Apogonids	25
Laamu	y	Miyaren	*E. heterolobus*	7
Thaa	n	Boadhi	*Apogon* sp	1
Thaa	n	Rehi	*S. gracilis*	3
Thaa	y	Boadhi	*Apogon* sp	8
Thaa	y	*Fathaa*	*Rhadamia sp*	5
Thaa	y	Miyaren	*E. heterolobus*	11
Thaa	y	Rehi	*S. gracilis*	27
Thaa	y	Muguraan	Caesionids	1

compares with the period before the tsunami showed a different pattern to that found in the outer atolls (Table 5.8). Most of the tuna fishers in Kaafu Atoll prefer to catch their bait at night and a higher proportion of these fishers (7/29: 24%) claim that bait fishing is currently poor and has declined from the period prior to the tsunami. When those that claimed that current conditions are poor and these were similar to that prior to the tsunami, almost half the fishers (48%) were concerned.

The reasons given for the current poor fishing were more often related to post-tsunami effects such as turbid waters and poor visibility and perceived habitat damage. Some also identified seasonal conditions contributing to the poor bait fishing conditions. The period prior to the survey was around the full moon and this may also have influenced the responses we obtained from fishers catching their bait at night.

FIGURE 5.5: Map of the islands from which fishers were interviewed at Malé market and the number of interviews made.

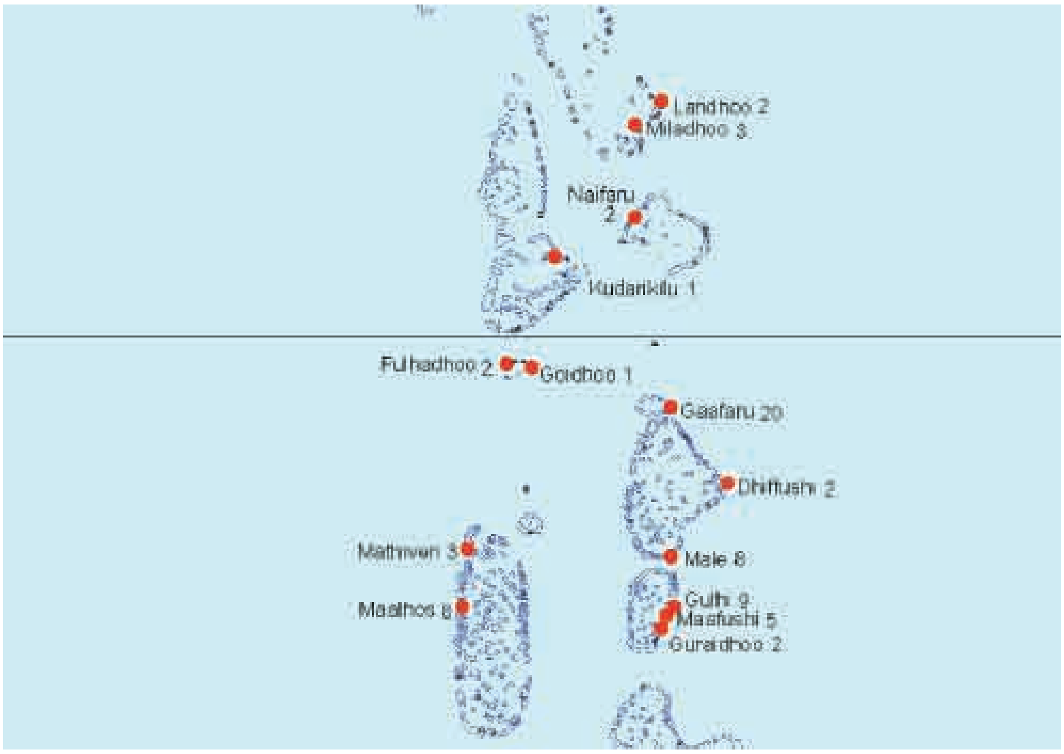


TABLE 5.6: The income of fishers (in Rufiyaa: 1 USD = 12.75 Rf) derived from each main fishing methods identified during the survey. Income is separated between that obtained last week and during the month prior to the tsunami.

Atoll	Type of fishing	n (%)	Weekly income last week (Rf)			Weekly income last month (Rf)		
			Average	Min	Max	Average	Min	Max
Baa	Pole-and-line	12 (39%)	1073	0	3300	700	50	1375
	Reef	8 (26%)	1757	300	6000	1268	250	3500
	Both	8 (26%)	938	350	5000	1020	250	2500
	Yellowfin tuna	3 (9%)	666	500	1000	1250	1000	1500
Laamu	Pole-and-line	38 (100%)	1752	230	13000	1016	250	6500
Thaa	Pole-and-line	55 (96%)	1692	0	10500	1200	120	7500
	Reef	2 (4%)	500	500	500	500	500	500

TABLE 5.7: Details of the fishers landing catch in Malé that were interviewed.

Atoll	Level of impact	Fishing	n	Min age	Max age	Average age	Average no of dependents	Maximum no dependents
Alifu Alifu	Low	n	3	18	32	26.7	3.3	6
Alifu Alifu	Low	y	8	19	54	36.6	6.4	15
Gaafu Dhaalu	Low	y	1	49	49	49.0	9.0	9
Kaafu	Substantial	n	5	20	41	31.4	7.8	14
Kaafu	Substantial	y	43	17	57	37.2	7.1	13
Lhaviyani	Substantial	y	2	42	50	46.0	9.0	10
Meemu	High	n	1	45	45	45.0	7.0	7
Noonu	Low	y	5	39	51	45.2	6.8	8

TABLE 5.8: The type of bait fishing practiced in each atoll and the fishers' perceptions of current bait fishing conditions and whether it is better or worse than before the tsunami. The responses where the fisher felt the bait fishing was currently poor and it was poorer than before the tsunami are bolded.

Atoll	Bait fishing method	Current bait fishing conditions	Comparison with before tsunami	Number of responses
Alifu Alifu	Both	Average	Better	1
		Good	Similar	1
	Daytime	Average	Poorer	2
		Good	Similar	1
		Poor	Better	1
	Night-time	Good	Similar	1
		Poor	**Poorer**	**1**
Dhaalu	Both	Good	Similar	1
	Daytime	Average	Similar	1
		Good	Similar	1
Kaafu	Both	Average	Poorer	1
		Average	Similar	2
		Good	Similar	1
	Daytime	Average	Similar	2
		Good	Similar	2
		Poor	Similar	1
	Night-time	Average	Poorer	2
		Average	Similar	1
		Good	Better	1
		Good	Poorer	2
		Good	Similar	7
		Poor	Better	1
		Poor	N/A	1
		Poor	**Poorer**	**7**
		Poor	Similar	7
Lhaviyani	Night-time	Good	Similar	1
		Poor	**Poorer**	**1**
Noonu	Both	Poor	Poorer	1
	Daytime	Average	Similar	1
		Poor	**Poorer**	**2**
	Night-time	Poor	Similar	1

Among fishers from other atolls, only night-time light fishers also reported poor fishing and a decline from the period prior to the tsunami. No fisher who collected their bait in the early morning by more traditional methods felt that there was difficulty in obtaining enough bait fish.

Despite almost half the fishers from Kaafu Atoll identifying poor bait fishing conditions at the moment, very few changed their bait fishing grounds since the tsunami (Table 5.9). Of those that had, they were all night-time fishers with lights who were targeting Rehi (*Spratelloides gracilis*). Unlike in the outer atolls, there were more fishers targeting yellowfin tuna and with Mushimas (*Selar crumenopthalmus*). There was a much less reliance on Caesionids in Kaafu and nearby atolls compared with the other atolls surveyed.

