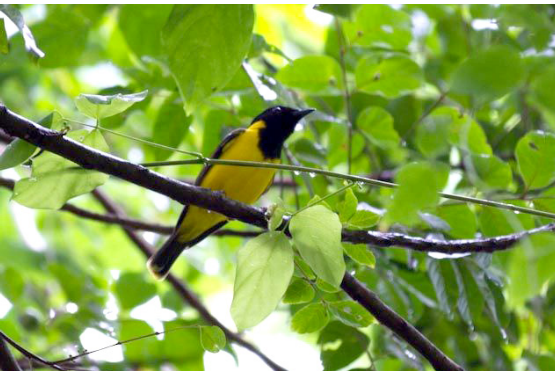
RAPID BIODIVERSITY ASSESSMENT OF THE VAVA´U ARCHIPELAGO, KINGDOM OF TONGA

FEBRUARY 2014



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RAPID BIODIVERSITY ASSESSMENT OF THE VAVA´U ARCHIPELAGO, KINGDOM OF TONGA

2014

J.N. ATHERTON, S.A. MCKENNA AND A. WHEATLEY

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ORGANISATIONAL PROFILES

BIRDLIFE INTERNATIONAL PACIFIC PARTNERSHIP

BirdLife International is a global network of 117 national NGOs (partners) – including seven in the Pacific – whose mission is "to conserve wild birds, their habitats and global biodiversity, working with people towards sustainability in the use of natural resources".

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MEIDECC is the Tongan Government's newest ministry, established on 1 July 2014. The new ministry brings together the Departments of Environment, Energy, Climate Change, Disaster National Emergency Management Office (NEMO), Meteorology, and Information and Communications, which were formerly under three different ministries. The ministry is committed to ensure the protection and proper management of the environment and the promotion of sustainable development for Tonga's present and future generations.

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For more information visit: www. doc. govt. nz/

SECRETARIAT OF THE PACIFIC REGIONAL ENVIRONMENT PROGRAMME (SPREP)

The Secretariat of the Pacific Regional Environment Programme (SPREP) has been charged by the governments and administrations of the Pacific region with the protection and sustainable development of the region's environment. SPREP is based in Apia, Samoa, with over 90 staff.

SPREP's activities are guided by its Strategic Action Plan 2011–2015, which was developed through extensive consultations with members, Secretariat staff and partner organisations. The plan establishes four strategic priorities, which form the basis and focus of SPREP's work: Climate change; Biodiversity and ecosystem management; Waste management and pollution control; and Environmental monitoring and governance. SPREP is actively engaged as a partner in many environmental management and conservation projects in the region such as this biodiversity assessment of Vava'u, as well as similar assessments done in upland Savaii (2012) and Nauru (2013).

For more information visit: www. sprep. org/

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As the United States' largest water, earth, and biological science and civilian mapping agency, the USGS collects, monitors, analyses, and provides scientific understanding about natural resource conditions, issues and problems. The diversity of our scientific expertise enables us to carry out large-scale, multi-disciplinary investigations and provide impartial scientific information to resource managers, planners, and other customers at home and overseas.

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VAVA'U ENVIRONMENTAL PROTECTION AGENCY

The Vava'u Environmental Protection Association (VEPA) is a Vava'u based NGO actively engaged in the conservation of Vava'u's natural resources. VEPA was incorporated as a national society in the Kingdom of Tonga in January of 2010 and is governed by a local board.

VEPA's programmes are run in accordance with our Strategic Action Plan 2012–2017, with an annual activities plan coordinating projects under our three defined areas of work: Biodiversity and conservation, Resource development, and Education and awareness. Our projects span all areas of the environment including the conservation and rehabilitation of marine and terrestrial species and ecosystems, climate change adaptation and waste management, with a large focus on ecosystem based adaptation through community conservation projects, awareness and school programmes.

VEPA works closely with the Government of the Kingdom of Tonga and partners with other Pacific Island organisations.

For more information visit: www. vavauenvironment. org

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This project was designed and implemented by staff of the Secretariat of the Pacific Regional Environment Programme (SPREP), the former Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR) of the Government of Tonga (since restructured as the Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC)) and the Vava'u Environmental Protection Agency (VEPA). Key logistical personnel were Bruce Jefferies and Paul Anderson (SPREP), Lupe Matoto and Winnie Veikoso (MEIDECC), and Karen Stone and Kate Walker (VEPA). We thank the following organisations for providing personnel for the RAP survey: the MEIDECC, the Ministry of Lands and Natural Resources (MLNR), the Ministry of Agriculture, Food, Forestry and Fisheries (MAFFF), VEPA, the Department of Conservation (NZ), the Birdlife Pacific Partnership, and the US Geological Survey. We thank the staff of the Port Wine Guest House in Neiafu for being such gracious hosts to so many sweaty scientists. We also thank the captains and crew of *Whale Song*, *Dev Ocean* and *Tin Cup* for getting us safely and cheerfully to and from the survey sites. All maps were produced by James Atherton, Paul Anderson and Kate Walker.

The Vava'u BIORAP was a success due to the outstanding contributions of the following individuals, most of whom are affiliated to the above mentioned institutions: Adam Backlin, Ana Loiloi Fekau, Andrew Bauman, Anitelu Toe'api, Art Whistler, Bruce Jefferies, David Butler (Terrestrial Team Leader), Douglas Fenner, Easter Galuvao, Eric Edwards, Fiona Webster, Fred Brook, Halalilika 'Etika, Haunani Ngata, Hoifua 'Aholahi, James Atherton, Karen Stone, Kate Walker, Lupe Matoto, Mael Imirizaldu, Marc Oremus, Mark O'Brien, Michael Donoghue, Paul Anderson, Penikoni Aleamotu'a, Saia Fonokalafi, Samuela Pakileata, Senituli Finau, Sheila McKenna (Marine Team Leader), Sione Mailau, Sione Tukia Lepa, Siosina Katoa, Tevita Fonokalafi, Tevita Taufa, Tonga Tu'iano, Viliami Hakaumotu and Winnie Veikoso.

We would like to express our particular gratitude to theTongan field team, for their indispensable help, good humour and enthusiasm throughout the survey. The future of biodiversity in Tonga is in safe hands. *Malo aupito!*

FOREWORD

This report presents the results and recommendations of a Biological Rapid Assessment Programme (BIORAP) carried out in the marine and terrestrial environments of the Vava'u Archipelago, Tonga, from 13 to 28 February 2014. Vava'u lies within the Polynesia–Micronesia Biodiversity Hotspot defined by Conservation International, which includes areas with significant biodiversity that are also highly threatened.

The overall purpose of the Vava'u BIORAP was to improve the state of knowledge of marine and terrestrial biodiversity, which in turn provides a scientific basis for the conservation and management of nationally, regionally and globally important ecosystems and biodiversity, including threatened species. The BIORAP process focusses on the identification of areas of conservation value, the investigation of opportunities for establishing marine and terrestrial protected areas, and the training of local scientists in biodiversity survey techniques.

This BIORAP was one of the activities for Tonga in the sub-regional project *Implementing the Island Biodiversity Programme of Work by Integrating the Conservation Management of Island Biodiversity* which is funded under the Global Environment Facility (GEF) programme *Pacific Alliance for Sustainability* (fourth replenishment funding round). Other countries included in the project are the Cook Islands, Nauru and Tuvalu. The United Nations Environment Programme(UNEP) and the Secretariat of the Pacific Regional Environment Programme (SPREP) are the implementing and executing agencies for this project, respectively.

Successful implementation of the BIORAP was made possible by the development of a strong partnership between SPREP, the Government of Tonga's new Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC), the Vava'u Environmental Protection Agency (VEPA) and the Waitt Foundation. Partnerships developed with land owners, local business operators and communities in the surveyed sites were also critical to BIORAP implementation.

This partnership enabled a team of more than 17 international specialists from a diverse range of institutions including the New Zealand Department of Conservation, BirdLife International Pacific Programme, SPREP, and the US Geological Survey to work alongside 18 Tongan government staff and civil society participants to successfully complete the survey.

The findings of this BIORAP survey have identified or reconfirmed the critical importance of the biodiversity and ecosystems of Vava'u's terrestrial and marine environments and the urgent need for follow-up activities to manage and mitigate threats for their conservation. This report provides a useful and pragmatic series of conclusions and recommendations that provide practical guidelines for the development of follow-up activities to support and inform national planning processes, such as the Tonga State of Environment report and the review of the *National Biodiversity Strategy and Action Plan*.

The challenge that faces the Government of Tonga and its partners is to ensure that the outcomes of the BIORAP survey along with the recommendations are translated into positive on-the-ground (and in-the- sea) action. Both SPREP and the Tongan Government believe the 'translation into action' is the key for the long-term success of the BIORAP process.

We commend all of the individuals and organisations that collaborated to carry out the field survey work and who contributed to this report. SPREP and the Government of Tonga are committed to continue to work together to ensure areas of significant biodiversity and ecosystem value of the Vava'u islands are established, well managed and protected for the long-term benefit of all.

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Lord Fulivai
Govenor of Vava'u

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Director-General
Secretariat for the Pacific Regional
Environment Programme

EXECUTIVE SUMMARY

The Biological Rapid Assessment Programme (BIORAP) is a biological survey based on a concept developed by Conservation International and designed to use scientific information to catalyse conservation action. BIORAP methods are designed to rapidly assess the biodiversity of highly diverse areas and to train local scientists in biodiversity survey techniques.

The BIORAP can be considered a spatial and temporal 'snapshot' of Vava'u's full range of biodiversity. The survey did not visit all sites of conservation value in the archipelago and was conducted over a relatively short period of 16 days. Nevertheless, the BIORAP is the most comprehensive biological survey conducted in Vava'u to date, and generated a huge volume of useful information on the biodiversity of the archipelago.

Up-to-date information on terrestrial and marine biodiversity, and threats to it, is crucial for conservation planning and management. However, in the case of Vava'u, no systematic conservation assessment of both marine and terrestrial conservation values had been conducted before the BIORAP. While many biological surveys have been conducted in Vava'u in the past, there had never been a comprehensive and multi-disciplinary assessment of marine and terrestrial biodiversity in the island group.

The Vava'u BIORAP was identified as a key national priority by the Government of Tonga, who approached the Secretariat of the Pacific Regional Environment Programme (SPREP) for assistance to coordinate the project under the Global Environment Facility (GEF)-supported *Integrated Islands Biodiversity Project* (IIBP), which includes the Cook Islands, Nauru, Tonga and Tuvalu. The IIBP is a US$4.5 million project (US$1.7 million from GEF) being implemented from 2012 to 2015 by SPREP in collaboration with the governments and non-governmental organisation (NGO) partners in the four project countries. The project assists the countries to implement their commitments under the Convention on Biological Diversity (CBD)'s Island Biodiversity Program of Work (IBPOW).

The Vava'u BIORAP was conducted from 13 to 28 February 2014. The survey involved 17 scientists and 18 Tongan Government staff. Fourteen islands were visited over the 16 days of the survey. The terrestrial survey involved assessments of land and sea birds, bats, plants, reptiles, land snails and insects while the marine survey included assessments of coral reef fish and commercial fish, corals and other marine invertebrates, sea turtles and cetaceans. The BIORAP was coordinated by SPREP, the Tongan Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR), which due to a recent restructure is now called the Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC), the Vava'u Environmental Protection Association (VEPA) and the Waitt Foundation.

Main findings

The main findings of the BIORAP for each taxonomic group are described below.

PLANTS

- The plant survey team visited 17 sites on 11 islands and also established nine plots where all the trees over 5 cm dbh (diameter at breast height) were measured. The data were then collated into tables showing the relative dominance of the component species.
- The flora of Vava'u was determined (from the BIORAP and previous surveys) to comprise about 262 native vascular plant species, divided into 188 dicots, 39 monocots, two gymnosperms, 30 ferns, and three fern allies. Eight Tongan endemic species are found in Vava'u, two of them endemic to Vava'u – *Atractocarpus crosbyi* and *Casearia buelowii*.
- Twelve new native species were recorded for Vava'u, including one new record for Tonga, *Boerhavia albiflora* (Nyctaginaceae). One endemic species, *Phyllanthus amicorum*, was previously known only from 'Eua. Additionally, 42 new weed species were recorded for Vava'u, 18 of them new for Tonga.
- Of the 262 native vascular plant species, 62 were not found during the present survey. Fourteen of the 62 have not been collected in Vava'u since 1892.
- Twenty-two plants identified as rare in Vava'u are reported from Vava'u, and 14of these were found during the present survey.
- About 180 voucher specimens were collected and distributed to various herbaria.

- Seven plant communities were recognised: (1) littoral strand; (2) coastal marsh; (3) mangrove forest; (4) lowland forest; (5) managed land; (6) successional vegetation; and (7) secondary forest. Very little undisturbed lowland forest was found.
- Key forest areas recommended for conservation include Mt Talau, Mo'ungalafa, Utula'aina and Utungake on 'Uta Vava'u, as well as Maninita, 'Euakafa and 'Oto islands.

REPTILES

- The reptile survey included inventories on 13 of 58 islands within the Vava'u island group, five of which had no previous reptile information – Kenutu, Maninita, 'Oto, Taula and 'Umuna.
- Fifteen sticky trap transects spanning 4.2 km and ten islands were sampled.
- Twenty-four visual encounter surveys were conducted for diurnal and nocturnal species, covering 22.3 km.
- A total of 417 terrestrial reptiles were recorded representing 11 species of lizard.
- The first record of the invasive common house gecko (*Hemidactylus frenatus*) within the Vava'u island group was collected.
- Twenty-nine new island species records were collected for reptiles across the Vava'u island group.
- No snakes or amphibians were detected.
- It is recommended that surveys be conducted for the Lau banded iguana across the Vava'u island group.
- The main island of 'Uta Vava'u has the most reptile diversity compared to the other islands in this group and is the highest priority island for reptile conservation in Vava'u.

BIRDS AND BATS

- The bird team visited 20 sites, six on Vava'u Island and 14 on other islands. Ten other islands were observed while passing by boat. Automatic bird recorders were set up at a few sites to supplement the team's observations. Five days of boat surveys were carried out at sea alongside the cetacean and sea turtle survey.
- A total of 38 species was recorded.
- The Tongan whistler (*Pachycephala jacquinoti*), endemic to the Vava'u group, was widespread in and near to areas of primary forest and is not considered under immediate threat.
- The blue-crowned lory (*Vini australis*), which had not been recorded on Vava'u for over 100 years, was found at two sites.
- The friendly ground dove (*Gallicolumba stairii*), which had been found at only one site during surveys in 1995/96, was located on three islands in this survey.
- Islands in the south of the group were found to hold very large numbers of seabirds, particularly nesting noddies (*Anous* spp.) and white terns (*Gygis alba*).
- At least two of the three islands subject to rat control programmes in 2002 appeared to be free of these mammals though a further follow-up is recommended.
- One invasive species, the red-vented bulbul (*Pycnonotus cafer*), was recorded but it seems confined to Utu Vava'u and has not reached significant numbers there.
- The avifauna team also made observations of bats. No sightings were made of the endangered Polynesian sheath-tailed bat (*Emballonura semicaudata*). Small colonies of the insular or Pacific flying fox (*Pteropus tonganus*) were seen on many of the small forested islands and larger colonies on 'Uta Vava'u with up to 250 bats present.
- Sites significant for rare landbirds include Moungalafa on 'Uta Vava'u, 'Euakafa Island and A'a and 'Oto islands.
- Sites significant for seabirds include Maninita, Taula and Lualoli islands, the northern cliffs of 'Uta Vava'u, and some of the other southern islands (e.g. Luahaipo and Lualui).