While tuna fishers landing their catches in Malé appear to have some difficulty in obtaining sufficient bait, their income was still higher than that obtained in the outer atolls (Table 5.10). Average weekly incomes both before and after the tsunami was generally higher for both tuna and reef fishers. This result is not unexpected as the prices for tuna in Malé are higher than that paid by the collector vessels and canning processors in the southern atolls. These higher incomes are probably offset by higher costs for items like fuel and possibly food. Our sample from the Malé market would also be biased upwards as the samples were obtained from the point of sale and would have represented mostly the successful fishers rather than be representative of the fisher population from that island.

TABLE 5.9: The most abundant baitfish species identified by each respondent from the survey at the Male market and whether they have changed bait fishing grounds since the tsunami.

Atoll	Ground Same ?	Most common bait species	Scientific name	Number of responses
Alifu Alifu	n	Rehi	*S. gracilis*	1
Alifu Alifu	y	Rehi	*S. gracilis*	7
Dhaalu	y	Rehi	*S. gracilis*	3
Kaafu	n	Rehi	*S. gracilis*	2
Kaafu	y	Muguraan	Caesionids	2
Kaafu	y	Mushimas	*S. crumenopthalmus*	1
Kaafu	y	Rehi	*S. gracilis*	32
Kaafu	y	Rinmas	*D. macruellus*	1
Lhaviyani	y	Mushimas	*S. crumenopthalmus*	2
Noonu	y	Muguraan	Caesionids	1
Noonu	y	Mushimas	*S. crumenopthalmus*	4

TABLE 5.10: The income of fishers (in Rf) derived from each main fishing methods identified during the survey. Income is separated between that obtained last week and during the month prior to the tsunami.

Atoll	Type of fishing	n (%)	Weekly income last week			Weekly income last month		
			Average	Min	Max	Average	Min	Max
Alifu Alifu	Pole-and-line	9 (100%)	1725	600	3000	930	250	2250
Dhaalu	Pole-and-line	3 (100%)	2500	1500	4000	791	1500	4000
Gaafu Dhaalu	Reef	1 (100%)	1000	1000	1000	2000	2000	2000
Kaafu	Pole-and-line	39 (91%)	2194	600	5000	1120	300	2750
Kaafu	Reef	4 (9%)	2233	1200	4000	1625	1600	1700
Lhaviyani	Pole-and-line	2 (100%)	2100	2000	2200	1250	1000	1500
Noonu	Pole-and-line	4 (80%)	950	750	1500	1937	750	3500
Noonu	Both	1 (20%)	1800	1800	1800	–*	–	–

* This fisher was not actively fishing the previous month.

CONCLUSIONS

The main conclusion from this rapid survey of the perceptions of active fishers to the effect of the tsunami is that they have found little change in their fishing conditions. The survey only examined impacts on the fisheries of two highly (Laamu and Thaa) and a moderately impacted atoll (Baa) Few fishers commented that fishing conditions for pole-and-line bait had changed from those experienced prior to the tsunami. Those that felt there was a change attributed these changes to seasonal effects.

The perceptions of fishers who were unable to fish due to boat damage or other personal difficulties was quite different and their income was obviously impacted by the tsunami event. The reason for this varied greatly between individuals and varied from being displaced, working on islands on the reconstruction to direct loss of their vessel.

Laamu Atoll

Fishers interviewed from Laamu Atoll were all pole-and-line tuna fishing and about two-thirds (63%) were back actively fishing. Most were full-time fishers (> 5 days per week) and were collecting on average, over 1700 Rf during the last week. This income was also similar, or higher than their recollections of the period prior to the tsunami. This is probably due to the increased prices paid by the tuna processors in Laamu since the tsunami (Fisheries unpubl. data). This income can be converted to similar units to the recent Vulnerability and Poverty Assessment (VPA)[12] (Rf/capita/day). When the average income of active fishers in Laamu is calculated in these units, it shows that they compare quite favourably (31 Rf/capita/day) with the national average for outer atolls (20 Rf/capita/day).

The main bait fish species caught in this atoll were Boadhi (*Apogonids*), which is unusual as they comprise less than 10% of the bait fish caught in the overall fishery[13]. The most commonly used bait fishing method in Laamu Atoll includes draping the bait net over the reef top in the early afternoon and hauling the net before dawn to catch the strongly reef-attached *apogonid* species (Boadhi). The effect of this bait fishing method on the reef would be expected to be quite severe as pieces of reef would attach to the net and break during hauling.

Thaa Atoll

The pattern of bait fishing in Thaa Atoll and the responses of most fishers were similar to those obtained in nearby Laamu Atoll. Pole-and-line tuna fishing was the major fishing activity of those interviewed. A similar percentage of fishers were still active (66%), but fewer fishers were active full-time (5–7 days/week). They used a similar mix of both night-time and daytime fishing methods for bait, but more were positive about the current status of the bait resource. Bait species composition was more similar to the overall fishery statistics[13], with Rehi and Miyaren being the most commonly reported species. Income of active fishers in Thaa Atoll was similar to that reported by fishers in Laamu. The average income per capita of active pole-and-line fishers in Thaa Atoll may be higher than in Laamu as the number of dependents was lower.

Baa Atoll

The range of fishing activities in Baa Atoll was more variable than in the other atolls. Pole-and-line tuna fishing was still the most common fishing activity, but about 30% of the active fishers were targeting reef fish and other reef-associated species. Bait fishing was almost exclusively done during the day, unlike that in other atolls. The participation rate was much lower in Baa Atoll (46%) compared with the other two atolls surveyed. Many fishers were actively involved in the reconstruction and only rarely fishing full-time. This is reflected in the lower income from fishing reported by fishers in Baa Atoll.

Reef fish fishers in Baa Atoll were also not active full-time as they commented that the tourist resorts were not buying as much fish due to the low occupancy rates. These fishers also did not notice any changes in the location of their fishing grounds or the catch rates of their target reef fish species.

Malé market

The fishers surveyed in Malé were mostly full-time fishers (5–7 days/week) and thus may be biased compared to the overall fisher community in their respective atolls. Most fishers interviewed were participants in the pole-and-line or Yellowfin tuna fisheries (90%) and may not be representative of the overall composition of fishers landing their catch in Malé.

Bait fishing was mostly conducted at night, which was more pronounced compared with that undertaken in other atolls. More of these fishers also felt that bait catch rates were poor and worse than before the tsunami. The most commonly targeted species was Rehi, which is similar to that found in Thaa and Baa.

Income of all fishers surveyed in Malé was generally higher than that reported from the outer atolls. These fishers are all earning well above the VPA daily average income per capita (20 Rf/capiat/day[12]).

Shortcomings of survey

This survey covered a representative range of impacted islands of three atolls and was necessarily of very short duration. Thus there will be a number of short-comings of the results that may not necessarily reflect the actual effects of the tsunami on reef-associated fisheries.

One short-coming is that fish species are longer lived than many invertebrate species and many affects may not become apparent until well after the physical effects have passed. In order to detect these effects, if they occur, a system of bait catch records and species composition needs to be kept. There are currently few systematic data on the catch rates and species composition of the bait fishery with which to assess any impacts quantitatively. A similar situation exists in the reef fisheries.

Another short-coming of the survey results is that there are few qualified scientists available for undertaking bait and reef fish studies and so the understanding of the dynamics and biology of these species during the survey might have biased the results. Staff who participated in the survey worked very diligently but difficulties and ambiguities in interpreting the survey form may have influenced the results.

The survey form was also hastily compiled after the study team decided that this would be the most sensitive approach given the lack of available catch rate data for these reef-associated fisheries. If subsequent surveys were to be undertaken, some minor modifications to the form would improve the quality of the data produced. Interviewer training is also recommended before beginning a survey in order to get consistency in recording among interviewers.

RECOMMENDATIONS

There are three main recommendations that follow from the conclusions from this survey. If these recommendations are taken up, they should lead to a more rigorous assessment of the actual impacts of events like a tsunami on fisheries for reef associated species. These are:

- That a national system of bait fish recording be incorporated in the current fishery data collection system. This should include a measure of the species composition and catch rate of each species, where possible. This will allow the Marine Research Centre to follow up on the perceptions of the Malé pole-and-line fishers that bait catches are poor and have recently declined.
- Similarly, there is an urgent need to strengthen the data collection for all reef fisheries. There are few data available and those are mostly out-of-date. There is no data currently available to assess any perceived declines in the populations of any species or species groups. We recommend a comprehensive system of data be collected from all reef fisheries in order to assess population trends.
- In parallel with the strengthening of the national fisheries data collection system, we recommend that Marine Research Centre receive institutional strengthening by improving the level of formal training of staff in bait and reef fisheries.

6 Summary of recommendations

THE WORK CONDUCTED BY THE AUSTRALIAN – MRC TEAM PROVIDED A RAPID ASSESSMENT OF THE STATUS OF MALDIVIAN CORAL REEF SYSTEMS AND ASSOCIATED FISHERIES AND ISLAND GEOMORPHOLOGY.

Although the assessments aimed to cover representative islands, reefs and habitats, it is clear that in the time available many atolls were not visited, the proportion of the reefs we visited was a relatively small sub-sample of these vast systems, and that in most cases we were able to provide only qualitative estimates of the effects at high taxa detail. The Maldivian coral reefs are complex, and prior to the tsunami they had been heavily impacted by the 1998 coral bleaching. Yet their importance to the country as a tourism draw card and source of fisheries production and essential protein for the Maldivian population cannot be underestimated. As an overarching observation, we think that given the importance and fragility of Maldivian coral reefs, more effort is needed to understand their dynamics, and in particular increased and routine monitoring of their health (live coral cover, species diversity, and associated ecosystems) is essential. For this to happen there is a need for significant capacity building in the fields of coral reef and fish ecology and assessment.

CORAL REEF ASSESSMENT

Immediate response

- As the clean up after the tsunami progresses, disposal of refuse and debris should be conducted in a way that minimises entry of debris, particularly plastics, clothes, ropes, nets and other flexible man-made materials into the marine environment.
- Human debris, particularly plastics, clothes, ropes, nets and other flexible materials can cause significant damage to marine life including corals, fish, whales, dolphins, turtles, and seabirds. A great deal of this type of debris has been generated by the tsunami. Currently, a great deal of this debris is still on islands, particularly on beaches. Further clean up to minimise entry of this material to the marine environment would help minimise further damage to the marine environment from the tsunami.
- As reconstruction of Maldivian towns progresses, the Government should maintain its highly important stand on a prohibition of mining coral rock.
- The physical structure of Maldivian coral reefs is an important element in protection of Maldivian societies from wave damage (storms, tsunamis etc). Given the very high mortality of corals experienced during the coral bleaching event of 1998, the current growth of Maldivian coral reefs has been greatly reduced. Every effort must be made to protect existing reef structures.

Long term response

- Existing initiatives to protect biodiversity through marine protected areas and manage fisheries for sustainability should be maintained and strengthened.
- In 1998, the ecosystem of the Maldives' coral reefs and related marine ecosystems received a significant impact from coral bleaching. Long term monitoring and surveys after the tsunami indicate that there has been some recovery of reef systems in all locations, but that this recovery has been slow in most places. Almost certainly, this slow rate of recovery is due to a limitation of larvae as very few mature corals remained after the bleaching event. In order for the ecosystem of the Maldives to remain healthy and continue its progress on the road to recovery, it requires that other, further impacts be kept within sustainable limits. A system of marine protected areas, such as the one recently declared at Addu Atoll, replicated on other atolls, would greatly enhance the health and resilience of the Maldives' marine ecosystems. A system of marine protected areas should be designed based on the best available information about patterns of biodiversity distribution and larval connectivity within and between atolls.

Capacity building

- The Maldives needs more personnel trained in coral reef and fisheries ecology to undertake assessment and monitoring of natural resources.
- The Maldivian economy is strongly dependent on natural resources, particularly through the tourism and fisheries industries. Capacity to assess and monitor these resources is essential if they are to be managed for sustainable use, so they can provide an ongoing economic resource for generations to come.

Environmental Monitoring

- Post-tsunami surveys should be conducted as soon as possible at Marine Research Centre long term monitoring sites.
- Three of the long term monitoring sites of the Marine Research Centre have already been surveyed post tsunami. These data provide the only available before/after tsunami comparison. The remaining long term monitoring sites that have not yet been surveyed since the tsunami should be re-surveyed as soon as possible to provide a more complete before/after comparison data set.
- The Government should continue to allocate resources for existing long term marine monitoring programmes and serious consideration should be given to expansion of such programmes.
- Existing long term marine monitoring programmes provided the only capacity to make before/after tsunami comparisons. This has provided the most definite assessment of tsunami effects. For similar purposes and to inform management of the Maldives' natural resources, such monitoring programmes are essential.

Reef and Island Geomorphology

Requirements for follow-up studies (in order of priority)

1. Detailed examination of a small number of uninhabited islands should be undertaken as soon as possible. This would involve:
    - detailed mapping of the reef and shorelines and sediment deposits
    - sediment analysis
    - mapping of vegetation toppling directions and the extent and nature of vegetation damage
    - a thorough assessment of island surface changes
    - the establishment of vertically referenced profile monitoring sites to determine further change and recovery.

    From more focussed studies, a better indication of the characteristics of the wave (including boundary water velocities) could be obtained. This knowledge would be more generally applicable within the Maldives, and to other atoll environments that are vulnerable to tsunami (such as those in the Pacific). A team of three, working for three to four days would adequately cover a typical island.
2. A simple monitoring program of island shorelines at selected sites should be implemented, in order to better understand seasonal and long term trends, and to understand the role of major environmental perturbations and the recovery from them.
3. The provision of high resolution before and after satellite images for the areas visited would make the rapid observations made in this study much more meaningful. This data would enable significant further interpretation from the data already collected.
4. Little is known about the internal stratigraphy of islands of the Maldives. Some geomorphological and geotechnical research in order to better understand how islands evolved and their internal structure is important to assist development planning.

Suggested considerations for planning
and after redevelopment:

5. Vegetation along shorelines has provided considerable protection from erosion by the tsunami. Unnecessary clearance of vegetation along the shoreline should be discouraged.
6. The occupation of land near the ends of islands, and in the vicinity of seasonal spits, should be avoided.
7. It is not common for village buildings to be constructed right on the shoreline. The practice of leaving a shoreline buffer should be continued.
8. Restoration in areas of damage, and reclamations and other structures should be planned and undertaken with a knowledge of coastal processes operating on the reefs, reef flats and island shores of the Maldives.
9. People should be encouraged to find alternatives to shoreline disposal of household rubbish.