MOTHS, BUTTERFLIES, ANTS AND DRAGONFLIES

- One hundred and ninety-two moths and butterflies (Lepidoptera), 19 ant species (Hymenoptera) and seven dragonflies (Odonata) were recorded in the survey.
- Micro-moth species remain unanalysed with many being cryptic undescribed species. Many macro-moth species (in 14 families) are new records for Tonga of moths known widely in the region.
- Four ant species are new records signalling exotic ant invasion is ongoing for Vava'u (and Tonga) since last reported in 2002.
- Exotic yellow paper wasp (*Polistes olivaceus*) occupies the entire archipelago and during the survey appeared likely to be impacting species and ecosystem values as reported elsewhere for invasive social wasps.
- The Tongan leafwing butterfly (*Doleschallia tongana tongana*) was not recorded in this survey or in another recent survey for Vava'u. The status of the butterflies likely host plant *Graptophyllum insularum* (Acanthaceae), potential range contraction, and the threatened species status of the leafwing butterfly in Tonga should all be assessed.
- The Fiji glasswing (*Acraea andromacha polynesiaca*) is said to be a regional endemic subspecies hosted on native *Passiflora*. Neither the butterfly nor its plant host have been recorded for many years in Fiji, Tonga or Samoa. The butterfly may well be extinct in Tonga and its threat status could be tentatively assigned extinct. The native passion vine should also have its threat status assessed.
- On the basis of native insect and also snail values some sites of remnant natural character on 'Uta Vava'u are worthy of conservation. Sites are associated with slopes, northern coastal bluffs, coastal littoral sites and exposed roughened limestone surfaces.
- Maninita Island has some distinctive insect associations likely associated with both its abundance of seabirds and current lack of rodents. This and other seabird dominated islands – particularly those without rodents – have additional conservation value for the invertebrate component of ecosystems.
- More comprehensive surveys of ant distributions and insect associations at recommended sites for conservation and also on outlying islands including Late and Fonualei would add insight to the developing picture of faunal values and invasion threats.

LAND SNAILS

- The extant land snail fauna of native forest remnants was surveyed at 23 sites in Vava'u, including 15 sites on the largest island, 'Uta Vava'u, and single sites on the smaller islands of 'Euaiki, Euakafa, Kulo, Maninita, Pangaimotu, Taula, Tuita and Vaka'eitu.
- Live snails and/or fresh empty shells of 41 terrestrial snail species were found, including two species endemic to Vava'u, three species endemic to Tonga, seven regionally endemic species known from Tonga and one or more adjacent island groups in the tropical southwest Pacific, 12 widely distributed Pacific species, and 12 extra-Pacific species native to Africa, Asia or the Americas.
- One endemic species, *Sinployea paucicosta*, was relatively widely distributed and locally common in native forest remnants on 'Uta Vava'u, and is assessed here as having an International Union for Conservation of Nature (IUCN) threat ranking of Critically Endangered. A second endemic species, *Sturanya culminans*, was common locally at a few sites only. It has evidently undergone a marked recent decline on 'Uta Vava'u, and is also assessed as having an IUCN threat ranking of Critically Endangered.
- No live snails or fresh shells were found of three other land snail species endemic to Vava'u, namely *Lamprocystis vavauensis*, *Thaumatodon vavauensis* and *Tuimalila infundibulus*. These species presumably now have highly restricted distributions on Vava'u and are Critically Endangered, or have gone extinct.
- Four areas of native forest that are of particular importance for land snail conservation on 'Uta Vava'u are identified: bluffs on Mo'ungalafa; coastal cliffs at Talehele northwest of Leimatu'a village; coastal flats, terraces and hillslopes east of Utula'aina Point; and the coastal flat and adjacent hillslopes at Vai-utu-kakau on the northeastern coast.
- Other important forest remnants on 'Uta Vava'u that were not surveyed during the present study, and which may contain relict populations of endemic land snail species, include: steep coastal slopes and inland bluffs north of Longomapu village; coastal slopes northeast of Longomapu; coastal cliffs west and north of Leimatu'a village; steep coastal slopes on the western and eastern sides of Utula'aina Point; steep coastal slopes on the western side of Mata'utuliki Point; and the

southern end of the peninsula south of Makave village. It is recommended that land snail surveys be carried out in these areas, as well as on the small, relatively unmodified cliff-girt islands of Kitu and Luamoko, and the outlying volcanic islands of Late, Fonualei and Toku.

- Effective biosecurity controls will be necessary to prevent highly invasive, exotic agricultural and ecological pest species such as the giant African snail (*Achatina fulica*) and the rosy wolf snail (*Euglandina rosea*) from becoming established in Vava'u and elsewhere in Tonga.
- The four most important locations for land snails identified during the present study are all on the main island of 'Uta Vava'u. They are, in order of priority, the native forest remnants at: the coastal cliffs northwest of Leimatu'a village; Vai-utu-kakau (north eastern coast of 'Uta Vava'u); the bluffs encircling Mo'ungalafa; and the headland east of Utula'aina.

STONY REEF CORALS

- Twenty-five dives were undertaken throughout the Vava'u Archipelago and on the adjacent island of Fonualei and coral reef diversity and health assessed.
- The reefs of the Vava'u group have a good diversity of hard corals, with a mean of 55 species per dive site and a total of 206 species in 55 genera observed during the 25 dives in this brief survey.
- The number of species found per dive site was similar to that in New Caledonia, Fiji and American Samoa. The total number of corals found in 25 dives was more in Tonga than in American Samoa, higher still in Fiji, and highest in New Caledonia. This is consistent with the well-known longitudinal diversity gradient in the Pacific, and Tonga appears to have exactly the diversity that would be predicted based on its location in the gradient.
- The sites with the greatest numbers of coral species were site 26 with 80 species, site 16 with 79 species, site 25 with 74 species, site 18 with 72 species, and site 15 with 70 species.
- Reef sites which were moderately exposed to waves had the highest number of coral species, followed in descending order by exposed reefs, sheltered reefs, limestone drop-offs and volcanic reefs.
- Site 16 had the highest Coral Replenishment Index, followed by sites 17, 15, and 19 in descending order. Site 1 had the highest Coral Rarity index, followed by sites 3, 25 and 2 in descending order. Site 16 had the highest combination of these two indices, followed by sites 1, 17 and 26 in descending order.
- A total of 197 species were found that had not been reported before from Vava'u, 95 species were found that had not been reported before from Tonga, and 67 species were recorded that represented extensions of their known biogeographic ranges.
- A total of 33 species were found that have been reported to have an elevated risk of global extinction, 17 species were found which have been proposed for listing under the US Endangered Species Act (ESA), and five species were found which were listed under the ESA.
- Conservation recommendations include the establishment of marine protected areas (MPAs), protecting the largest reef fish species throughout the country, signing the Convention on International Trade in Endangered Species (CITES), protecting sea turtles, and monitoring the reefs by repeating the benthic and fish transects annually.

MARINE MACROINVERTEBRATES

- A list of marine macroinvertebrate species was compiled for 27 coral reefs sites surrounding selected islands. The survey involved approximately 27 hours of scuba diving to a maximum depth of 35m.
- The survey included a separate rapid assessment of three commercially valuable marine invertebrate species (sea cucumbers, giant clams and trochus) conducted by representatives from the Tonga Ministry of Agriculture and Food, Forests and Fisheries.
- A total of 249 species from 146 genera were identified in the survey. This included representatives from 101 families, 39 orders and 17 classes across seven phyla.
- Phylum Mollusca accounted for the highest number of species recorded for all 27 sites assessed in the survey (96 species), while the Phylum Annelida accounted for the lowest number (two species).
- Species richness among sites ranged from 15 at site 4 (Fonualei island, north) to 38 species at site 22 (Euakafa Island, south), with an average of 28.7 (± 0.95 SE).

- Alcyoniidae and Holothuriidae were the two most prevalent families, occurring at 85% of the sites (23 of 27 sites).
- The most common species were two species of soft coral (Family Alcyoniidae): *Sarcophyton* sp. (23 sites) and *Lobophyton* sp. (22 sites).
- A total of 279 sea cucumbers was counted and 14 species of sea cucumbers were identified, with a maximum of eight species identified at site 21 ('Oto Island).
- The abundance of high and very high commercial value sea cucumber species was low, accounting for only 17% of the 279 individuals.
- Four species of giant clam (*Tridacna maxima*, *T. squamosa*, *T. derasa* and *T. crocea*) were recorded in the survey. The boring giant clam (*Tridacna crocea*) is a new species record for Tonga.
- The highest densities of clams were found on three sites around Toku Island (sites 6, 7 and 8). These sites accounted for nearly 60% of all clams counted in the survey.
- A total of 59 trochus (*Tectus nilotocus*) was recorded in the survey.
- Strong indications of overexploitation of both sea cucumbers and giant clam species were noted across sites in the survey.
- Conservation recommendations include: developing comprehensive invertebrate species lists that are regularly updated;ensuring adequate representation of all the major habitats when conducting future taxonomic surveys; development of conservation legislation and establishing MPAs to include highly diverse sites of macroinvertebrate species; reducing harvesting pressure on all sea cucumbers and giant clam species, and monitoring regularly; closure or temporary moratorium on harvesting all commercially valuable sea cucumbers; comprehensive stock assessment of both giant clam and trochus species around Vava'u; and developing awareness and education programmes on the importance of coral reefs and their associated flora and fauna, including marine macroinvertebrates.

CORAL REEF FISH

- A rapid assessment of coral reef fish was carried out around the Vava'u Archipelago at 25 sites during 25 hours of underwater visual observations while scuba diving. Reef fish over 5cm in length were recorded.
- Data were collected primarily on exposed, moderately exposed and sheltered fringe reefs. Each island, where possible, had two dives carried out, one leeward and one windward. All data were recorded from depths between 30m and 3m. Other critical habitats such as pelagic zones, mangrove forests and seagrass beds were not included in this study.
- A total of 406 species of reef fish was recorded during the survey period including one range extension for *Caseio lunaris*. No new species of fish were recorded and no collections of fish species were made.
- Reef fish fauna is dominated by Pomacentridae (57 species), Labridae (52 species), Chaetodontidae (31 species), Acanthuridae (31 species), Scaridae (22 species) and Serranidae (24 species).
- Low species numbers of piscivores and carnivores, including sharks, were recorded throughout the survey.
- The following conservation recommendations are made: reduce anthropogenic effects including the removal of mangroves, runoff and pollution of coastal areas; conduct seasonal closures of spawning grounds to protect Lutjanids and Serranids; design and implement marine managed areas and give research and data support to Special Managed Areas; implement protection for *Cheilinus undulates* and *Bolbometopon muricatum* including a moratorium on night spearfishing; develop alternative livelihood sources to reduce economic pressure faced by communities; develop environmental guidelines for tourism operators and visiting yachts on use of coral reef ecosystems; review current fishing practices and legislation including netting and spearfishing of important fish species; protect and monitor herbivorous species that control algae growth on reefs; and monitor and map climate change impacts on coral reef ecosystems.

TARGETED FISH SPECIES

- A total of 226 species (one not previously recorded) belonging to 75 genera and 34 families were identified at over 27 study sites.
- Targeted fish population of Vava'u appears to represent a composition quite common and representative of healthy coral reef ecosystems.
- Fish communities were highly dominated by the families of surgeonfishes (Acanthuridae) and parrotfishes (Scaridae). Families of snappers (Lutjanidae) and goatfishes (Mullidae) were poorly represented. Families of groupers (Serranidae),

snappers (Lutjanidae) and emperors (Lethrinidae) were underrepresented while sweetlips (Haemulidae) appear to be on the edge of local extinction for the reef sites surveyed.

- The structure of fish communities was unbalanced with a high rate of herbivore species and a very low rate of predators such as large carnivore species and piscivore species.
- For at least six species, no mature individual were observed. This means that all the individuals that were observed didn't yet reach the size were they can reproduce.
- Strong signs of overfishing were observed. There is an important need for management measures to ensure sustainable stock exploitation and food security overtime.
- The reef areas along the sites of Joe's Spit (Toku Island), Fangasito Island, Maninita Island and Euakafa Island were identified as priority conservation sites.
- The following recommendations are made: reduce fishing pressure and encourage good fishing practices; further protect reproduction as a critical ecological process to ensure stock recovery overtime; create protected areas that will allow resource recovery while benefitting adjacent fisheries through the spillover effect; implement support measures such as raising awareness and involving communities in the management of their resources, providing good incentives for alternative livelihoods and raising funds for conservation.

REEF CONDITION

- Twenty-seven sites were assessed for reef health. Reefs were grouped into six classifications based on exposure to swell and wave energy.
- Reef health was assessed based on percentage coral cover and the frequency of bleaching, disease, coral predators, physical damage and pollution.
- Coral cover was variable. The lowest cover was observed on volcanic reefs to the north of Vava'u (1.9%) and the highest on moderately exposed reefs in the south (70.6%).
- A coral bleaching event was just starting to occur at the time of survey, with 16 of the 27 sites showing signs. At each of the 16 sites less than 5% of the reef was affected but bleaching was likely to have intensified as the summer progressed. At the time of survey the water temperature was 29–30°C. It is recommended that prior to final decisions in regard to which reefs are to be protected as MPAs, the reefs are resurveyed for live coral cover and coral health.
- Predation by the crown of thorns starfish and the corallivorous snail *Drupella cornis* was generally low. Four sites had one or two crown of thorns starfish and two sites had slightly more.
- The urchin *Diadema* can indicate reef disturbance. Very high densities were observed at one site only.
- Generally the evidence of disease was low with no coral disease observed at 12 of the 27 sites. Symptoms consistent with white band disease were observed on one or two colonies at 12 sites.
- Physical damage to the reefs was negligible at all sites. Cyclone Ian which passed through Tonga in January 2014 appears to have had little impact, except at one site.
- Observations of rubbish and fishing debris were highest at the sites closest to the town of Neiafu. The incidence of rubbish was low at all other sites. One site showed evidence of eutrophication from septic tanks associated with a nearby tourist resort.
- Large marine fauna including sharks, dolphins and turtles were more frequently observed at the more remote northern sites. For most other sites there were very few or no sightings of large marine fauna.
- A reef condition index was calculated based on coral, fish and invertebrate biodiversity, coral cover and the density of target fish. Sites with a reef score of more than 85% and a low incidence of disease, predation and pollution were considered the most eligible reefs for MPA status. In total seven sites, all located in the southern part of Vava'u, scored more than 85% and are considered the most suitable areas for protection as MPAs.

CETACEANS AND MARINE TURTLES

- The Vava'u island group has long been a renowned spot for humpback whales (*Megaptera novaeangliae*) but it also hosts marine turtle nesting sites and its waters are likely used by numerous other species of cetaceans. The BIORAP project has provided the opportunity to gain further knowledge on the status of these species.

- A total of nine boat surveys were conducted around the Vava'u island group, Fonualei and Toku. A distance of 852 km was travelled in shallow and deep waters during 56 hours and 23 minutes at sea. Weather conditions were mostly good (Beaufort Sea State ≤ 2, 82% of the time).
- Ten groups of small cetaceans were encountered, representing at least three species: spinner dolphin (*Stenella longirostris*), short-finned pilot whale (*Globicephala macrorhynchus*) and bottlenose dolphin (*Tursiops* sp.). Group encounter rate was relatively low (1.2 groups per 100 km of effort) although similar to that found in some other archipelagos of Oceania (e.g. Fiji and Vanuatu).
- Spinner dolphin was the main species observed in coastal waters (n = 6 groups). They are likely to form small resident populations around the islands. However, no area was found to be consistently used by groups of this species.
- Biopsy samples were collected from 19 individuals. Preliminary analyses indicate higher mitochondrial DNA (mtDNA) diversity in spinner dolphins than in short-finned pilot whales. Phylogenetic reconstructions show that bottlenose dolphins around the Vava'u Island group belong to the species *T. truncatus*.
- Evidence was found of the presence of two species that were not previously recorded in the waters of Tonga: the Cuvier's beaked whale (*Ziphius cavirostris*) and the rough-toothed dolphin (*Steno bredanensis*). With these findings, there are now 14 cetacean species officially listed in Tonga.
- The humpback whale population for Tonga has recently been estimated at over 2,000 individuals. Some movement of individuals between other regions of Oceania occurs but a high level of site fidelity has been shown within the region that is also supported by genetic analyses of population structure.
- Recent predictive habitat modelling around the Vava'u island group has shown that favourable habitat for mother–calf pairs of humpback whales included shallow, near shore regions, whilst areas of predicted suitable habitat for adult-only groups included deeper areas further offshore around the periphery of the island region and including seamounts and banks.
- Few turtles were seen during the boat surveys and these were mostly green turtles (*Chelonia mydas*). However, data from the Vava'u Turtle Monitoring Program have helped identify potential foraging habitat of importance in the Vava'u island group.
- Past and recent surveys of turtle nesting sites suggest that Maninita, Fonua'one'one and Taula islands are important for hawksbill turtles (*Eretmochelys imbricata*). Turtle nesting has historically occurred on many islands throughout the Vava'u island group but it is likely that decades of egg poaching from nests and catches of large female green turtles have greatly impacted the local populations.