Rapid assessment of reef and lagoon fisher perceptions of tsunami damage to their fisheries

- That a national system of bait fish recording be incorporated in the current fishery data collection system. This should include a measure of the species composition and catch rate of each species, where possible. This will allow the Marine Research Centre to follow up on the perceptions of the Malé pole-and-line fishers that bait catches are poor and have recently declined.
- Similarly, there is an urgent need to strengthen the data collection for all reef fisheries. There are few data available and those are mostly out-of-date. There is no data currently available to assess any perceived declines in the populations of any species or species groups. We recommend a comprehensive system of data be collected from all reef fisheries in order to assess population trends.
- In parallel with the strengthening of the national fisheries data collection system, we recommend that Marine Research Centre receive institutional strengthening by improving the level of formal training of staff in bait and reef fisheries.

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Appendix 1

Fisheries Questionnaire

POST TSUNAMI SOCIO-ECONOMIC SURVEY

Name: Age: Marital Status: Single Married Divorced

No. of dependents:

Date: Atoll: Island:

Do you currently go fishing? Y N

If "NO" why? Boat damaged Gear lost frightened working on the island

If "YES" what type of fishing do you do? Tuna fishing Reef fishing

If a **"TUNA FISHERMAN"**

In the last week how many days did you go fishing. 1 2 3 4 5 6 7

During last week did you do light bait fishing or the regular bait fishing? Light Regular Both

Did you consider the bait fishing to be: Poor Average Good

How does bait fishing compare to before the tsunami? Poorer Similar Better

What species of bait did you catch (can be more than one)

Rehi Hondeli Miyren Thaavalha Boadhi Muguraan Nilamehi Bureki

Which type of bait did you catch most? (Circle one)

Rehi Hondeli Miyren Thaavalha Boadhi Muguraan Nilamehi Bureki

Was your bait ground the same as before the tsunami? Y N

If "NO", why?

I've been relocated Poor catch Not the season for the species of bait

If a **"REEF FISHERMAN"**

What type of reef fishing do you do?

Shark Grouper Lobster Aquarium Behe-der-mer Other Reef Fishing

Are you a full time reef fishermen? Y N

Do you consider daily catch the same as before the tsunami? Y N

If the answer is "NO" why? Habitat damaged Fish has gone

Do you go to the same fishing grounds as before the tsunami? Y N

If "NO" why? No good fishing on our regular fishing ground relocated

What was your income last week? >500 501–1000 >1000

What was your income last week? <500 501–1000 >1000

What was your income last month >500 501–1000 >1000

What was your income last month <500 501–1000 >1000

If the fishing was poorer is it because? Poor visibility No bait habitat damaged

In the last week how many days did you go fishing. 1 2 3 4 5 6 7

Appendix 3.1

Details of location and sampling for each survey site

Atoll	site no.	Reef name	atoll position	aspect	method	latitude	longitude
Raa	1	Vaffushi	west	east	manta	5 37.790 N	72 51.771 E
Raa	1	Vaffushi	west	east	scuba	5 37.884 N	72 51.741 E
Raa	1	Vaffushi	west	east	scuba	5 37.884 N	72 51.741 E
Raa	2	Vaffushi	west	channel	manta	5 37.848 N	72 51.401 E
Raa	2	Vaffushi	west	channel	scuba	5 37.860 N	72 51.327 E
Raa	2	Vaffushi	west	channel	scuba	5 37.860 N	72 51.327 E
Raa	3	Vaffushi	west	west	manta	5 38.288 N	72 50.385 E
Raa	4	Tilin Faru	west	channel	manta	5 37.688 N	72 50.627 E
Raa	4	Tilin Faru	west	channel	scuba	5 37.697 N	72 50.623 E
Raa	4	Tilin Faru	west	channel	scuba	5 37.697 N	72 50.623 E
Raa	5	Tilin Faru	west	east	manta	5 36.394 N	72 50.627 E
Raa	5	Tilin Faru	west	east	scuba	5 36.332 N	72 50.478 E
Raa	5	Tilin Faru	west	east	scuba	5 36.332 N	72 50.478 E
Raa	6	Tilin Faru	west	west	manta	5 36.615 N	72 49.615 E
Raa	7	Kukulhudhoo	west	west	manta	5 29.023 N	72 49.969 E
Raa	8	Kukulhudhoo	west	channel	manta	5 29.629 N	72 50.406 E
Raa	9	Kukulhudhoo	west	east	manta	5 28.366 N	72 51.956 E
Raa	10	Fenfushi	west	channel	manta	5 23.855 N	72 53.073 E
Raa	10	Fenfushi	west	channel	scuba	5 23.871 N	72 53.063 E
Raa	10	Fenfushi	west	channel	scuba	5 23.871 N	72 53.063 E
Raa	11	Fenfushi	west	channel	manta	5 22.852 N	72 53.871 E
Baa	1	Hanifarurah	east	east	manta	5 10.6 N	73 9.634 E
Baa	2	Hanifarurah	east	channel	manta	5 10.199 N	73 9.13 E
Baa	3	Hanifarurah	east	west	manta	5 11.053 N	73 8.243 E
Baa	4	Maabeyrufaru	east	east	manta	5 14.29 N	73 11.707 E
Baa	5	Maabeyrufaru	east	channel	manta	5 12.629 N	73 11.231 E
Baa	6	Anga	central	east	manta	5 10.829 N	73 6.472 E
Baa	7	Anga	central	west	manta	5 11.360 N	73 4.817 E
Baa	8	Honubadhoo	central	west	manta	5 9.885 N	73 3.114 E
Baa	9	Dhigu	central	east	manta	5 9.556 N	73 4.571 E
Baa	10	Dhigu	central	west	manta	5 10.58 N	73 3.858 E
Baa	11	Nelivaru	east	west	manta	5 7.420 N	73 4.994 E
Baa	12	Nelivaru	east	channel	manta	5 7.317 N	73 6.076 E
Baa	12	Nelivaru	east	west	scuba	5 7.420 N	73 4.994 E
Baa	12	Nelivaru	east	west	scuba		
Baa	13	Nelivaru	east	east	manta	5 7.257 N	73 6.103 E
Baa	14	Eydhafushi	east	west	manta	5 6.175 N	73 3.838 E
Baa	14	Eydhafushi	east	west	scuba	5 6.349 N	73 4.971 E
Baa	14	Eydhafushi	east	west	scuba		
Baa	15	Eydhafushi	east	east	manta	5 6.073 N	73 4.639 E
Baa	16	Kalhunaiboli	east	west	manta	5 2.895 N	73 0.005 E
Baa	17	Kalhunaiboli	east	channel	manta	5 2.254 N	72 59.171 E