Conservation recommendations

This BIORAP focusses on presenting the findings of the biological survey and in particular the biological values of the sites surveyed. The BIORAP is not a strategic conservation plan for Vava'u and therefore does not go into detail on the specific actions for each site nor does it attempt to prioiritise sites or actions.

However, a number of general conservation recommendations were made by different members of the BIORAP team. These have been consolidated along with justifications for the measures recommended. More detailed information on the recommendations can be found within the respective chapter for each focal group.

The conservation recommendations are grouped under nine broad headings:

- Conserve sites of significant conservation value;
- Improve conservation of threatened species;
- Improve management and use of marine resources;
- Manage the threat to the key sites from invasive species;
- Raise public awareness on conservation values of the Vava'u Archipelago;
- Raise awareness on and enforce existing environmental laws;
- Improve knowledge of the ecology and biodiversity of the Vava'u Islands;
- Ensure ecotourism is managed sustainably;
- Reduce runoff, pollution and sedimentation.

Eight terrestrial and 16 marine sites (three of which are also identified as important terrestrial sites) have been identified that have significant conservation values and require special conservation effort. The key features of each site, including their approximate area, conservation values, ownership, threats and recommended conservation actions are shown in tables in the document. Special effort should be made to manage sites holistically in a ridge to reef approach that develops synergies between terrestrial and marine values.

It is recommended that a key next step is to conduct a conservation planning process in partnership with all stakeholders in Vava'u to develop a detailed action plan for the conservation of the sites. This plan should include: the possible merger of sites into larger conservation units; specific management objectives for each site; and where appropriate the preparation of site management plans and proposals for further funding support.

Conclusion

The BIORAP survey has reconfirmed the critical importance of the biodiversity and native ecosystems of Vava'u's terrestrial and marine environments and the urgent need for follow-up activities to manage and mitigate the many threats to their integrity. A pragmatic series of recommendations is provided for the implementation of site based and species conservation based actions.

In the past few centuries the forest cover on Vava'u has declined from close to 100% to about 10% today, with concomitant declines in the distribution and abundance of much terrestrial biodiversity, including plants, birds, flying foxes, reptiles, insects and land snails, and the extinction of many species, especially birds and land snails. Fishing pressure in Vava'u has resulted in severe declines in turtles and specific groups of fish and invertebrate species and a collapsing fishery around the archipelago. New invasive species continue to arrive in Tonga while existing invasive species continue to spread to new islands and impact on the structure and function of native ecosystems. Climate change, including the impact of sea level rise and changed weather patterns, is likely to have significant impacts on native biodiversity in the future.

It is now up to all relevant parties, including the Government of Tonga, the Vava'u Environmental Protection Agency and their various development partners, and the people of Vava'u, to use these findings to develop and implement a comprehensive conservation strategy that maintains or even enhances the unique heritage value of the Vava'u Archipelago.

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND INFORMATION ON THE BIORAP

The Biological Rapid Assessment Programme (BIORAP) is a biological survey based on a concept developed by Conservation International and designed to use scientific information to catalyse conservation action. BIORAP methods are designed to rapidly assess the biodiversity of highly diverse areas and to train local scientists in biodiversity survey techniques.

Up-to-date information on terrestrial and marine biodiversity, and threats to it, is crucial for conservation planning and management. However, in the case of Vava'u, no systematic assessment of marine and terrestrial conservation values had been conducted before the BIORAP. While many biological surveys have been conducted in Vava'u in the past, there had never been a comprehensive and multi-disciplinary assessment of marine and terrestrial biodiversity in the island group. Consequently, the Vava'u BIORAP was identified as a key national priority by the Government of Tonga, who approached the Secretariat of the Pacific Regional Environment Programme(SPREP) for assistance to coordinate this project under the Global Environment Facility (GEF) funded *Integrated Islands Biodiversity Project* (IIBP) which includes the Cook Islands, Nauru, Tonga and Tuvalu. The IIBP is a US$4.5 million project (US$1.7 million from GEF) being implemented from 2012 to 2015 by SPREP in collaboration with relevant government and non-governmental organisation (NGO) partners in the four project countries, to help the countries implement their commitments under the Convention on Biological Diversity (CBD) Island Biodiversity Program of Work (IBPOW).

According to the terms of reference for the BIORAP, the expected outcomes and deliverables of the Vava'u BIORAP include the following:

- Development and documentation of appropriate survey methodologies for marine and terrestrial biodiversity assessment;
- Assessments of the status and distribution of biodiversity with particular attention to special conservation priorities such as rare, endemic and/or threatened species and ecosystems;
- Identification of constraints and opportunities for ongoing conservation activities including the identification of new conservation areas and approaches;
- Training and nurturing of counterpart staff including the transfer of appropriate skills and technology;
- Production of a BIORAP report comprising text with maps and photos to SPREP's specification.

Criteria generally considered during BIORAP surveys to identify priority areas for conservation across taxonomic groups include: species richness, species endemism, rare and/or threatened species, and habitat condition (Morrison and Nawadra 2009). Measurements of species richness can be used to compare the number of species between areas within a given region. Measurements of species endemism indicate the number of species endemic to some defined area and give an indication of both the uniqueness of the area and the species that will be threatened by alteration of that area's habitat (or conversely, the species that may be conserved through conservation efforts).

The Vava'u BIORAP was conducted from 13 to 28 February 2014. The survey involved 17 scientists and 18 Tongan Government staff (see Table 1.1). Fourteen islands were visited over the 16 days of the survey. The terrestrial survey involved assessments of land and sea birds, bats, plants, reptiles, land snails and insects while the marine survey included assessments of coral reef fish and commercial fish, corals and other marine invertebrates, sea turtles and cetaceans. The BIORAP was coordinated by SPREP, the Vava'u Environmental Protection Association (VEPA), the Waitt Foundation and the Tongan Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR). The latter ministry has since been split into two new ministries – the Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC) and the Ministry of Lands and Natural Resources (MLNR). Staff from the Ministry of Agriculture, Food, Forestry and Fisheries (MAFFF) also participated in the survey.

Table 1.1. Vava'u BIORAP participants.

International staff	Area of expertise for international staff	Tongan Government staff
Name and organisation		**Name and ministry**
Marine team		
Dr Andrew Bauman, Consultant	Marine invertebrate biologist/ ecologist	Penikoni Aleamotu'a, MEIDECC
Michael Donohue, SPREP	Cetaceans and sea turtles, Marine Team Leader	Senituli Finau, MEIDECC
Dr Douglas Fenner, Consultant	Coral taxonomist	Sione Mailau, MAFFF
Mael Imirizaldu, Consultant	Commercial fish biologist	Tonga Tu'iano, MAFFF
Dr Sheila A. McKenna, Consultant	Marine Team Leader, Marine Component Report Coordinator and 2nd Editor	
Dr Marc Oremus, Consultant	Marine mammal specialist including turtles	
Karen Stone, VEPA	Fish biodiversity Biologist/ecologist	
Kate Walker, VEPA	Turtle specialist	
Dr Fiona Webster, Consultant	Coral reef health specialist/biologist	
Terrestrial team		
James Atherton, Consultant	GIS support for ecosystems, BIORAP Report Coordinator and 1st Editor	Hoifua 'Aholahi, MEIDECC
Adam Backlin, USGS	Terrestrial reptiles	Halalilika 'Etika, MLNR
Dr David Butler, Consultant	Terrestrial Team Leader, land and marine avifauna	Ana Loiloi Fekau, MEIDECC
Dr Fred Brook, Consultant	Land snails	Saia Fonokalafi, MEIDECC
Dr Eric Edwards, NZ DOC	Terrestrial entomology	Tevita Fonokalafi , MAFFF, Vava'u
Bruce Jefferies, SPREP	BIORAP management and coordination	Viliami Hakaumotu, MEIDECC
Dr Mark O'Brien, Birdlife Pacific Partnership	Land and marine avifauna	Siosina Katoa, MEIDECC
Dr Art Whistler, Consultant	Botanical/ecosystems	Lupe Matoto, MEIDECC
		Samuela Pakileata, MEIDECC
		Tevita Taufa, MLNR, Vava'u
		Anitelu Toe'api-Civil Society
		Sione Tukia Lepa, MEIDECC
Administration Support		
		Haunani Ngata, MEIDECC WinnieVeikoso, MEIDECC, V ava'u

After the survey part of the BIORAP ended on 26 February, a debriefing and discussion was held with all BIORAP participants, local partners and government representatives on 27 February. These discussions informed the recommendations provided in Chapter 13. A formal reception was also held on the evening of 27 February at the Port Wine Guesthouse and attended by dignitaries such as the Minister of Agriculture, Forestry, Fisheries and Food Hon. Sangster Saulala and Chief Magistrate Paula Tatafu. At the reception the BIORAP findings (marine and terrestrial) were presented and a slide show of photos of the survey work was shown.

1.2. Background information on Vava'u

The Vava'u Archipelago is located in the tropical southwest Pacific in the vicinity of 18.6oS 174.0oW, and is part of the Kingdom of Tonga. It comprises the main island of 'Uta Vava'u (95.95 km^2, maximum elevation of 215 m), bounded on its southern side by a cluster of 57 smaller islands (c. 0.02–9.0 km^2, 1–100 m elevation) and the outlying islands of Late (17.5 km^2, 519 m elevation) to the west, and Fonualei (4.2 km^2, 195 m elevation) and Toko (0.43 km^2, 8.0 m elevation) to the north-northwest (Figure 1.1). 'Uta Vava'u and most of the adjacent smaller islands are formed of karstic limestone, have a stepped topography with prominent elevated, marine-eroded terraces, and are mantled with thick, airfall-derived volcanic soils. Some of the small, low islands in the southern part of the group are formed entirely or predominantly of unconsolidated sand or coral gravel, and similar unconsolidated sediments underlie narrow coastal plains bordering parts of some of the small limestone islands, and back-beach flats in some embayments on the main island. The outlying islands of Fonualei, Late and Toku are all volcanic in origin.

Much of the original native forest cover of 'Uta Vava'u and the adjacent smaller islands has been removed during the three millennia of human occupation of this group, but remnants of mature forest are still present in some areas that are too steep or rocky for cultivation, including steep coastal slopes and inland scarps and knolls, and on some of the smaller cliff-bound islands (e.g. Kitu, Kulo and Luamoko). Areas of mature native forest have also persisted on some of the small, low, southern islands (e.g. Maninita and Taula), and in some more gently sloping parts of 'Uta Vava'u, most notably on coastal terraces and beach flats in the vicinity of Utula'aina Point and Vai-utu-kakau.

The main islands of the Vava'u Archipelago, as well as the entire Kingdom of Tonga, are located on the crest of the Tongan Ridge bordered by the volcanically active Tofua Arc to the west and the Tongan Trench to the east. The islands occur within the South Pacific gyre and are subject to the South Equatorial current. Surface currents vary in strength, width and depth. Southeast trade winds of 15–25 knots predominate from May to September whereas northeast winds of 10–20 knots occur during the summer months. Cyclone season occurs from late November to April. The tides in Vava'u are diurnal and the sea water temperatures range from an average of approximately 24°C to 28°C depending on season. Surrounded by deep oceanic waters, Vava'u hosts a wide range of marine habitats and species, most notably perhaps the coral reefs and migrating humpback whales.

1.3. Sites surveyed

1.3.1. TERRESTRIAL SITES SURVEYED

Terrestrial site selection was based on the following criteria: sites where past biological surveys had been done and had recorded significant biodiversity values (in particular Steadman et al. 1999); sites with currently intact native forest (using satellite imagery and recent land cover maps); and sites already managed as a national park (e.g. Mt Talau) or proposed as national parks (e.g. Maninita). Furthermore, sites were selected to obtain a good geographic spread of the islands, and with a range of different island types and geologies. In all cases, approval from local landowners was obtained before sites were visited.

Thirty-three different sites were surveyed by the terrestrial survey teams (Figure 1.2). While most terrestrial survey teams visited most of the 33 sites, some sites were only visited by one survey team and in some cases islands were only surveyed from the lagoon and not landed on. For example, the southern group of islands from Fonua'one'one to Fatumanga was observed by the bird survey team but they did not land on any of these islands (Figure 1.2).

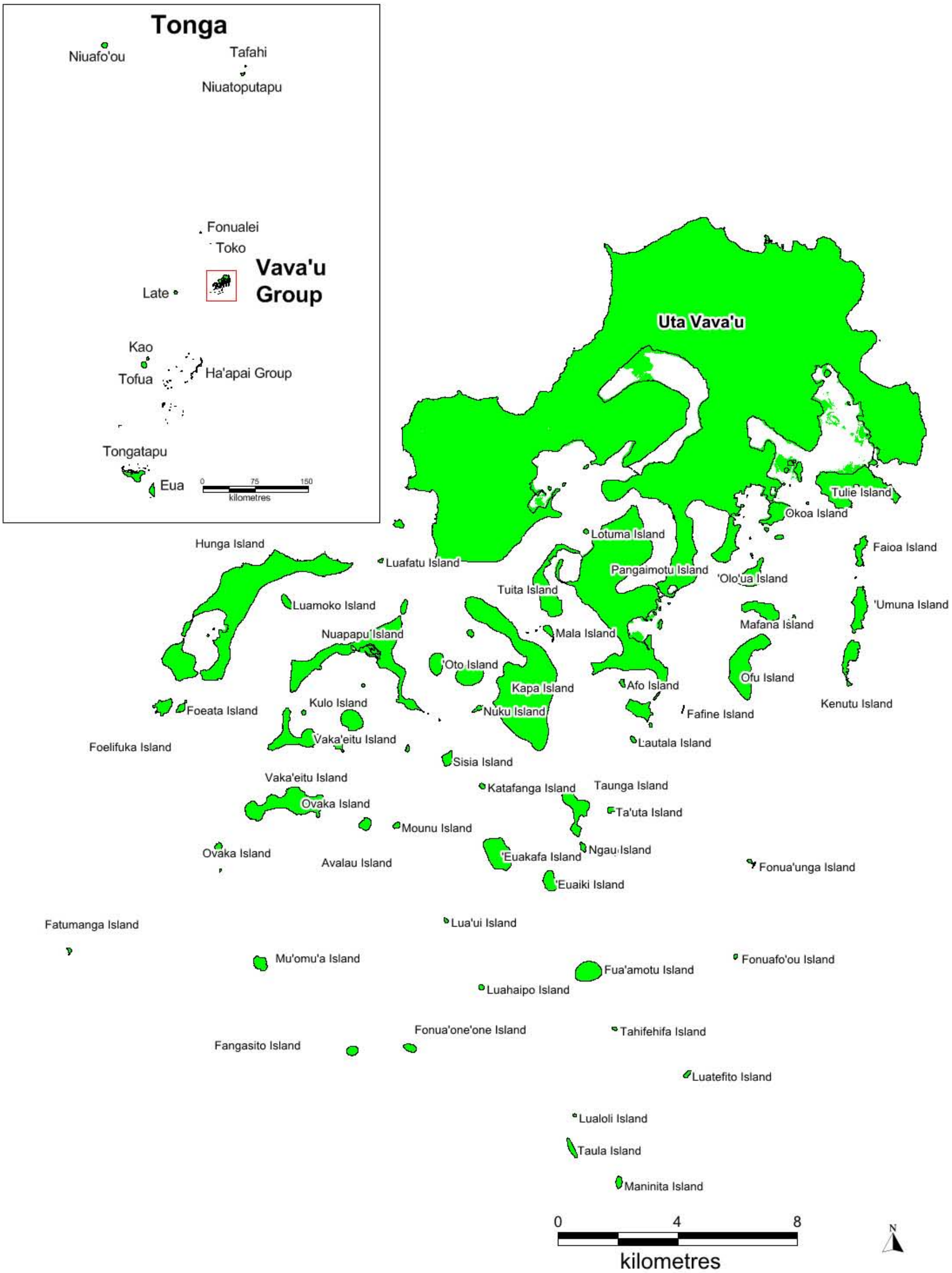

Figure1.1. Location of Vava'u.

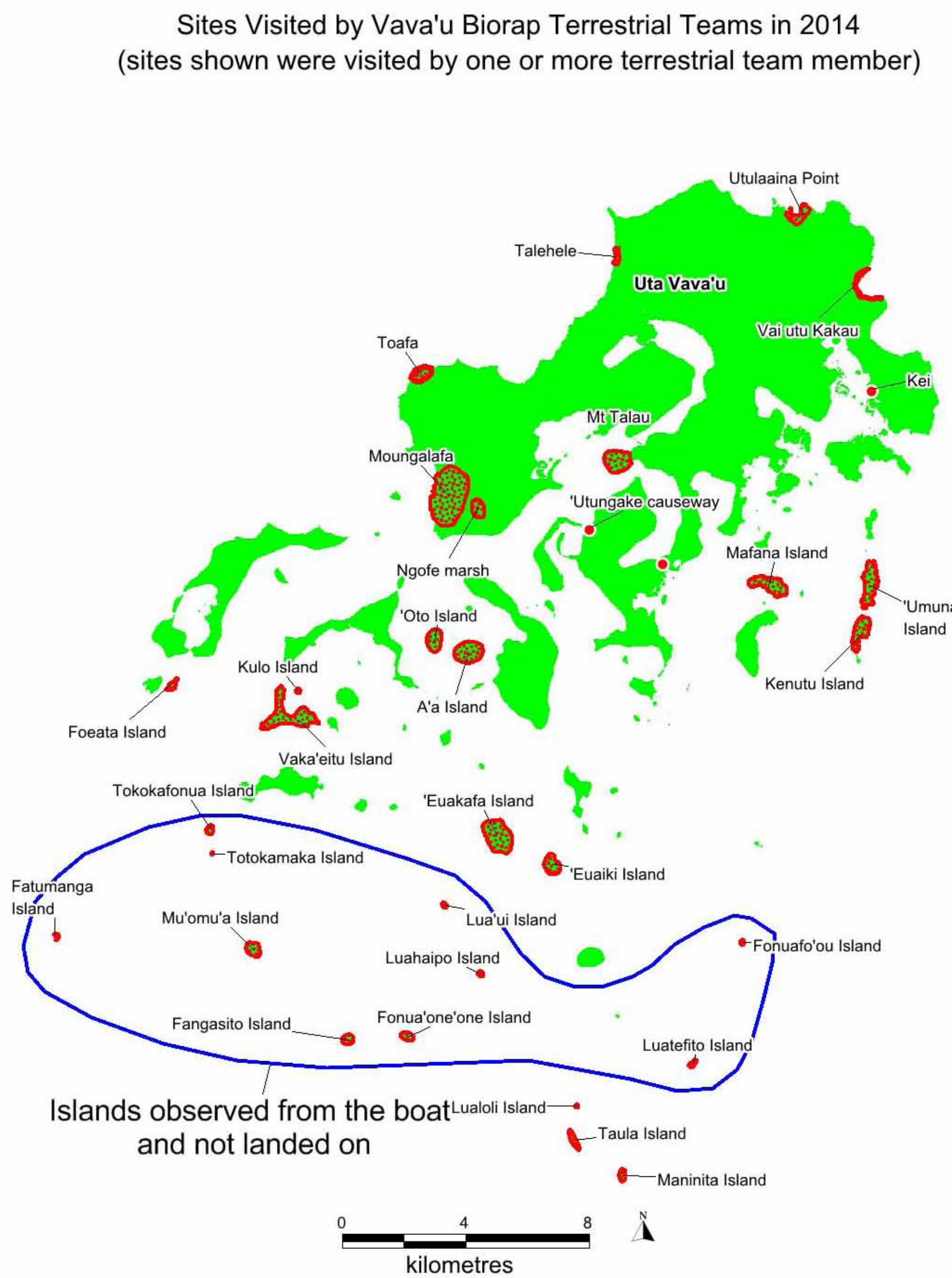

Figure 1.2. The terrestrial sites visited by one or more of the terrestrial survey teams.

1.3.2. MARINE SITES SURVEYED

To survey the marine biodiversity and habitats of the Vava'u archipelago, the marine team was divided into two groups. The first group was dedicated to the assessment of coral reefs sites while the second group committed to an assessment of cetaceans and marine turtles.

To assess the coral reef sites the boat *Plan B* with a small boat tender was used. The 27 coral reef survey sites were chosen in cooperation with the Ministry of Lands, Environment, Climate Change and Natural Resources and are presented in Figure 1.3. These selected sites were predominantly fringing reefs, which are commonly associated with limestone islands such as those found in Vava'u. Only the islands of Fonualei, A'a and 'Oto are comprised of different reef habitat and structure. Fonualei is a volcanic island while the islands of A'a and 'Oto are limestone drop-offs. Fringing reefs were characterised by the extent of the exposure to swell, which predominantly comes from a south to southeast direction. In some instances when a researcher was unable to dive, no data were collected at that site for their focal taxa. These site exceptions are noted within the respective chapter (e.g. in Chapter 9, coral reef fish, sites 26 and 27 not surveyed).

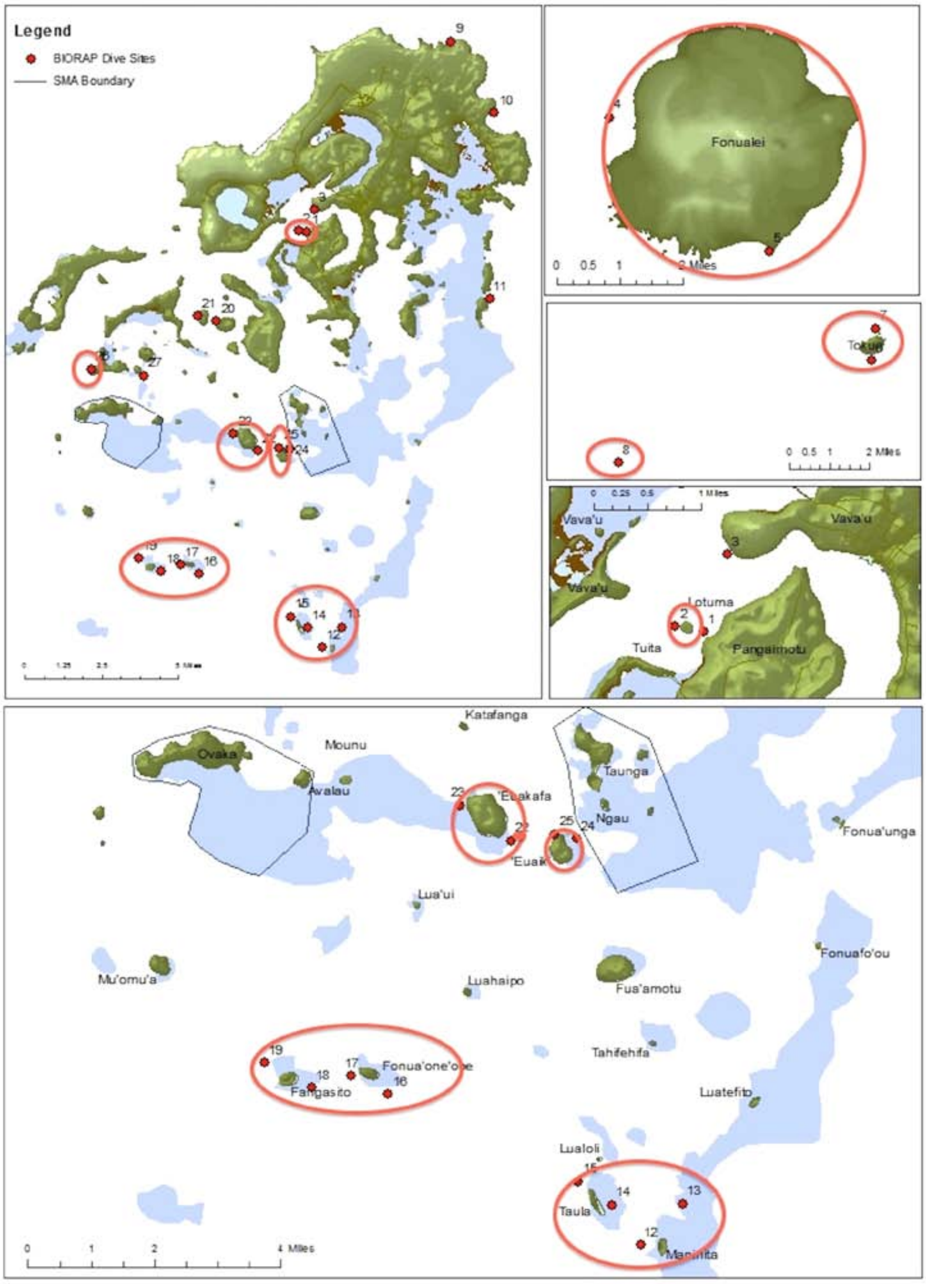

Figure 1.3. Map of reef sites visited by the marine team.

The second group of the marine team, focusing on cetaceans and sea turtles, did not follow predefined transects but attempted to cover each type of habitat within the waters surrounding Vava'u (Figure 1.4). Three main types of habitat were considered and defined as follow:

- Coastal habitat: waters within 1 km of shoreline or outer barrier reef (usually <500 m deep), opening on slope and oceanic waters (representing 38% of total distance covered);
- Inner waters: shallow waters (<200 m) roughly delimited by the Vava'u island group and barrier reefs spreading south of the main islands (33% of total distance covered);
- Slope and oceanic waters: deeper waters (>500 m) offshore coastal areas or barrier reef (29% of total distance covered).

Opportunistic surveys from *Plan B* allowed to cover oceanic waters north of Vava'u, as well as the coastal waters of Toku and Fonualei, two small islands located at 50 and 70 km from the northern tip of Vava'u, respectively. *Dev Ocean* survey tracks starting from the Vava'u group (either Neiafu or Foeata) were designed on a daily basis, depending on areas that had not been previously surveyed, as well as on the wind and sea conditions. Coastal waters around both large and small islands of the group were extensively covered. The main island was circumnavigated twice. Offshore surveys were mostly on the western side of the group but on one occasion oceanic waters to the south-east were also covered (Figure 1.4).

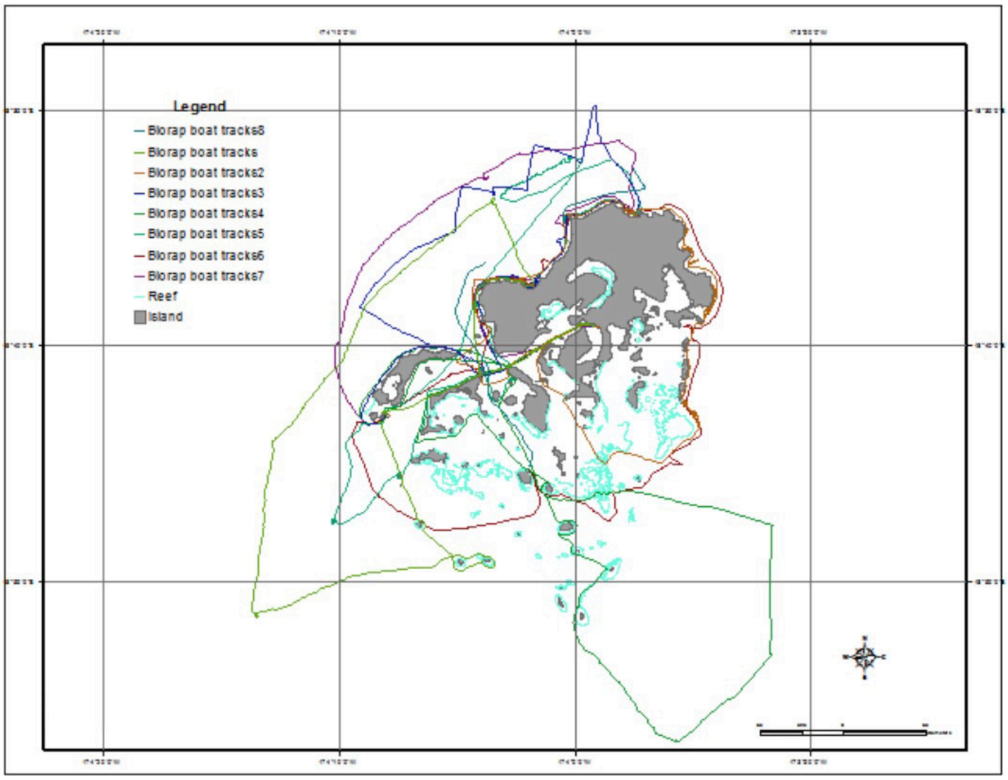

Figure 1.4. The seven survey tracks around the Vava'u archipelago sampled by the cetacean and sea turtles group of the marine team.

1.4. Structure of this report

This report is structured around 13 chapters, 11 of which cover different taxonomic groups or themes, each written by a different scientific team. The first five chapters after the introductory chapter cover terrestrial themes – plants, reptiles, birds (and bats), insects and land snails – while the next six chapters cover marine themes –reef corals, marine macro invertebrates, coral fish, commercial fish, coral reef condition and finally cetaceans and sea turtles. The final chapter pulls together the conservation recommendations and conclusions from all scientists.

1.5. Next steps

The BIORAP has confirmed the high biodiversity and ecosystem values of the Vava'u archipelago. A series of pragmatic recommendations to retain and enhance these values has been made. Important follow-up activities include the review of Tonga's National Biodiversity Strategy and Action Plan (NBSAP) and development of Tonga's State of Environment (SOE) report. However, the key next step is to prepare and implement a stategic action plan for the conservation of the archipelago. This should include defining the specific management objectives for priority sites and species and where appropriate the preparation of site management plans and funding proposals for further support.