Atoll	site no.	Reef name	atoll position	aspect	method	latitude	longitude
Baa	18	Kalhunaiboli	east	east	manta	5 2.193 N	73 0.502 E
Baa	18	Kalhunaiboli	east	east	scuba		
Baa	18	Kalhunaiboli	east	east	scuba		
Baa	19	Maa (south)	west	east	manta	5 6.357 N	72 50.815 E
Baa	20	Maa (south)	west	east	manta	5 5.555 N	72 50.173 E
Baa	20	Maa (south)	west	east	scuba	5 5.569 N	72 50.171 E
Baa	20	Maa (south)	west	east	scuba	5 5.569 N	72 50.171 E
Baa	21	Maa (south)	west	west	manta	5 4.933 N	72 49.082 E
Baa	22	Maa (south)	west	west	manta	5 7.779 N	72 49.419 E
Baa	22	Maa (south)	west	west	scuba	5 8.570 N	72 49.655 E
Baa	22	Maa (south)	west	west	scuba	5 8.570 N	72 49.655 E
Baa	23	Maahuruvalhi	west	west	manta	5 9.971 N	72 50.627 E
Baa	24	Maahuruvalhi	west	west	manta	5 12.424 N	72 50.827 E
Baa	24	Maahuruvalhi	west	west	scuba	5 11.827 N	72 50.780 E
Baa	24	Maahuravalhi	west	west	scuba	5 11.827 N	72 50.780 E
Baa	25	Maahuruvalhi	west	east	manta	5 11.746 N	72 51.801 E
Baa	25	Maahuravalhi	west	east	scuba	5 11.750 N	72 51.80 E
Baa	25	Maahuravalhi	west	east	scuba	5 11.750 N	72 51.80 E
Baa	26	Hanikandu	west	west	manta	5 18.446 N	72 53.635 E
Baa	27	Hanikandu	west	east	manta	5 17.922 N	72 54.703 E
Baa	27	Hanikandu	west	east	scuba	4 18.069 N	72 55.008 E
Baa	27	Hanikandu	west	east	scuba	4 18.069 N	72 55.008 E
Baa	28	Boatu Urunu	central	west	manta	5 12.638 N	72 54.548 E
Baa	29	Boatu Urunu	central	east	manta	5 12.630 N	72 55.406 E
Baa	30	Nibiligaa	central	west	manta	5 10.107 N	72 57.154 E
Baa	31	Nibiligaa	central	east	manta	5 10.061 N	72 57.920 E
Baa	32	Borangali	central	east	manta	5 8.062 N	73 0.657 E
Baa	33	Borangali	central	west	manta	5 8.686 N	72 59.776 E
Baa	33	Borangali	central	east	scuba	5 8.063 N	73 0.674 E
Baa	33	Borangali	central	east	scuba	5 8.063 N	73 0.674 E
Baa	34	Kalhunaiboli	east	east	scuba	5 2.144 N	73 0.470 E
Baa	34	Kalhunaiboli	east	east	scuba	5 2.144 N	73 0.470 E
South Male	1	Finolhu Faru	East	East	5 min swim	04.06.273 N	73.31.886 E
South Male	2	Guraidhoo Kandu	East	Channel	scuba	03.53.5 N	073.28.0 E
South Male	2	Guraidhoo Kandu	East	Channel	manta	03.53.640 N	73.27.642 E
South Male	3	Guraidhoo Kandu	East	Channel	manta	03.53.437 N	073.27.948 E
South Male	4	Gulhee Uthuru Kandu	East	Channel	manta	04.00.016 N	073.30.149 E
South Male	5	Gulhi Faru	East	West	scuba	03.59.6 N	073.30.1 E
Vaavu	1	Raiyganduhulhamgu Kandu	West	Channel	manta	03.25.633 N	073.22.324 E
Vaavu	2	Raiyganduhulhamgu Kandu	West	Channel	manta	03.25.785 N	073.22.087 E
Vaavu	3	Raiyganduhulhamgu Kandu	West	Channel	manta	03.25.802 N	073.22.154 E
Vaavu	4	Foththeyo Muli	East	West	scuba	03.29.4 N	073.42.00 E
Vaavu	4	Foththeyo Muli	East	West	manta	03.26.762 N	073.45.225 E

Atoll	site no.	Reef name	atoll position	aspect	method	latitude	longitude
Vaavu	5	Foththeyo Muli	East	West	manta	03.26.525 N	073.45.077 E
Vaavu	6	Foththeyo Muli	East	East	manta	03.29.788 N	073.44.718 E
Vaavu	7	Foththeyo Muli	East	East	manta	03.30.311 N	073.44.381 E
Vaavu	8	Hurahu Kandu	East	Channel	manta	03.28.764 N	073.42.158 E
Vaavu	9	Dhiggaru Fahlu	East	East	manta	03.29.213 N	073.41.778 E
Vaavu	10	Keyodhoo Maa Kandu	East	Channel	scuba	03.28.20 N	073.33.10 E
Vaavu	10	Keyodhoo Maa Kandu	East	Channel	manta	03.27.864 N	073.33.394 E
Vaavu	11	Keyodhoo Kandu	East	Channel	manta	03.27.485 N	073.32.830 E
Vaavu	12	Vihamaafaru Falhu	East	East	manta	03.34.959 N	073.30.342 E
Vaavu	13	Dhevana (Miyaru) Kandu	East	Channel	scuba	03.34.80 N	073.30.2 E
Vaavu	13	Dhevana (Miyaru) Kandu	East	Channel	manta	03.34.760 N	073.29.809 E
Vaavu	14	Kudadhiggaru Falhu	East	East	manta	03.34.844 N	073.30.341 E
Vaavu	15	Masaraa Falhu	West	Channel	scuba	03.37.8 N	073.22.0 E
Vaavu	15	Masaraa Falhu	West	Channel	manta	03.38.167 N	73.21.839 E
Vaavu	16	Masaraa Falhu	West	West	manta	03.38.619 N	073.21.763 E
Vaavu	17	Masaraa Falhu	West	East	manta	03.38.012 N	073.22.168 E
Vattaru	1	Vattaru Falhu	East	East	manta	03.14.115 N	073.27.877 E
Vattaru	2	Vattaru Falhu	East	Channel	manta	03.13.773 N	073.27.338 E
Vattaru	3	Vattaru Falhu	East	West	manta	03.13.421 N	073.25.866 E
Meemu	1	Kolhuvaariyaafushi Faru	East	East	manta	2.46.790 N	73.25.970 E
Meemu	1	Kolhuvaariyaafushi Faru	East	East	scuba	02.47.00 N	073.26.00 E
Meemu	2	Kolhuvaariyaafushi Faru	West	Channel	manta	2.45.502 N	73.22.782 E
Meemu	3	Kolhuvaariyaafushi Faru	East	West	manta	2.47.547 N	73.25.55 E
Meemu	3	Kolhuvaariyaafushi Faru	East	West	scuba	02.48.50 N	073.25.75 E
Meemu	4	Maausfushi Faru	East	West	manta	2.48.729 N	73.25.988 E
Meemu	5	Thuvarudhekunu Kandu	West	Channel	manta	2.53.667 N	73.22.834 E
Meemu	6	Thuvaru Faru	West	West	manta	2.54.125 N	73.22.444 E
Meemu	6	Thuvaru Faru	West	West	scuba	02.54.00 N	073.22.30 E
Meemu	7	Thuvaru Faru	West	West	manta	2.55.691 N	73.22.440 E
Meemu	8	Thuvaru Faru	East	East	manta	2.56.156 N	73.22.439 E
Meemu	9	Muli Faru	East	East	manta	2.55.149 N	73.35.184 E
Meemu	9	Muli Faru	East	East	scuba	02.54.25 N	073.34.10 E
Meemu	10	Muli Faru	East	West	scuba	02.55.00 N	073.35.25 E
Meemu	11	Dhiggaru Fahlu	East	Channel	scuba	03.06.75 N	073.34.25 E
Meemu	11	Dhiggaru Faru	East	Channel	manta	3.6.382 N	73.33.986 E
Meemu	12	Medufushi Faru	East	East	manta	2.53.679 N	73.35.110 E
Meemu	13	Muli Faru	East	Channel	manta	2.55.775 N	73.35.160 E
Meemu	14	Medufushi Faru	East	West	manta	2.53.129 N	73.33.778 E
Meemu	15	Naalaafushi Faru	East	West	swim	2.53.856 N	73.34.101 E
Meemu	16	Dhiggaru Faru	East	East	manta	3.6.966 N	73.34.166 E
Meemu	17	Dhiggaru Faru	East	East	manta	3.7.407 N	73.32.966 E
Laamu	1	Isdhoo Faru	East	East	swim	02 06.872 N	73 34.580 E
Laamu	2	Medhufinolhu Faru	East	East	swim	02 03.743 N	73 32.503 E
Laamu	3	Dhabidhoo Faru	East	West	swim	02 03.969 N	73 31.682 E
Laamu	4	Fushi Faru	East	Channel	swim	02 02.600 N	73 32.123 E
Laamu	5	Maabaidhoo Faru	East	Channel	swim	02 02.266 N	73 31.893 E
Laamu	5	Maabaidhoo Faru	East	East	swim	02 02.163 N	73 32.212 E
Laamu	7	Maabaidhoo Faru	East	Channel	swim	02 01.330 N	73 32.222 E