1.6. References

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CHAPTER 2 PLANTS OF VAVA'U

ART WHISTLER AND JAMES ATHERTON

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2.1. Summary

- The Principal Investigator, Art Whistler, visited Vava'u from 12 to 28 February 2014 to do a vegetation and flora survey of the island, assisted by James Atherton who focused on vegetation mapping.
- The flora of Vava'u was determined to comprise about 262 native vascular plant species, divided into 188 dicots, 39 monocots, two gymnosperms, 30 ferns, and 3 fern allies. Eight Tongan endemic species are found in Vava'u, two of them endemic to Vava'u – *Atractocarpus crosbyi* and *Casearia buelowii*.
- Twelve new native species were recorded for Vava'u, including one new one for Tonga, *Boerhavia albiflora* (Nyctaginaceae). One endemic species, *Phyllanthus amicorum*, was previously known only from 'Eua. Additionally, 42 new weed species were recorded for Vava'u, 18 of them new for Tonga.
- Of the 262 native vascular plant species, 62 were not found during the present survey. Fourteen of the 62 have not been collected in Vava'u since 1892.
- Twenty-two plants identified as rare in Vava'u re reported from Vava'u, and 14 of these were found during the present survey.
- About 180 voucher specimens were collected and distributed to various herbaria.
- Seven plant communities were recognised: (1) Littoral Strand; (2) Coastal Marsh; (3) Mangrove Forest; (4) Lowland Forest; (5) Managed Land; (6) Successional Vegetation; and (7) Secondary Forest. Very little undisturbed Lowland Forest was found.
- Nine plots recorded using a Geographical Position System (GPS) were set up and all the trees over 5 cm dbh (diameter at breast height) were measured. The data were then collated into tables showing the relative dominance of the component species.
- Recommendations are made about setting up protection or recognition for several sites. Key forest areas recommended for conservation include Mt Talau, Mo'ungalafa, Utula'aina and Utungake on 'Uta Vava'u, as well as Maninita, 'Euakafa and 'Oto islands.

2.2. Introduction

2.2.1. THE FLORA OF TONGA

Characteristics of a flora

The flora of an area is usually thought of as a list (or book) that includes all the plants occurring in that area. This list can include all flowering plants, all vascular plants (flowering plants, gymnosperms and ferns), or all plants (including algae, lichens, etc.). Together the flowering plants, gymnosperms and ferns are classified as 'higher plants', a category known scientifically as Tracheophyta, and this is what was studied during the Vava'u BIORAP. The higher plants are divided into two main groups (called 'divisions', which together comprise the 'plant kingdom') – ferns, which are placed in the Pteridophyta (individually called pteridophytes), and seed plants, which are placed in the Spermatophyta (individually called spermatophytes). Between the ferns and seed plants, but typically included in the pteridophytes, is a heterogeneous assemblage of plants called 'fern allies', which in Tonga comprises only eight species. The seed plants are divided into two groups: Gymnospermae (called gymnosperms, or sometimes, conifers) and Angiospermae (flowering plants). Only two native gymnosperms are found in Tonga, the endemic *Podocarpus pallidus* (Podocarpaceae) and the indigenous

Cycas seemannii (Cycadaceae). The angiosperms are divided into two groups: monocots and dicots. These two groups are further divided into groups called 'families', which range in size from a single species to thousands of species. All family names can be identified by the ending '-ceae'.

Plant species can be classified by their distribution: they are either *native*, i.e. they occur naturally in the area having arrived by non-human transport, or they are *alien*, i.e. they are introduced species having arrived by direct or indirect human transport. Alien species can be further divided into species introduced by the Polynesians (i.e. brought in prior to c. 1773, and called *Polynesian introductions*) and those introduced in modern times (i.e. after c. 1773, and called *modern introductions*) by Europeans or by Polynesians traveling by means of western transport (boats, and nowadays, planes). Alien plants can also be divided another way into *intentional introductions* (plants brought intentionally, usually useful plants) and *unintentional introductions* (plants accidentally arriving in Tonga, typically weeds).

Native plants can be divided into two categories, *endemic* and *indigenous*. Endemic means restricted to a certain area; plants endemic to Tonga are found only in Tonga. Indigenous, in its current usage, refers to native species with a wider distribution (i.e. those naturally found in Tonga as well as elsewhere). These terms are relative, because their meaning depends upon how the 'area' is defined. For example, a plant occurring in Samoa and Tonga can be referred to as endemic to western Polynesia, but then it would be indigenous to these two areas when they are treated individually. However, in practical usage endemism is usually applied to countries, archipelagoes or islands.

Botanical collections in Vava'u

Although the first botanical collections in Tonga date to the Captain Cook South Pacific expeditions (1773–1777), the expedition's botanists did not collect in Vava'u, nor did other collectors who visited the Tongan archipelago during the next 60 years. The first Vava'u collections date to the 1840 visit of G. Barclay. These unnumbered specimens, at least 35 of which are known, are now stored at Kew Gardens in London. In 1852, the *Calliope* under the command of Captain J. E. Home visited Tonga. Home apparently collected mostly on Tongatapu, but three specimens are reported from Vava'u. These unnumbered specimens are stored at the British Museum in London. In 1852, W. Harvey collected in Tonga, mostly or entirely on Vava'u. These unnumbered specimens, at least 93 of which are known, are stored at the British Museum, with duplicates at Kew Gardens and the Gray Herbarium at Harvard University in Cambridge, Massachusetts. The Swiss physician E. Graeffe visited Tonga in the early 1860s and may have collected on Vava'u, but his collection localities are often in error. Two of his four recorded species labeled as from Vava'u are otherwise unknown from there, and are now considered to be in error. A half century passed after the main exploring expeditions before further major collections were made in Vava'u. C. S. Crosby, who visited Vava'u in about 1892, collected about 276 known specimens that are stored at Kew Gardens and were listed by I. H. Burkill in his publication on the flora of Vava'u (1901). In 1926, W. A. Setchell collected briefly on Vava'u, resulting in about 10 specimens. His collections are stored at Kew Gardens, the University of California Berkeley Herbarium, and the Bishop Museum Herbarium in Honolulu, but have only been partially published (Yuncker 1959).

The four largest Tongan collections have been made in the last 60 years. The first of these was in 1953 by T. G. Yuncker who, on the basis of his specimens and those of an earlier collector (Hurlimann in 1951), published a flora, *Plants of Tonga (*Hurlimann 1967), in 1959. Yuncker's Vava'u collections, numbering about 287 specimens, are stored at the Bishop Museum in Hawai'i, with smaller duplicate sets at the Smithsonian in Washington, DC and the Gray Herbarium. Another major Tongan collection was made by M. Hotta in 1961, but the manuscript of his work (Hotta 1962) was never published. His Vava'u specimens, numbering about 378, are stored in the Kyoto University Herbarium in Japan.

The modern period of collection in Tonga, as defined here, began with the work of G. Buelow who worked there from 1977 to 1983 and compiled by far the largest collection of any botanist working in Tonga (c. 3,300 numbers; however, so far only about 1,050 specimens of native and naturalised species have been located by the author). He collected throughout Tonga, but his work has never been published. His Vava'u specimens, comprising about 326 numbers, are stored at the Christchurch Herbarium in New Zealand, and the Bishop Museum. At about the same time (1977 and 1978) another significant but smaller collection was made by W. R. Sykes. Sykes' collections, which probably number over 900 (nos. 1 to 903), are stored at Christchurch but have never been published. Although he collected only about ten specimens by himself in Vava'u, he and Buelow together collected another approximately 48 specimens, which are included under the Buelow collections in this report.

The most recent large collection of Tongan plants was made by the present author (W. A. Whistler) during his work in Tonga (1984–present). Information from these collections and his fieldwork in Tonga are the basis of a comparison of the vegetation of Tonga with that of Samoa (Whistler 1992), but little taxonomic work has been done on the plants he collected. His collections, numbering about 327 specimens, are stored in his personal collection at the University of Hawai'i Herbarium with numerous duplicates in various other herbaria. Another recent collection was made by J. Franklin et al. during botanical studies in Vava'u in 1993 and 1995. This collection, numbering about 170 specimens, is stored at the University of San Diego but it has not been studied taxonomically. Other small and basically unstudied collections were made MacDaniels in 1927 (about 21 Vava'u specimens) and Soakai in 1958–1959 (at least 57 and probably many more specimens from Vava'u).

Publications on the flora

The most complete publication on the flora of Tonga is *Plants of Tonga* (Yuncker 1959), which includes the species occurring in Vava'u, but is out of date since it is now 55 years old. An earlier, less complete flora was published by W. B. Hemsley (1894), but it does not include much useful information on Vava'u. The first major publication on the Vava'u flora was by I. H. Burkill (1901), based upon the collections made in Vava'u in 1892 by Crosby, but it is also out of date since it was published over a century ago. A large manuscript on the flora of Tonga was prepared by Hotta (1962), but was never published and exists only as a manuscript. It includes his collections from the whole Tongan archipelago, including Vava'u. The number of his Vava'u specimens is apparently higher than that of any other collector in the islands. A fern flora of 'Eua was published by Sykes (1977), but it does not deal with Vava'u ferns. Likewise, St. John (1977) published flora notes about the northern island of Niuatoputapu, but it does not include information on the flora of Vava'u. Sykes (1981) published a checklist of Late Island in his work on the vegetation there. A more recent publication, Cribb and Whistler (2011) includes all the orchids known from Tonga, including the eight native orchids reported from Vava'u. Much of the flora is also covered by various articles on the flora of the Fijian region by A. C. Smith. The best source of up-to-date information about the Tongan species, nearly all of which occur in Fiji, is the six volume flora of Fiji published by A. C. Smith (1979–1996). Other information on the flora of Tonga is found in an ethnobotanical study of Tonga by Whistler (1991), and a study of the rare plants of Tonga (Whistler 2011).

Characteristics of the flora

The flora of Tonga is very similar to those of the adjacent islands and archipelagos, particularly Samoa and Fiji (although it is considerably smaller then both of them). It is estimated to comprise 338 native angiosperm species, only 3% (15 species) of which are thought to be endemic to Tonga, with no endemic genera. The flora also includes two gymnosperm species and 96 fern and fern ally species. The flora of Vava'u is obviously much smaller than the flora for the whole of Tonga, and based upon the present BIORAP field studies and previous publications, comprises about 262 native vascular plant species. Eight of the native Vava'u species are endemic to Tonga, and two of the eight are endemic to Vava'u – *Atractocarpus crosbyi* (Figure 2.1) and *Casearia buelowii* (Figure 2.2).

Figure 2.1. *Atractocarpus crosbyi* (photo by A. Whistler).

Figure 2.2. *Casearia buelowii* (photo by A. Whistler).

Also included in the flora of Vava'u are alien or introduced species. Some of these aliens are cultigens, which are grown for their usefulness for food, medicine and ornamentation, and are not a significant part of the natural environment. However invasive species, often called weeds, are a major part of the landscape. Some of these alien weedy species were brought in by the early Polynesians, but most of them are modern introductions. Most of the former type – the Polynesian introductions – are of minor importance and many have disappeared. In all, about 181 species are reported to be weedy in Vava'u, all but 27 of them modern introductions. See the discussion on the flora of Vava'u in the Results section.

2.2.2. THE VEGETATION OF TONGA

The first comprehensive description of the flora of Tonga (Whistler 1992) recognised 16 plant communities in the archipelago: (1) herbaceous strand; (2) littoral shrubland; (3) *Pandanus* scrub; (4) littoral forest; (5) coastal marsh; (6) montane marsh; (7) mangrove forest; (8) coastal forest; (9) lowland forest; (10) montane forest; (11) summit scrub; (12) montane scrub; (13) lowland volcanic scrub; (14) managed land; (15) secondary scrub; (16) secondary forest; and (17) fernland. Other vegetation studies, such as Drake et al. (1996), Uhe (1974), Park and Whistler (2001), Ellison (1990), Palmer (1988), Straatsmans (1964), Sykes (1981) and Woodroffe (1984), studied only specific types of vegetation or vegetation occurring on islands other than Vava'u.

Several investigators generally led by J. Franklin did a series of vegetation studies in Vava'u from 1993 to 2005. Publications on these studies include Franklin (2003), Franklin et al.(1999, 2004, 2006, 2013), Franklin and Rey (2004), Steadman et al. (1999) and Wiser et al. (2002). These did not deal directly with the classification of the vegetation of Tonga, but with forest dynamics. Eliminating types of vegetation not found on Vava'u, and combining the first four categories into a single community, results in the following plant communities on Vava'u recognised here: (1) littoral strand; (2) coastal marsh; (3) mangrove forest; (4) lowland forest; (5) managed land; (6) successional vegetation; and (7) secondary forest.

2.3. Methods and sites visited

2.3.1. SAMPLING PLOTS

The members of the BIORAP team consulted together, studied previous literature and examined aerial photos to select a number of study sites that could hopefully be visited. Not all of the sites selected were visited by the whole team because the team members usually worked independently. The botanical team visited most of the study sites, nine of which were selected as suitable for the establishment of forest plots. Figure 2.3 shows the location of all sites visited by the botanical team, while Annex 2.1 gives basic information about each site. Figures 2.4 and 2.5 show some of the sites visited.

The nine selected sites are identified as follows: (1) Mt Talau secondary forest; (2) Mafana secondary forest; (3) Mo'ungalafa secondary forest; (4) Toafa disturbed lowland forest; (5) Vaka'eitu lowland forest; (6) 'Oto lowland forest; (7) Mo'unga Lafa lowland forest; (8) 'Euakafa lowland forest; and (9) Utula'aina lowland forest. Forest plots were sampled on these nine sites, while notes were taken on the vegetation and flora of the other sites visited.

The nine sites were visited and studied to determine the best location, orientation and size of plot to be sampled. Major considerations were accessibility and safety of establishing plots in the area, as well as the uniformity of the vegetation and the absence of signs of recent disturbance. In each of the plots, a 50 m tape measure was laid out, and if the area permitted, another one added to the end to make a 100 m centerline. Once the end points were established, their GPS coordinates were recorded so that the sites can be revisited in the future to see what changes occur there over time (see the GPS coordinates in the Results section). The boundaries were then roughly marked off 5 m on either side of the line, making the plot sizes 500 or 1,000 m^2.

Figure 2.3. Location map of sites visited by the botanical team.

Figure 2.4. Utula'aina Lowland Forest (photo by J. Atherton).

Figure 2.5. Littoral Strand on 'Umuna island (photo by J. Atherton).

While the plots were being marked off by the field crew, the principal investigator made a checklist of all vascular plant species present in the plot and the surrounding area. Then the field team measured all trees in the plot having a minimum diameter at breast height (dbh) of 5 cm using a dbh tape. The dbh figures were recorded and were later used to calculate the relative dominance of the trees present. Figures 2.6 and 2.7 show the field work.

To present the data for the nine plots, the sum of the basal (i.e. cross-sectional) area of the individuals of each tree species was calculated. The species were then put into the right hand table column in order of their total basal area, from high to low. For each species, the number of trees sampled, the number of trees with a dbh of 15 cm or more, and the total basal area were put into the next three columns. The total basal area of all the trees was then summed at the bottom of the fourth column. The relative dominance parameter is the most important one in determining which species are the most important in the plot. This is calculated by dividing the basal area of each of the species by the sum of the basal area of all of the species, and is shown in the fifth column. The use of basal area to determine dominance is a standard vegetation ecology method. The data for the nine plots are shown in Annex 2.2.

2.3.2. RECORDING THE FLORA

In addition to the vegetation plots, the flora was also studied. Lists of species present, both native and alien species, were made for each of the sites visited, and also for other areas that were visited but not chosen for a plot. The purpose of these lists is to add to the flora additional species not found in the plots, and to see if any species might be disappearing. A number of new native and weedy species were recorded during field work. Voucher specimens were collected for flowering or fruiting individuals found during the work, and sometimes sterile (non-flowering or non-fruiting) species if their identity was not certain. In fact, the Principal Investigator knew nearly every native and weedy species encountered, making identification more accurate. The voucher specimens were taken back to the base of operations (the Portwine Guesthouse in Neiafu), and voucher herbarium specimens were prepared. Whenever possible, an original and three duplicates were pressed. The fresh specimens were put into sections of newspaper, numbered, and put between cardboard ventilators. The two sections of a wooden plant press were then added to the ends, and the whole press with specimens was wrapped up tightly by the press straps. The press was then put onto cinderblocks, between which a space heater was placed. The whole set up was then wrapped up with a blanket-like sheet of impermeable material, and the heat turned on to dry the specimens. At first the specimens were not drying fast enough, but eventually by tinkering with the set up, most of the specimens dried in one or two days. At the end of the BIORAP, the voucher specimens in newspapers were put in numerical order and packaged up for shipment back to Samoa. In Samoa, the specimens were separated into sets to be sent to Tonga, Auckland Museum Herbarium and the University of Hawai'i Herbarium.