Atoll	site no.	Reef name	atoll position	aspect	method	latitude	longitude
Laamu	8	Kalhaidhoo Faru	East	West	swim	01 59.828 N	73 31.879 E
Laamu	9	Baresdhoo Faru	East	West	swim	01 58.553 N	73 32.002 E
Laamu	10	Maabaidhoo Faru	East	Channel	swim	02 01.132 N	73 32.250 E
Laamu	10	Maabaidhoo Faru	East	Channel	scuba	02 02.266 N	73 31.893 E
Laamu	11	Maabaidhoo Faru	East	East	scuba	02 02.163 N	73 32.212 E
Laamu	11	Kalhaidhoo Faru	East	East	swim	01 59.684 N	73 32.516 E
Laamu	12	Maabaidhoo Faru	East	Channel	scuba	02 01.330 N	73 32.222 E
Laamu	12	Maabaidhoo Faru	East	Channel	scuba	02 01.132 N	73 32.250 E
Laamu	12	Gan Faru	East	East	swim	01 55.081 N	73 33.105 E
Laamu	13	Gaadhoo Faru	East	Channel	scuba	01 49.218 N	73 26.202 E
Laamu	13	Gaadhoo Faru	East	Channel	swim	01 49.218 N	73 26.202 E
Laamu	14	Fonadhoo Fushi	East	West	scuba	01 49.963 N	73 29.308 E
Laamu	14	Fonadhoo Fushi	East	West	swim	01 49.963 N	73 29.308 E
Laamu	15	Maandhoo Faru	East	West	swim	01 52.316 N	73 31.030 E
Laamu	16	Unnamed Patch reef	Central	allround	swim	01 53.317 N	73 25.061 E
Laamu	17	Unnamed Patch reef	Central	allround	swim	01 55.023 N	73 23.627 E
Laamu	18	Bodumaabulhali Faru	West	East	swim	01 50.409 N	73 16.420 E
Laamu	19	Maavah Faru	West	Channel	swim		
Laamu	20	Maavah Faru	West	West	swim	01 53.049 N	73 14.127 E
Laamu	21	Munnafushi Faru	West	East	swim	01 58.597 N	73 17.725 E
Laamu	22	Ziyaaraiyfushi Faru	West	Channel	swim	01 59.831 N	73 19.099 E
Laamu	23	Vadinolhu Faru	West	West	swim	02 00.458 N	73 19.961 E
Thaa	1	Hiriyanfushi Faru	East	East	swim	02 13.042 N	73 10.058 E
Thaa	2	Veymandhoo Faru	East	Channel	swim	02 11.280 N	73 05.981 E
Thaa	3	Thimarafushi Faru	East	Channel	scuba	02 12.327 N	73 08.312 E
Thaa	3	Thimarafushi Faru	East	Channel	swim	02 12.327 N	73 08.312 E
Thaa	4	Hiriyanfushi and Usfushi Faru	East	West	swim	02 13.660 N	73 10.345 E
Thaa	5	Fenfushi Faru	East	West	scuba	02 17.787 N	73 16.317 E
Thaa	5	Fenfushi Faru	East	West	swim	02 17.787 N	73 16.317 E
Thaa	6	Maalefushi Faru	East	East	swim	02 18.521 N	73 18.348 E
Thaa	7	Kalhufahalafushi Faru	East	East	swim	02 26.479 N	72 21.363 E
Thaa	8	Kalhufahalafushi Faru	East	West	swim	02 26.100 N	73 20.870 E
Thaa	9	Vilufushi Faru	East	West	swim	02 29.583 N	73 18.582 E
Thaa	10	Vilufushi Faru	East	East	swim	02 30.230 N	73 19.135 E
Thaa	11	Olhugiri Faru	East	Channel	swim	02 30.181 N	73 16.128 E
Thaa	12	Dhiffushi Faru	East	West	swim	02 31.243 N	73 12.978 E
Thaa	13	Kandoodhoo Faru	West	West	swim	02 19.804 N	72 54.032 E
Thaa	14	Kandoodhoo Faru	West	Channel	swim	02 18.612 N	72 55.042 E
Thaa	15	Kandoodhoo Faru	West	East	swim	02 20.636 N	72 54.920 E

Appendix 3.2

Classes used for estimation of benthic cover and the incidence/abundance of tsunami damage indicators

Based on Australian Institute of Marine Science long term monitoring programme and English et al. 1997.

A – Presence/absence		B – 3 point. Low/High		C – 6 point. Area estimates		
Class	Desc	Class	Desc	Class	Range (%)	Desc
0	ABSENT	0	ABSENT	0	0	None
1	Present	1	Present/limited extent/severity	1	1-10	Low
				2	11-30	Medium
		2	Common/ extensive/ severe	3	31-50	Common
				4	51-75	High
				5	76-100	Extreme

Appendix 3.3

Fisheries questionnaire

Summary of coral reef survey data including estimates from broad-scale manta tow, snorkel swim and scuba swim surveys. Data is averaged over transects within sites. Atoll and site numbers coincide with those presented on figures 3.3 to 3.9 that present the sum of disturbances to coral communities and substrate that are listed separately here.