2.4. Results

2.4.1. FLORA

Over 180 voucher specimens, most of them with duplicates, were collected and eventually sent to the designated institutions. Nearly all of these were identified while in Tonga, but several needed further study by the Principal Investigator back in Hawai'i. The voucher specimens were then added to the list of specimens already known from Vava'u, and a comprehensive list of the flora of Vava'u was prepared (Annex 2.3). The species in the table were first arranged into five groups: (1) dicots; (2) monocots; (3) gymnosperms; (4) ferns; and (5) fern allies. The species in each group were then separated into their respective plant families arranged in alphabetical order, with the species within the families also in alphabetical order. The scientific name of each species is followed in the second column by the authors who named them.

Figure 2.6. Laying down the 50m transect tape in the Utula'aina lowland forest (photo by J. Atherton).

Figure 2.7. Hoifua measuring the diameter at breast height (dbh) of a tree (photo by J. Atherton).

Based on the previous literature and the new collections, a total of 440 species are reported to be native or naturalised in Vava'u. This includes 262 native species, divided into 188 dicots, 39 monocots, two gymnosperms, 30 ferns and three fern allies. Tonga has 15 endemic species, eight of which are found in Vava'u, including the new record *Phyllanthus amicorum*. Two species are endemic to Vava'u – *Atractocarpus crosbyi* and *Casearia buelowii*.

New species recorded for Tonga

A number of new species records were documented during the BIORAP. The previous published material consisted principally of Burkill's flora of Vava'u (1901) and Yuncker's flora of Tonga (1959), in addition to Hotta's unpublished manuscript (1962) that includes numerous species collected in Vava'u. During the BIORAP, 12 new native species records were noted for Vava'u, and are shown in bold font in Table 2.1. Eleven of the 12 are species previously reported from Tonga but not Vava'u, and one, *Phyllanthus amicorum*, was previously thought to be endemic to 'Eua (and hence was a single-island endemic). One species collected on Maninita Island, *Boerhavia albiflora* (Nyctaginaceae), is a new record for Tonga. Some of the new records are not surprising, such as *Terminalia catappa* (telie) and *Vigna marina* (lautolu), which are common Tongan species that were undoubtedly present all along but were just not collected before.

In addition to the 12 new native species, 42 weed species new to Tonga were recorded during the survey. These are also show in Table 2.1 in plain font. Like the native species, some of these have probably been present for a long time but were just missed by the early collectors. Eighteen of the weedy species are new records for Tonga, and are footnoted as such in the table.

Table 2.1. New plant records for Vava'u. Native plant species are in bold, while introduced species are in plain text.

FAMILY	Species and author(s)	Vouchers
DICOTYLEDONAE		
ACANTHACEAE	*Blechum pyramidatum* (Lam.) Urb.[1]	13611
	Ruellia prostrata (L.) Poir. [1]	(Observed 2014)
AIZOACEAE	***Sesuvium portulacastrum*** (L.) L.	13555
ASTERACEAE	*Bidens alba* (L.) DC. [1]	11348
	Calyptocarpus vialis Less. [1]	12968
	Crassocephalum crepidioides (Benth.) S. Moore	13613 [2]
	Elephantopus mollis H. B. K.	13608
	Eleutheranthera ruderalis (Sw.) Schultz-Bip.	(Observed 2014)[2]
	Erigeron bellioides DC. [1]	13628
	Pseudelephantopus spicatus (Aubl.) C. F. Baker	(Observed 2014) [2]
	Tithoniadiversifolia (Hems.) A. Gray [1]	(Observed 2014)
	Tridax procumbens L. [1]	12969
	Wedelia trilobata (L.) Hitchc. [1]	(Observed 2014)
BIGNONIACEAE	*Spathodea campanulata* Beauv.	(Observed 2014)
	Tecoma stans (L.) H. B. K.	(Observed 2014)
CAPPARACEAE	***Capparis cordifolia*** Lam.	13464, 13512, 13626
COMBRETACEAE	***Terminalia catappa*** L.	13527
EUPHORBIACEAE	*Chamaesyce hypericifolia* (L.) Mill sp. [1]	13577, 13595
	Chamaesyce prostrata (Ait.) Small	(Observed 2014)
	Phyllanthus amicorum Webster	13482
FABACEAE	*Bauhinia monandra* Kurz	(Observed 2014)
	Canavalia rosea (Sw.) DC.	(Observed 2014)
	Desmodium incanum DC.	Franklin 33. (Observed 2014)
	Glycine wightii (Wight & Arn.) Verdc. [1]	13547[2]

FAMILY	Species and author(s)	Vouchers
	Macroptilium atropurpureum (DC) Urb. [1]	(Observed 2014)
	Macroptilium lathyroides (L.) Urb.	(Observed 2014)
	Mimosa diplotricha C. Wright ex Sauvalle[1]	(Observed 2013)
	Senna occidentalis (L.) Link	(Observed 2014)
	Sophora tomentosa L.	13572
	Vigna marina (Burm.) Merr.	13484
MYRTACEAE	*Psidium guajava* L.	(Observed 2014)
NYCTAGINACEAE	***Boerhavia albiflora*** Fosb.	6033, 13553
ONAGRACEAE	*Ludwigia octovalvis* (Jacq.) Raven	6033, 13541
OXALIDACEAE	*Oxalis barrelieri* L.[1]	13535
PASSIFLORACEAE	*Passiflora laurifolia* L.	(UCSD). (Observed 2014)
PIPERACEAE	*Peperomia pellucida* (L.) Kunth [1]	13536
PORTULACACEAE	***Portulaca lutea*** Sol. ex Forst. f.	13556
SOLANACEAE	*Cestrum nocturnum* L.	13493[2]
	Solanum torvum Sw.	(Observed 2014)[2]
MONOCOTYLEDONAE		
COMMELINACEAE	*Commelina benghalensis* L.	(Observed 2014)
CYPERACEAE	*Kyllinga brevifolia* Rottb.1	13548[2]
ORCHIDACEAE	*Vanilla planifolia* Jacks. ex Andrews[1]	(Observed 2014)
POACEAE	*Brachiaria mutica* (Forssk.) Stapf[1]	(Observed 2014)
	Digitaria ciliaris (Retz.) Koel.	13517[2]
	Paspalum dilatatum Poir.	13594
	Paspalum fimbriatum H. B. K.	12967, 13492
POACEAE	*Arundo donax* L.	(Observed 2014)
	Paspalum paniculatum L.[1]	13444
	Paspalum urvillei Steud.[1]	(Observed 2014)
	Sorghum sudanense (Piper) Stapf	(Observed 2014)
	Sporobolus diander (Retz.) Beauv.	(Observed 2014)
	Sporobolus virginicus Kunth	13525
	Stenotaphrum micranthum *(*Desv.) C. E. Hubb.	13524, 13586
FERNS		
POLYPODIACEAE	***Drynaria rigidula*** (Sw.) Bedd.	13623

1 New weed record for Tonga.

2 Species collected previous to the BIORAP, but after Burkill, Yuncker or Hotta.

Native species not recorded during the survey

A major problem in Pacific island biodiversity is the disappearance of species from islands or archipelagos. If a species is endemic to an island and disappears from there, it becomes extinct. If a species is indigenous, i.e. it is found there and elsewhere, and disappears from an island, it still may occur elsewhere in its range. This local loss of biodiversity is called extirpation. Tonga has only 15endemic vascular plant species, so most of the potential loss of species is from extirpation of indigenous species rather than extinction.

A list of native species known to occur in Tonga but not found during the present survey is presented in Table 2.2, and includes 62 species. The BIORAP survey was carried out over about two weeks, which is a short time to find all the native species present. Of the 62 species not found, 14 have been missing since after Crosby collected in Vava'u over a century ago (1892). Some of the 14 are likely to have been based upon a mistaken locality, as are two species collected by Graeffe (*Plumbago zeylanica* and *Melastoma denticulatum*) that have already been excluded from the list in Annex 2.3 because Graeffe's data for Fiji, Tonga and Samoa are known to sometimes be flawed. Additionally, a fern ally, *Lycopodium cernuum*, and a fern, *Dicranopteris linearis*, reported by Crosby from Vava'u do not appear to have the right habitat there, and may actually have been collected on one of the nearby volcanic islands. Another species, *Halodule uninervis*, may have been missed because it is a seagrass (marine Angiosperm).

Table 2.2. Native species recorded from Vava'u but not found during the BIORAP.

FAMILY	Species and author(s)	Collectors
DICOTYLEDONAE		
APOCYNACEAE	***Cerbera odollam*** Gaertn.	Crosby
CAPPARACEAE	*Capparis quiniflora* DC.	Buelow
CONVOLVULACEAE	***Ipomoea fimbriosepala*** Choisy in DC.	Crosby?
	Operculina turpethum (L.) A. Silva Manso	Crosby
CUCURBITACEAE	*Luffa cylindrica* (L.) Roehmer	Barclay, Yuncker
	Zehneria samoensis (A. Gray) Fosb. & Sachet	Buelow
MALVACEAE	*Sida samoensis* Rechinger	Crosby, Yuncker
MENISPERMACEAE	*Stephania forsteri* (DC.) A. Gray	Harvey, Crosby, Yuncker, Hotta, Buelow
MYRISTICACEAE	*Myristica hypargyraea* A. Gray	Buelow
MYRSINACEAE	*Rapanea myricifolia* (A. Gray) Mez	Whistler
MYRTACEAE	*Syzygium brackenridgei* (A. Gray) C. Muell.	Crosby?, Buelow?
OLACACEAE	*Ximenia americana* L.	Crosby, Yuncker
PORTULACACEAE	***Portulaca samoensis*** Poell.	Barclay, Crosby
RHAMNACEAE	*Ventilago vitiensis* A. Gray	Buelow
RUBIACEAE	*Atractocarpus crosbyi* (Burk.) Puttock	Barclay, Crosby, Yuncker, Buelow, Franklin, Whistler
	Gynochtodes epiphytica (Rech.) Sm. & Darwin	Buelow
	Psychotria carnea (Forst. f.) A. C. Sm.	Harvey
	Psychotria insularum A. Gray	Crosby, Whistler
SAPOTACEAE	*Planchonella membranacea* Lam.	Buelow
SCROPHULIARIACEAE	*Lindernia crustacea* (L.) F. Muell.	Crosby, Buelow
SOLANACEAE	***Solanum amicorum*** Benth.	Barclay, Harvey, Crosby
STERCULIACEAE	*Heritiera littoralis* Ait.	Crosby, Yuncker, Buelow, Whistler
THYMELAEACEAE	*Phaleria glabra* (Turrill) Domke	Yuncker, Hotta
ULMACEAE	*Celtis harperi* Horne ex Baker	Whistler
URTICACEAE	*Procris pedunculata* (Forst.) Wedd.	Buelow

FAMILY	Species and author(s)	Collectors
MONOCOTYLEDONAE		
ARACEAE	*Epipremnum pinnatum* (L.) Engl.	Yuncker, Hotta
CYMODOCEACEAE	***Halodule uninervis*** (Forssk.) Boiss.	Crosby
CYPERACEAE	*Mariscus javanicus* (Houtt.) Merr. & Metcalfe	Crosby, Yuncker
	Mariscus seemannianus (Boeck.) Palla	Buelow
	Scleria polycarpa Boeck.	Crosby, Yuncker, Hotta
	Torulinium odoratum (L.) S. Hooper	Yuncker, Hotta, Buelow
LEMNACEAE	*Lemna perpusilla* Torrey	Buelow, Whistler
LILIACEAE	*Dianellaintermedia* Endl.	Crosby, Yuncker, Hotta, Buelow
ORCHIDACEAE	*Dendrobium tokai* Reichenb. f.	Yuncker, Hotta, Soakai
	Didymoplexis micradenia (Reichenb. f.) Hemsl.	Buelow
	Geodorum densiflorum (Lam.) Schlechter	Crosby, Yuncker, Buelow, Whistler
	Phaius tankervilleae (Banks ex L'Her.) Bl.	Crosby
ORCHIDACEAE	***Spathoglottis plicata*** Bl.	Crosby
	Taeniophyllum fasciola (Forst. f.) Reichenb. f.	Hotta, Buelow
POACEAE	***Cenchrus caliculatus*** Cav.	Barclay, Crosby
	Cymbopogon refractus (R. Br.) A. Camus	Yuncker, Hotta
	Heteropogon contortus (L.) Beauv. ex R. & S.	Crosby, Yuncker, Hotta, Whistler
	Miscanthus floridulus (Labill.) Warb.	Whistler
	Oplismenus compositus (L.) Beauv.	Crosby, Yuncker, Hotta
RUPPIACEAE	*Ruppia maritima* L.	Yuncker, Buelow
FERNS		
ADIANTIACEAE	*Adiantum hispidulum* Sw.	Crosby, Yuncker, Sykes
ASPIDIACEAE	*Tectaria dissecta* (Forst. f.) Lellinger	Yuncker, Hotta, Franklin
DENNSTAEDTIACEAE	*Microlepia speluncae* (L.) Moore	Crosby, Hotta
GLEICHENIACEAE	*Dicranopteris linearis* (Burm.) Underw.	Crosby
HYPOLEPIDACEAE	*Hypolepis tenuifolia* (Forst. f.) Bernh.	Crosby, Yuncker
LINDSAEACEAE	*Lindsaea ensifolia* Sw.	Crosby, Yuncker, Hotta
OPHIOGLOSSACEAE	***Ophioglossum pendulum*** L.	Crosby
PTERIDACEAE	*Acrostichum aureum* L.	Barclay, Crosby, Yuncker
SCHIZAEACEAE	*Schizaea dichotoma* (L.) J. E. Sm.	Crosby, Franklin, andtwo others
	Schizaea melanesica Selling	Crosby, Whistler
THELYPTERIDACEAE	*Amphineuron opulentum* (Kaulf.) Holttum	
	Christella dentata (Forssk.) Brownsey & Jermy	Harvey, Hotta
	Cyclosorus interruptus (Willd.) H. Ito	Crosby, Hotta
	Sphaerostephanos unitus (L.) Holttum	Crosby, Hotta
VITTARIACEAE	*Antrophyum plantagineum* (Cav.) Kaulf.	Yuncker, Whistler
FERN ALLIES		
LYCOPODIACEAE	***Lycopodium cernuum*** L.	Crosby
PSILOTACEAE	***Psilotum complanatum*** Sw.	Crosby

Plant species in bold have not been recorded for over 100 years.

Most of the other missing species are widespread ones that, while rare in Vava'u, are common elsewhere (including in the rest of Tonga), such as the purselane *Portulaca samoensis* and the orchids *Spathoglottis plicata* and *Phaius tankervilleae*. However, several species are more threatened. The grass *Cenchrus caliculatus* is disappearing throughout its Pacific range, and the only recent collections in Tonga are from the cliffs of 'Eua. The nightshade *Solanum amicorum* is found only in Tonga and Niue, but has nearly disappeared from both places. The morning-glory *Operculina turpethum* is likewise disappearing over much of its Pacific range, possibly being replaced by an alien relative, *Operculina ventricosa*. The small prostrate mallow *Sida samoensis*has also become rare in Tonga as well as other parts of its range, including Samoa and Niue.

Rare native species not recorded during the survey

Seventy-seven native plants (along with 20 Polynesian cultigens and weeds) were identified as rare, threatened or endangered in Tonga in a publication on the rare plants of Tonga (Whistler 2011), and 19 of these have been recorded from Vava'u. During the field work, three more of the Tongan rare species – *Sapindus vitiensis*, *Capparis cordifolia* and *Phyllanthus amicorum* – were found, bringing the total number of identified rare plants recorded from Vava'u to 22 (Table 2.3). Of these, 14 were found during the BIORAP. Twelve were collected, and two – *Sesbania coccinea* found on Maninita Island and *Croton microtiglium* found once in one of the forest plots on the main island – were seen but not collected. *Sesbania* appears to be naturally restricted in Tonga to Maninita Island, and is rare elsewhere in Polynesia. One species, the sedge *Lepironia articulata*, is the dominant species in the center of Ngofe Marsh, but rare elsewhere in Tonga. Three of the species noted in Section 4.1.2 above (*Cenchrus caliculatus*, *Operculina turpethum* and *Sida samoensis*) are likely to have been extirpated from Vava'u, and for some, possibly Tonga. *Solanum amicorum* was not included on the rare list, but should have been since it has not been found lately in either Tonga or Niue, which comprise all of its native range. Another species, the new record *Boerhavia albiflora*, should also be considered rare since it is known in Tonga only from a single island – Maninita.

Table 2.3. Rare native plants recorded from Vava'u (Whistler 2011).

Scientific name	Tongan name	Collections[1]	Last collection	2014 collection[2]
Atractocarpus crosbyi	(none)	11/11	2013	–
Capparis cordifolia	(none)	0/4	–	NR
Capparis quiniflora	(none)	1/2	c. 1979	–
Casearia buelowii	(none)	3/3	c. 2013	C
Cenchrus caliculatus	Hefa	1/2	1892	–
Croton microtiglium	(none)	3/5	1987	X
Dalbergia candenatensis	(none)	3/5	c. 1979	C
Eulophia pulchra	(none)	1/2	1987	C
Heteropogon contortus	(none)	4/9	1988	–
Lepironia articulata	kutu kofe	4/4	1987	C
Limnophila fragrans	(none)	1/4	c. 1979	C
Luffa cylindrica	mafa'i	2/9	1953	–
Ochrosia vitiensis	Totohina	6/6	2002	C
Operculina turpethum	(none)	1/7	1892	–
Peperomia pallida	(none)	1/3	1975	C
Pittosporum brackenridgei	masi kona	1/2	2013	C
Phyllanthus amicorum	(none)	0/16	–	NR
Sapindus saponaria	ngatata hina?	0/4	–	NR
Serianthes melanesica	Mohemohe	7/10	2013	C
Sesbania coccinea	'ohai	5/5	2001	X
Sida samoensis	(none)	2/9	1953	–
Ventilago vitiensis	(none)	1/3	1979	–

1 The first number is the number of collections made in Vava'u, the second number is the number made in the whole Tongan archipelago.

2 C= collected during the current BIORAP; X = recorded during the BIORAP; NR = new record for Vava'u.

3 *Plumbago zeylanica* was recorded once from Vava'u, but the Graeffe specimen's cited location on Vava'u is likely in error. Its only other Tongan collection record is from Tafahi, where it probably persists.

Perhaps the rarest and most threatened species currently known to exist in Tonga is *Casearia buelowii* (Figure 2.2). It is known only from the top of Mt Talau. It was found in flower there in January 2013 and in fruit in February 2014. The other Vava'u endemic, *Atractocarpus crosbyi*, was not found during the present survey, but was seen several times during a visit by the Principal Investigator to Vava'u in 2013 (Figure 2.1).

2.4.2. VEGETATION

The vegetation of Vava'u is highly disturbed, with probably well over 90% of the native vegetation severely modified. The vegetation can be divided into 'plant communities' as follows, based on the previous literature (e.g. Whistler 1992) and the current field work: (1) littoral strand; (2) coastal marsh; (3) mangrove forest; (4) lowland forest; (5) managed land; (6) successional vegetation; and (7) secondary forest.

Littoral strand

Littoral strand refers to all types of natural vegetation occurring on the seashore and dominated by plant species whose presence and distribution are affected either directly or indirectly by the sea. Littoral strand differs from most inland vegetation in both its extent (total area) and distribution. It occupies a very narrow area on the immediate coast, and typically exhibits zonation into several bands that run roughly parallel to the coastline. It occurs on nearly all undisturbed shores of Vava'u, typically from just above the high-tide mark up to 5 or 10 m elevation. The environmental conditions in areas of littoral strand are among the harshest in Tonga because of its exposed situation on the coast. Littoral species, therefore, must have some degree of salt tolerance to survive the salt spray, brackish ground water and occasional, although not prolonged, seawater inundation. Most littoral plants are heliophytes ('sun plants') that require bright sunlight for establishment and growth, a need that generally excludes them from shady forest habitats. The physiological characteristics littoral plants share account for their typical restriction to a narrow zone of vegetation along the shore – they are limited inland by competition from the more vigorous species of the lowland forest, and seaward by the ocean.

Where littoral zonation occurs, two or more zones can be sometimes be distinguished. On rocky shores the seaward margin of the littoral strand is typically dominated by herbaceous plants – grasses, sedges and creeping vines, as well as the low shrub *Pemphis acidula* (ngingie). On sandy shores, this seaward zone is usually dominated by herbs, vines such as *Canavalia sericea* and grasses such as *Thuarea involuta* (kefukefu). Inland from this, a zone of shrubby vegetation typically dominated by *Scaevola taccada* (ngahu) often occurs, and further inland a forest zone dominated by one or more littoral tree species such as *Hernandia nymphaeifolia* (fotulona), *Tournefortia argentea* (touhuni), *Guettarda speciosa* (puopua), *Xylocarpus moluccensis* (lekileki), *Excoecaria agallocha* (feta'anu), *Terminalia catappa* (telie) and several others. Some of the small islands have nothing but littoral strand. No vegetation plots were established in this type of vegetation.

Coastal marsh

A marsh is an area of herbaceous, hydrophytic ('water plant') vegetation covering flat areas of soil saturated with fresh or brackish water. The term 'swamp' is sometimes mistakenly used to denote this kind of vegetation, but swamp is usually thought of as being dominated by woody rather than herbaceous vegetation. Areas of standing water may be present, particularly during the rainy season. Only one significant area of coastal marsh occurs in Vava'u – Ngofe marsh at the west end of the main island. This marsh is characterised by the presence of concentric zones of vegetation surrounding the waterlogged centre. The centre is dominated by the leafless sedge *Lepironia articulata* (kutu kofe), which may reach 2 m in height. This species is rare in Tonga outside this marsh. A zone entirely dominated by a second leafless sedge, *Eleocharis dulcis* (kutu), surrounds the central *Lepironia* zone, possibly because it cannot out-compete the *Lepironia* in the wettest central area. Surrounding these two central zones is a third zone dominated by the leafy sedge *Rhynchospora corymbosa* (mahelehele) and the showy-flowered *Ludwigia octovalvis* (no Tongan name). The outermost zone is disturbed and is dominated by a number of wetland herbaceous species, such as the grasses *Paspalum scrobiculatum* (no Tongan name) and *Paspalum conjugatum* (vailima), and other native and alien weed species. In at least one place, this marginal area is under taro cultivation. A few trees are also found in the zone, especially *Erythrina fusca* (ngatae Fisi). No vegetation plots were established in this type of vegetation.

Mangrove forest

Large areas of mangrove are found along the shores of Vava'u, but this type of vegetation was not visited during the BIORAP. Mangroves are common on mudflats, along estuaries, and in sheltered lagoons where sedimentation is occurring. In this newly forming habitat, scrub and forest vegetation replace the sea by means of halophytic (saltloving or salttolerant) pioneer species that colonise the new land surface. Although they are most characteristic of the tropics, mangroves are occasionally found in subtropical areas. T heir northernmost locationis Bermuda (32° north), and their southernmost the

Chatham Islands (44° south) east of New Zealand. The characteristic trees of mangrove vegetation typically belong to the mangrove family Rhizophoraceae, but elsewhere in the tropics mangrove species belong to several different families. The three most typical mangrove species in Vava'u are *Rhizophora mangle* (tongo), *Rhizophora stylosa* (tongo), and the much larger *Bruguiera gymnorrhiza* (tongolei). Several other tree species are often associated with mangrove vegetation, but are not exclusive to it and occur only in areas along the mangrove margins.

The major climatic factors in mangrove communities (e.g. rainfall and temperature) are similar to those in other coastal vegetation communities. The essential difference in mangrove vegetation is the presence of saline water that saturates the soil; in most cases, the ground is inundated twice daily by the tides. The waterlogged, anaerobic soil is the major factor precluding other species from inhabiting these wetlands. Mangroves are able to survive under these adverse conditions because of the presence of specialised breathing roots called 'pneumatophores', an adaptation that allows the plants to absorb oxygen directly from the air. In *Rhizophora* the pneumatophores are spreading prop roots, while in *Bruguiera* they appear as knobby roots protruding from the muddy soil. Mangroves are not obligate halophytes because they do not require saltwater to survive. Under experimental conditions they do quite well in freshwater, but outside of saline soils they are at a competitive disadvantage to rainforest trees.

Lowland forest

Uta Vava'u, which is an uplifted coral island covered in some places with soil derived from volcanic ash, was originally mostly covered by a dense tropical rainforest, but the arrival of the first Polynesians about three thousand years ago brought about major and irreversible changes to the vegetation. The growing population cleared the forest to plant crops and establish villages, and this modification has been going on for so long that hardly any of the original vegetation remains. Any original vegetation that remains is usually on steep and/or rocky slopes that are unsuitable for agriculture or villages.

The inland areas of Vava'u are fairly homogeneous in regard to elevation (the maximum elevation of Vava'u is only about 200 m), so the major differences in substrate are whether there is soil or limestone rock on the surface. Exposure is also an issue, with proximity to the sea and side of the island where the vegetation occurs being important. There have been no attempts to divide the inland forests of Vava'u other than on the basis of how disturbed they are (refer to Franklin 2003, Franklin 2007, Franklin & Rey2006, Franklin et al 1999, Franklin et al 2004, Franklin et al 2006, Franklin et al 2013). Drake et al. (1996) recognised two main types of forest on 'Eua – one dominated by *Calophyllum neoebudicum* (tamanu) and the other by *Myristica hypargyraea* (kotone). It is likely that most of the flat areas of better soil were originally dominated by tamanu (see Plot 9), but this has virtually all been removed since the areas where it occurs are ideal for agriculture. From the data gleaned from a mere nine plots, it might be accurate to divide the lowland forest into three associations: one found in more exposed coastal areas and often dominated by *Planchonella grayana* (kalaka) and other characteristic species; a second in rocky, more protected areas and dominated by *Maniltoa grandiflora* (pekepeka) and other characteristic species; and a third found on areas of better soil and dominated by tamanu. It is difficult, however, to divide Vava'u's remaining forests since there is so little left of it. The forest type on 'Eua dominated by kotone is not duplicated on Uta Vava'u, since that species is rare and apparently restricted to one small area on the latter island. Most of the native Vava'u trees are found in lowland forest. Five plots established during the BIORAP were in this type of vegetation, while one was intermediate between lowland forest and secondary forest.

Managed land

Managed land vegetation comprises the vegetation on land actively managed by people for their uses, including paved and unpaved roads, roadsides, village greens, plantations and pastures. When trees are felled, the land may be converted into permanent plantations or utilised for a short while for growing crops. But Vava'u soils, like others in the tropics, are characteristically poor in minerals, and much of the available mineral content is tied up in the trees. When the trees are felled and burned or left to rot, the minerals suddenly released into the soil are quickly washed away or are used up by the crop plants. After a few crop cycles, the harvest greatly diminishes and the land is abandoned or planted with permanent tree crops. Active management prevents disturbed land from returning to its natural plant cover and promotes the dominance of cultivated plants (which are wanted) and weeds (which are not). The amount of management in the form of weeding or spraying determines whether the cultivated or weedy plants dominate; once active management ends, herbaceous weeds soon dominate.

A weed may be defined as any plant growing where it is not wanted. This definition is based on both where the plant is growing and its economic impact on human activities, rather than on the intrinsic properties of the plant itself. Weeds are sometimes called 'adventives', which is perhaps a better term that does not involve economic importance in its definition, but weed is the name in common usage. 'Invasive weeds' are those that aggressively become established in the environment. About 180 plants can be classified as weeds in Vava'u, most of them non-native species ('aliens'). When land is managed, such as when plantations are maintained and weeded, weeds (and intentionally grown species) will dominate until the management has ended or until secondary forest trees and shrubs shade out the alien plants after a period of plant succession. Most of the surface of Vava'u is covered by managed land. No vegetation plots were established in this type of vegetation.

Successional vegetation

Successional vegetation is the scrubby vegetation found on recently disturbed land or recently abandoned managed land. The first stage following abandonment or severe disturbance is dominated by herbaceous adventive plants (i.e. weeds, as noted above). This stage, in turn, is followed by one in which new shrub or tree invaders eventually dominate for a while. In managed land, the woody species are eliminated or at least inhibited by cutting or weeding, but when management ends they can become established and grow above the herbaceous plants, producing shade that is unfavorable for the growth of most of the smaller plants beneath them. Vines, however, can avoid being shaded out (for a while at least) by climbing on the shrubs and trees to maintain their place in the sun.

The dominant trees of successional vegetation are fastgrowing, lightloving species, most of which are short and do not reach the height of typical forest trees. When taller tree species eventually overtop the shorter ones and shade them out, there is a transition to the next community, secondary forest, but the line between the two is necessarily indistinct. Although classified as a community here, successional vegetation can also be viewed as an intermediate stage between managed land and secondary forest, but this is a problem inherent in the goal to classify vegetation into discrete units. The most characteristic trees of successional vegetation on Vava'u are pioneer species such as *Macaranga harveyana* (loupata), *Homalanthus nutans* (fonua mamala) and *Hibiscus tiliaceus*(fau, beach hibiscus), all of which are native. No vegetation plots were established in this type of vegetation.

Secondary forest

Secondary forest is forest typically dominated by fastgrowing trees with small, easily dispersed seeds that require relatively sunny conditions for germination and/or establishment. This term can easily be confused with the term 'disturbed forest', which is usually applied to a climax forest damaged by cyclones or other natural phenomena. As used here, secondary forest is a successional stage between successional vegetation (which has resulted from a more thorough disturbance) and lowland forest. Although superficially similar in structure to lowland forest, its population structure and flora are quite different. Secondary forest trees dominate the canopy, but other species – particularly ones that can germinate and become established in shady conditions (and which usually have larger seeds) – typically dominate the smaller size classes. Without further disturbance, the sunny conditions required for germination and establishment of the secondary forest trees will no longer be present, and the slower growing canopy tree species that dominate the smaller size classes will eventually prevail when the larger secondary forest trees of the canopy age and die. After a long period, the climax forest that develops will be virtually indistinguishable from lowland forest in the area.

Secondary forest does not always form large tracts; it sometimes occurs in small patches in a mosaic pattern in climax forest, either in sites of former 'swiddens' (agricultural plots) or in openings created by natural tree falls. The process by which lightloving tree species become established and grow under canopy openings caused by the fall of a canopy tree is called 'gap replacement'. The most common secondary forest tree species on Vava'u include *Rhus taitensis* (tavahi), *Alphitonia zizyphoides* (toi), *Elattostachys apetala* (ngatata), *Grewia crenata* (fo'ui) and *Glochidion ramiflorum* (masikoka). Also sometimes present is the invasive red-bead tree *Adenanthera pavonina* (lopa), although during the survey it was found in only one of the nine plots (Mt Talau). Three plots sampled during the BIORAP were in secondary forest, and one is intermediate between secondary forest and lowland forest.

2.4.3. THE PLOTS

Refer to Figure 2.3 for the location of the nine plots, Annex 2.1 for key information on the plots and Annex 2.2 for the actual plot data for each plot.