Atoll	Site	Reef	Aspect	Survey Method	Damage to living corals			Damage to reef substrates		
					Toppled	Broken	Smothered	Turned	Deposition	Excavation
Baa	1	Hanifarurah	east	manta	0	0	0	1.5	0	0
Baa	2	Hanifarurah	channel	manta	0	0	0	8	0	0
Baa	3	Hanifarurah	west	manta	0.5	2	0	5	0	0
Baa	4	Maabeyrufaru	east	manta	0	0.5	0	2.5	0	0
Baa	5	Maabeyrufaru	channel	manta	0.625	0	0	1.875	0	2.5
Baa	6	Anga	east	manta	0	0	0	2.5	0	0
Baa	7	Anga	west	manta	1	0	0	1	0	0.5
Baa	8	Honubadhoo	west	manta	0	0	0	8.125	0	0
Baa	9	Dhigu	east	manta	0.5	0.5	1.5	1.5	0.5	0.5
Baa	10	Dhigu	west	manta	0.5	0	0	11	0	0
Baa	11	Nelivaru	west	manta	0	0	0	0	0	0
Baa	12	Nelivaru	channel	manta	0	0	0	0	0	27.5
Baa	12	Nelivaru	west	Scuba 10m	0	0	0.25	0	0.5	0
Baa	13	Nelivaru	east	manta	0	1	0	2	0	3
Baa	14	Eydhafushi	west	manta	0	0	0	2.5	0	0
Baa	14	Eydhafushi	west	Scuba 10m	0	0	0.25	0	0	0
Baa	15	Eydhafushi	east	manta	0	0	0	8.5	0	2
Baa	16	Kalhunaiboli	west	manta	0	0	0	2.5	0	0
Baa	17	Kalhunaiboli	channel	manta	0	0	0	0	0.5	0
Baa	18	Kalhunaiboli	east	manta	0	0	0	0.5	0	0
Baa	18	Kalhunaiboli	east	Scuba 7m	0	0	0	0	0	0
Baa	18	Kalhunaiboli	east	Scuba 10m	0	0	0	0	0	0
Baa	19	Maa (south)	east	manta	0	0.5	0	3	0	9
Baa	20	Maa (south)	east	manta	0	0	0	0.5	9	0.5
Baa	20	Maa (south)	east	Scuba 7m	0	0	5.5	8	0	5
Baa	20	Maa (south)	east	Scuba 10m	0.5	0	1.5	1	0	0
Baa	21	Maa (south)	west	manta	0	0	0	0	0	0
Baa	22	Maa (south)	west	manta	0	0	0	0	36	0
Baa	22	Maa (south)	west	Scuba 7m	0	0	5	4	3	0
Baa	22	Maa (south)	west	Scuba 10m	0	0	1.5	0	0	0
Baa	23	Maahuruvalhi	west	manta	0	0	0	0	17	0
Baa	24	Maahuravalhi	west	Scuba 10m	0	0.5	0.5	0	0	0
Baa	24	Maahuruvalhi	west	manta	0	0	0	0	3.5	0
Baa	24	Maahuruvalhi	west	Scuba 7m	2	6.5	5.5	1	4	0
Baa	25	Maahuravalhi	east	Scuba 7m	29	26	5.5	20	62.5	17
Baa	25	Maahuravalhi	east	Scuba 10m	5	6.5	8.5	41	13.5	12.5
Baa	25	Maahuruvalhi	east	manta	36	45	0	20	0	87.5
Baa	26	Hanikandu	west	manta	0	0	0	0	0	0
Baa	27	Hanikandu	east	manta	0	0	0	0	4	0

Atoll	Site	Reef	Aspect	Survey Method	Damage to living corals			Damage to reef substrates		
					Toppled	Broken	Smothered	Turned	Deposition	Excavation
Baa	27	Hanikandu	east	Scuba 10m	0.5	0	1.5	0	0	0
Baa	28	Boatu Urunu	west	manta	0	0	0	0	0	0
Baa	29	Boatu Urunu	east	manta	0	0	0	0	0	12.5
Baa	30	Nibiligaa	west	manta	0	0	0	3.5	0	0
Baa	31	Nibiligaa	east	manta	0	0	0	0	1.5	0
Baa	32	Borangali	east	manta	0	0	0	2	17	0
Baa	33	Borangali	east	Scuba 7m	0.5	0	0	0.5	2	0
Baa	33	Borangali	east	Scuba 10m	0.5	0	1.5	1	25	0
Baa	33	Borangali	west	manta	0	0	0	1.5	52.5	0
Baa	34	Kalhunaiboli	east	Scuba 7m	0	0	0	0	0	0
Baa	34	Kalhunaiboli	east	Scuba 10m	0	0	0	0	0	0
Laamu	1	Isdhoo	East	swims	0	0	0	0	0	0
Laamu	2	Medhufinolhu	East	swims	0	0	0	0	0	0
Laamu	3	Dhabidhoo	West	swims	20	17.5	12	14.5	6.5	1.5
Laamu	4	Fushi	Channel	swims	2	0	0	5	0.5	0
Laamu	5	Maabaidhoo	Channel	swims	8.5	2.5	10.5	24.5	17	0
Laamu	5	Maabaidhoo	East	swims	0.5	0	0	0.5	0	0
Laamu	7	Maabaidhoo	Channel	swims	11.5	6.5	10	10.5	15	0
Laamu	8	Kalhaidhoo	West	swims	7	7.5	8	13.5	45	0
Laamu	9	Baresdhoo	West	swims	1.5	0.5	9.5	4.5	10.5	0
Laamu	10	Maabaidhoo	Channel	swims	2.5	0.5	2	6	29	0
Laamu	10	Maabaidhoo	Channel	Scuba 10m	2	1	0	5	1.5	0
Laamu	11	Kalhaidhoo	East	swims	2	3	0	3	0	0
Laamu	11	Maabaidhoo	East	Scuba 10m	0	0	0	0	0	0
Laamu	12	Gan	East	swims	0	0	0	0	0	0
Laamu	12	Maabaidhoo	Channel	Scuba 10m	3.25	1.75	4	13	7.25	0.25
Laamu	13	Gaadhoo	Channel	swims	2.5	0	0.5	29	0	0
Laamu	13	Gaadhoo	Channel	Scuba 10m	0.5	0	0	0	0.5	0.5
Laamu	14	Fonadhoo Fushi	West	swims	0.5	0	0	3.5	0	0
Laamu	14	Fonadhoo Fushi	West	Scuba 10m	1	0.5	2.5	2.5	0.5	0
Laamu	15	Maandhoo	West	swims	1	0.5	0	0	0	0
Laamu	16	Unnamed reef	allround	swims	0	0	0	0	0	0
Laamu	17	Unnamed reef	allround	swims	0	0	0	0	0	0
Laamu	18	Bodumaabulhali	East	swims	0	0	0	0	0	0
Laamu	19	Maavah	Channel	swims	1.25	0	3.75	13.75	13.75	0
Laamu	20	Maavah	West	swims	0	0	0	0	0	0
Laamu	21	Munnafushi	East	swims	0	0	0	0	0	0
Laamu	22	Ziyaaraiyfushi	Channel	swims	4.2	0	0	5.83	1.7	0
Laamu	23	Vadinolhu	West	swims	1.7	0.83	0	0	0	0
Meemu	1	Kolhuvaariyaafushi	East	manta	0.75	0.5	21.5	1.25	26.9	0
Meemu	1	Kolhuvaariyaafushi	East	Scuba 10-15	0.5	0	0	1	0	1
Meemu	2	Kolhuvaariyaafushi	Channel	manta	0	0	0	0	0	0
Meemu	3	Kolhuvaariyaafushi	West	manta	0	0	0	0	0	0
Meemu	3	Kolhuvaariyaafushi	West	Scuba 10-15	1.5	1	43	2.5	53.8	0
Meemu	4	Maausfushi	West		1.75	1.75	12.5	3.25	21.5	0.75
Meemu	5	Thuvarudhekunu Kandu	Channel		7.25	2.25	1.25	12	31.55	3.25
Meemu	6	Thuvaru	West		1	1.25	0	1.75	0.75	2

Atoll	Site	Reef	Aspect	Survey Method	Damage to living corals			Damage to reef substrates		
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Meemu	7	Thuvaru	West		0	0	0	0.75	0.75	0
Meemu	8	Thuvaru	East		0.25	0.25	0	12.75	11	2.5
Meemu	9	Muli	East		0.75	0.75	0.25	6.25	7.5	0
Meemu	9	Muli	East	Scuba 10-15	0	0	0	0	0	0
Meemu	10	Muli	West	Scuba 10-15	3.5	3.5	23	6.5	32	1.5
Meemu	11	Dhiggaru Fahlu	Channel	Scuba 10-15	2	1	0	24	8.5	6.5
Meemu	11	Dhiggaru	Channel		0.5	0.5	0	0	0	0
Meemu	12	Medufushi	East		0	0	0	2.5	6.5	6.5
Meemu	13	Muli	Channel		0	0.25	0	0	1	0
Meemu	14	Medufushi	West		0	0	0	0	1.875	0
Meemu	15	Naalaafushi	West		0	0	0	0	4	0
Meemu	16	Dhiggaru	East		0	0	0	0	20.5	0
Meemu	17	Dhiggaru	East		0	0	0	0	0	0
Raa	1	Vaffushi	east	manta	0	0.5	0	1	0.5	0
Raa	1	Vaffushi	east	Scuba 7m	1	0.5	0	1.5	0.5	0
Raa	1	Vaffushi	east	Scuba 10m	1	1	0	0.5	0	0
Raa	2	Vaffushi	channel	manta	0	0	0	0	0.5	0
Raa	2	Vaffushi	channel	Scuba 7m	0	0	0	0	2	0
Raa	2	Vaffushi	channel	Scuba 10m	0	0	0	0	0	0
Raa	3	Vaffushi	west	manta	0	0	0	0	0	0
Raa	4	Tilin	channel	manta	0.5	0	0	0	0	0
Raa	4	Tilin	channel	Scuba 7m	0	0	6.5	0	6.75	1.5
Raa	5	Tilin	east	manta	0	0	0	0	0.5	0
Raa	5	Tilin	east	Scuba 7m	1.5	2.5	0	1	6	0
Raa	5	Tilin	east	Scuba 10m	0.5	0	0.5	0	5	0
Raa	6	Tilin	west	manta	0	0	2	0	7.5	0
Raa	7	Kukulhudhoo	west	manta	0	0	0	0	0.5	0
Raa	8	Kukulhudhoo	channel	manta	3.5	3.5	0	9	0	16.2
Raa	9	Kukulhudhoo	east	manta	0	0	0	0	1.5	0
Raa	10	Fenfushi	channel	manta	0	0	0	0	12.5	0
Raa	10	Fenfushi	channel	Scuba 7m	0.5	0	7.5	2.5	33.8	3.5
Raa	10	Fenfushi	channel	Scuba 10m	0.5	0	5	0	1.5	0
Raa	11	Fenfushi	channel	manta	0	0	0	0	0	0
Sth Male	1	Finolhu	East	manta	1	0.75	0	1.25	0	0.5
Sth Male	2	Guraidhoo Kandu	Channel	manta	0	0	0.5	0	30.5	0
Sth Male	2	Guraidhoo Kandu	Channel	Scuba 10-15	0	0	0	5	13	13
Sth Male	3	Guraidhoo Kandu	Channel	manta	4.17	0	0	0	17	0
Sth Male	4	Gulhi Uthuru Kandu	Channel	manta	0	0	0	0	35	0
Sth Male	5	Gulhi	West	Scuba 10-15	0	0.5	0	0	2	0
Thaa	1	Hiriyanfushi	East	swims	0	0	0	0	0	0
Thaa	2	Veymandhoo	Channel	swims	0	0	0	8.75	0	0
Thaa	3	Thimarafushi	Channel	swims	0	0	0	12.5	0	0
Thaa	3	Thimarafushi	Channel	Scuba 10m	0.5	0	0.5	1	0	0
Thaa	4	Hiriyanfushi	West	swims	0	0	0.5	3	0	0
Thaa	5	Fenfushi	West	swims	1.5	1.5	4	8.5	7.5	1
Thaa	5	Fenfushi	West	Scuba 10m	1.7	0.8	1.7	7.5	1.7	0
Thaa	6	Maalefushi	East	swims	0	0	0	0	0	0
Thaa	7	Kalhufahalafushi	East	swims	0	0	0	0	0	0

Atoll	Site	Reef	Aspect	Survey Method	Damage to living corals			Damage to reef substrates		
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Thaa	9	Vilufushi	West	swims	6.5	35	8	7.5	55.3	2
Thaa	10	Vilufushi	East	swims	0.5	0	0	2	0	0
Thaa	11	Olhugiri	Channel	swims	17	3.5	9.5	5	57.8	0
Thaa	12	Dhiffushi	West	swims	0	2	3.5	2.5	4	4
Thaa	13	Kandoodhoo	West	swims	0	0	0	0	0	0
Thaa	14	Kandoodhoo	Channel	swims	0	0	0	0	0	0
Thaa	15	Kandoodhoo	East	swims	3.5	16.5	7	14.5	4.5	1.5
Vaavu	1	Raiyganduhulhamgu Kandu	Channel	manta	18	3	11.5	12	23.5	0
Vaavu	2	Raiyganduhulhamgu Kandu	Channel	manta	1.5	0	0	0	38.6	0
Vaavu	3	Raiyganduhulhamgu Kandu	Channel	manta	0	1	0	0	3	0
Vaavu	4	Foththeyo Muli	West	manta	0.5	0	0	0	53	0
Vaavu	4	Foththeyo Muli	West	Scuba 10-15	2	2.5	0	3.5	1.5	4
Vaavu	5	Foththeyo Muli	West	manta	0	0.5	3	0	9.5	0
Vaavu	6	Foththeyo Muli	East	manta	0	0	0	0	1.5	0
Vaavu	7	Foththeyo Muli	East	manta	0	0	0	0	0	0
Vaavu	8	Hurahu Kandu	Channel	manta	0	0	0	0.5	0	0
Vaavu	9	Dhiggaru Fahlu	East	manta	0	0	0.5	0	18	0
Vaavu	10	Keyodhoo Maa Kandu	Channel	manta	0.5	0	0	0.5	3	0
Vaavu	10	Keyodhoo Maa Kandu	Channel	Scuba 10-15	0	0	0	1.5	1.5	0
Vaavu	11	Keyodhoo Kandu	Channel	manta	0	0	0	0	2	0
Vaavu	12	Vihamaafaru Falhu	East	manta	0.625	0	0	0	19.375	0
Vaavu	13	Dhevana (Miyaru) Kandu	Channel	manta	0.5	0	0	0	0	0
Vaavu	13	Dhevana (Miyaru) Kandu	Channel	Scuba 10-15	0.5	0.5	0	25.5	21	5
Vaavu	14	Kudadhiggaru Falhu	East	manta	0	0	0.5	0	16.5	0
Vaavu	15	Masaraa Falhu	Channel	manta	0	0	0	0	0	0
Vaavu	15	Masaraa Falhu	Channel	Scuba 10-15	0.5	1.5	0.5	12.5	15	0
Vaavu	16	Masaraa Falhu	West	manta	0	0	0	0	1.7	0
Vaavu	17	Masaraa Falhu	East	manta	0	0	0.5	0	0	0
Vattaru	1	Vattaru Falhu	East	manta	0	0	0	0	0	0
Vattaru	2	Vattaru Falhu	Channel	manta	0	0	0	0	3	0
Vattaru	3	Vattaru Falhu	West	manta	1	0	0.5	0	20.3	0