Plot 1. Mt Talau secondary forest

This plot (W174 00.101, S18 38.871) is located on top of Mt Talau and comprises an area of 500 m^2 (50 x 10 m). The two dominant tree species were typical secondary forest trees – the native *Alphitonia zizyphoides* (toi) and the invasive alien *Adenanthera pavonina* (lopa), with a combined relative dominance of 39%. The three most common species (i.e. the trees with the greatest number of individuals), all of them understorey or subcanopy species, were *Cryptocarya turbinata* (motou), *Elaeocarpus floridanus* (ma'ama'alava) and *Vavaea amicorum* (ahi vao), which together comprised 57% of all the sampled trees. Twenty-two tree species were measured in the plot, the most significant of which is *Casearia buelo*wii (no Tongan name), which is known only from Mt Talau. The site is otherwise a typical secondary forest, as shown by the dominant tree species and the population dynamics that indicate the forest is undergoing 'plant succession' and will eventually, without further disturbance, begin to resemble lowland forest when the dominant secondary forest trees die and are not replaced.

Plot 2. Mafana secondary forest

This plot (W173 57.493, S18 40.920) is located on the west end of Mafana Island and comprises an area of 500 m^2 (50 x 10 m). The dominant species in this secondary forest was the native tree *Rhus taitensis* (tavahi), which had a relative dominance of 54%. All nine of the individuals were over 15 cm dbh, which indicates that the dominant tavahi is not reproducing itself and will eventually be replaced by other species. This plot could be described as agroforest because of the presence of two coconut palms and patches of *Hibiscus tiliaceus* (fau) that are typically associated with human activity and plantations. They had a combined relative dominance of 19%. The typical secondary forest trees *Alphitonia zizyphoides* (toi) and *Elattostachys apetala* (ngatata) were also present, with a combined relative dominance of 11%. The five species mentioned above have a combined relative dominance of 84%, indicating that the vegetation in this plot is highly disturbed. With 108 trees per 1000 m^2, this plot has the second fewest number of trees in the sampled area. The most common species were tavahi, fau and ngatata, which together comprised 54% of the individuals counted. A mere 12 tree species were recorded in the plot, which makes it the most species-poor plot of the nine sampled. The area is probably still being disturbed by the activities of villagers or by people from the nearby resort.

Plot 3. Mo'ungalafa secondary forest

This plot is located on top of Mo'ungalafa (W174 03.175, S18 39.246) and comprises an area of 1000 m^2 (100 x 10 m). The two dominant tree species were typical secondary forest trees – the native *Alphitonia zizyphoides* (toi) and *Rhus taitensis* (tavahi), with a combined relative dominance of 54%. These two species are the most characteristic trees of mature secondary forest in Tonga. The five most common species were toi and tavahi, along with *Glochidion ramiflorum* (masikoka), *Morinda citrifolia* (nonu), *Ficus scabra* (masi ata) and *Micromelum minutum* (takafalu). The latter four are understorey or subcanopy species, and the six trees together account for 67% of all the sampled trees. Twenty-nine tree species were recorded in the plot, which makes it the most species-rich plot of the nine sampled. The site is a typical mature secondary forest on Vava'u, as shown by the dominant tree species being mostly large with a population structure that shows that they are not reproducing themselves and will eventually be replaced by mature forest species whose seedlings are better adapted to a shady forest floor.

Plot 4. Toafa disturbed lowland forest

This plot is located at Toafa near the sea cliff on the west end of the main island (W174 03.680, S18 37.416) and comprises an area of 1000 m^2 (100 x 10 m). The dominant species in this disturbed lowland forest was the native secondary forest tree *Elattostachys apetala* (ngatata), which had a relative dominance of 21%. However, close behind it were the lowland forest trees *Calophyllum neoebudicum* (tamanu) and *Canarium harveyi* ('ai), which had a combined relative dominance of 35%. The fourth dominant was the native cycad *Cycas seemannii* (longolongo), which is a gymnosperm understorey species not found in any of the other plots. The two typical mature secondary forest species *Rhus taitensis* (tavahi) and *Alphitonia zizyphoides* (toi) were represented only by a total of five trees with a combined 8% relative dominance. This indicates that the disturbance to this forest may have been only partial rather than a compete clearing for agriculture, since the most common species is the lowland forest tree tamanu. The other common species were 'ai, *Meryta macrophylla* (kulukulufa), *Pittosporum* cf. *arborescens* (masikona), *Elaeocarpus floridanus* (ma'ama'alava) and *Anacolosa lutea*. Together these six species comprised 54% of the total trees sampled. The 232 trees per 1000 m^2 makes this the plot with the highest number of trees in the sampled area. Nineteen species were encountered in the plot.

Plot 5. Vaka'eitu lowland forest

This plot (W174 06.158, S18 43.131) is located on an eastfacing slope at the north end of Vaka'eitu Island and comprises an area of 1000 m^2 (100 x 10 m). The three dominant tree species were *Planchonella grayana* (kalaka), *Zanthophyllum pinnatum* (ake) and *Serianthes melanesica* (mohemohe), which together had a relative dominance of 63%. The dominance of the kalaka, which is mostly a coastal species, and the most common species ake (with 36 trees in the plot) indicate that this forest fits into the concept of a 'coastal forest' that is somewhat different than lowland forest typically dominated by *Maniltoa grandiflora* (pekepeka). Two of the other dominant species, *Drypetes vitiensis* (no Tongan name) and *Guettarda speciosa* (puopua), are also typically found near the coast. The *Drypetes* and the kalaka were second and third in numbers of trees in the plot, but together they comprised only 23 individuals compared to the 36 for the ake. This forest appears to be very intact and undisturbed, since none of the 18 species present can be classified as secondary forest species. Notably absent in this regard were *Rhus taitensis* (tavahi) and *Alphitonia zizyphoides* (toi), which are characteristic of major disturbance.

Plot 6. 'Oto lowland forest

This plot (W174 03.360, S18 42.300) is located on an eastfacing slope on the north end of 'Oto Island several kilometres south of the main island, and comprises an area of 500 m^2 (50 x 10 m). T he three dominant tree species were *Chionanthus vitiensis* (afa) with 26% relative dominance, *Maniltoa grandiflora* (pekepeka) with 16%, and *Planchonella grayana* (kalaka) with 15%. These are all lowland forest trees, as were every other species in the plot except the secondary forest tree *Elattostachys apetala* (ngatata) which, however, had only 2% relative dominance. Consequently, this plot is a typical, relatively undisturbed lowland forest. The most common trees in the plot were afa (22 trees), *Ixora calcicola* (no Tongan name, 16) and pekepeka (13). Lxora is a small understorey tree, and no individuals which reached 15 cm dbh. Together the three most common species accounted for 56% of the trees measured in the plot . The two dominant species were represented in all of the size classes, which shows that this forest is a stable climax forest. Eighteen tree species were recorded in the plot. It is not valid to compare this to plots that were 1000 m^2, since the larger size would usually mean more species.

Plot 7. Mo'ungalafa lowland forest

This plot is located on the main island on an eastfacing slope at the south end of Mo'ungalafa (W174 03.032, S18 39.331) and comprises an area of 1000 m^2 (100 x 10 m). The dominant tree species was *Maniltoa grandiflora* (pekepeka), with a relative dominance of 19%. This was followed by *Cryptocarya turbinata* (motou, 14%), *Garuga floribunda* (manaui, 14%) and *Pleiogynium timoriense* (tangato, 11%). The motou is a subcanopy species, while the other three are canopy species. The most common species by far was the motou with 38 individuals, followed by 25 for the understorey species *Vavaea amicorum* (ahi vao). Together these two trees represented 53% of the trees measured. The typical mature secondary forest trees*Rhus taitensis* (tavahi) and *Alphitonia zizyphoides* (toi) were entirely absent from the site, which indicates the forest is relatively undisturbed. Only three typical understorey secondary forest trees, *Elattostachys apetala* (ngatata), *Glochidion ramiflorum* (masikoka) and *Grewia crenata* (fo'ui), were recorded in the plot, and represented a total relative dominance of only 7%. All four of the dominant species had individuals in both small and large size classes, showing that the vegetation is in a stable climax condition. Twenty-five tree species were found in the plot, making it the second most species-rich plot of the nine sampled.

Plot 8. 'Euakafa lowland forest

This plot is located on the uninhabited island of 'Euakafa several kilometres south of the main island on a northfacing slope (W174 02.256, S18 45.421) and comprises an area of 500 m^2 (50 x 10 m). The dominant tree species was *Maniltoa grandiflora* (pekepeka) with a relative dominance of 43%. This was followed by *Garuga floribunda* (manaui) with 36% relative dominance and *Chionanthus vitiensis* (afa) with 11%. The most common species by far was the pekepeka with 27 individuals and afa with 24. Together these two trees represented 76% of the trees measured. T he typical mature secondary forest trees *Rhus taitensis* (tavahi) and *Alphitonia zizyphoides* (toi) were entirely absent from the site, which indicates the forest is relatively undisturbed. The dominant pekepeka had individuals in both small and large size classes, showing that the vegetation is in a stable climax condition. Manaui, however, had only four large trees and no small ones, indicating that it may eventually disappear from the plot. Sixteen tree species were found in the plot.

Plot 9. Utula'aina lowland forest

This plot is located on the northeast coast of the main island (W173 56.722, S18 34.511) just north of Holonga Village, and comprises an area of 1000 m^2 (100 x 10 m). It was the best area of native forest found during the BIORAP, because it was located on relative flat, non-rocky soil and was nearly undisturbed lowland forest. It was probably preserved from destruction because it is one of the few flat areas found below the steep cliffs that mark the northern side of the island. Taking timber out along the steep coastal track to the top of the cliff would have been an arduous task. The dominant tree species were *Maniltoa grandiflora* (pekepeka) with a relative dominance of 23%, *Pleiogynium timoriense* (tangato) also with 23%, and *Syzygium clusiifolium* (fekika vao) with 16%. What is remarkable about this plot is that over half of the trees sampled (54) belonged to one subcanopy species – fekika vao. Only one other species, pekepeka, had over five individuals in the sample. Only a single individual secondary forest tree, *Rhus taitensis* (tavahi), was found in the plot, and this tree may have become established after some climatic event (e.g. a cyclone) that did minimal damage to the forest. The forest is probably classified as a climax forest, since the dominant tree is represented in all the size classes. However, the second dominant species, tangato, was represented by only large individuals. This may indicate that this species is a secondary forest tree. Eighteen tree species were recorded in this plot.

2.5. Discussion

The most obvious botanical aspect of Vava'u determined by the survey is that the vegetation is highly disturbed. Probably over 90% of the native forest has been removed or severely altered, so much so that it is difficult to find any areas of lowland forest. The last remaining original type of forest appears to be found only on the cliffs of the main island, which are unsuitable for any human purposes, and on rugged, uninhabited outer islands. These cliffs and rugged islands are virtually inaccessible, which may be a key to their future protection. There are no active timber operations in Vava'u, and native species are not harvested other than perhaps a few trees for firewood or light construction, so in this regard they are relatively safe. The only significant area of primary lowland forest encountered during the BIORAP was situated at Utula'aina on the coast just to the east of the beach north of Holonga Village. This flat coastal area could have been utilised for agroforest, but for some reason has not been, perhaps because of its distance from Holonga and difficulty of taking cut timber up the steep trail.

Only ten of the 57 or so outer islands (i.e. other than the main island) were visited. Of these, the highest ones with the least human disturbance are the ones with the best native vegetation. The best areas on these islands are the slopes, some of which are not nearly as steep as those on the main island. The soil on these tends to be jagged limestone, making it something of a 'coastal forest' dominated by species that can survive on the rocky substrate near to the sea. 'Euakafa and Vaka'eitu were probably the islands with the best vegetation among those that were visited. Maninita was not visited by the Principal Investigator, but others on the biological team collected a few specimens there. The island is relatively pristine, has numerous seabirds, and is home to several plant species that are otherwise rare in Vava'u, including the new Tongan record *Boerhavia albiflora* and the rare *Sesbania coccinea* that is known from nowhere else in Tonga.

A number of species known to occur or to have occurred on Vava'u seem to have disappeared or are disappearing. There are several reasons why the missing native species have become rare or extirpated from Vava'u: (1) loss of habitat; (2) competition, especially from introduced invasive species; (3) herbivory; and (4) natural rarity. Loss of habitat after the arrival of the first Polynesian settlers about 3,000 years ago is probably the most serious cause of plants becoming rare in Tonga. After the original settlement, the population expanded and started utilising the environment, especially the lowland forest that covered nearly all of the islands. Forests were cut down for housing sites and plantations, and marshes were utilised for growing taro. A major cause of habitat destruction has undoubtedly been the indiscriminate use of fire, which has long been integral to the Tonga shifting agriculture system. Species already uncommon became threatened, and some have probably already been extirpated.

Competition is perhaps the second most important cause of rarity of Tongan plant species. Tongan native plants developed together in the archipelago environment over thousands and even millions of years, and each of them developed traits that allowed them to survive in the little-changing habitat. However, the first Polynesian settlers arriving in Tonga brought with them alien plant species that changed the vegetation dynamics. Some of these species were cultigens that do not reproduce naturally by themselves, but some were adventive species that produce seeds and thereby spread into the native habitats. Even more serious were the changes wrought by the more numerous and aggressive alien weedy species brought to Tonga after the arrival of Europeans from about 1773. Some native plant species were probably dependent upon natural forest clearings and open sunny conditions for their seedlings to grow and develop. The arrival of so many new weedy species (about 180 so far on Vava'u) has caused these clearings to now be rapidly covered with a smothering growth of alien weeds that block out the sunlight needed by the native species.

Herbivory has been a major problem for native Pacific species ever since the introduction of alien mammals by the Polynesians. Prior to the arrival of the first settlers, there were no native terrestrial mammals present in Polynesia other than bats. Tonga has one apparently native fruit bat that is more helpful to native plants than it is harmful, since fruit bats are major seed dispersers. Polynesians brought two herbivorous mammals with them – the Polynesian rat (*Rattus exulans*) and the pig. The Polynesian rat's influence on the native flora of Polynesia is only now being understood. They are major seed consumers, particularly of palms, and are now thought to have led to the extinction, extirpation and drastic population reduction of palms in widely dispersed places such as Easter Island, Hawai'i and Fiji. An intriguing idea is that the palm *Pritchardia pacifica*, which is not known anywhere in the wild except on the cliffs of 'Eua, may once have been a part of lowland rainforest on other islands in Tonga, including Vava'u. Pigs have had serious effects in many places in Polynesia, including most of the main islands of Tonga, because of their rooting habits and taste for some native species. Herbivores of modern introduction, especially goats, cattle, horses and sheep, have probably also caused much damage to native vegetation in Tonga. This can especially be seen on small uninhabited Vava'u islets where goats are let loose and become established.

Some species are probably naturally rare in Tonga, for a variety of reasons. The most common one is probably the chance recent arrival of species that have not had enough time to spread. A possible example of this is *Capparis cordifolia* that is restricted to just a few littoral habitats on Tongatapu and 'Eua, and based on the present survey, Vava'u. These species may be considered to be 'vagrants' that reached Tonga or Vava'u by accident, but stayed rare or were extirpated because of limited suitable habitat or other reasons.

2.6. Conservation recommendations

Several recommendations are made here about the flora and vegetation of Vava'u, including areas and species that should be given some kind of protection.

2.6.1. PROTECTION OF RARE SPECIES

Several species occurring in Vava'u are rare and in need of protection. The rarest of them is probably *Casearia buelowii* (no Tongan name) that is known from Mt Talau. It was found in flower there in January 2013 and in young fruit in February 2014. The seeds should be collected and propagated to save this rare species. A good place for this might be the Ene'io Botanical Garden in Vava'u, whose owner, Haniteli Fa'anunu, shows a keen interest in the flora of Tonga. A second species, *Atractocarpus crosbyi* (no Tongan name) is also endemic to Vava'u. It has attractive flowers that look like small gardenias, and perhaps would be a good candidate for propagation as a native ornamental. It was not found during the present survey, but has been found a number of times in the recent past.

Two tree species should also be considered for propagation. *Serianthes melanisica* (mohemohe) is an attractive leguminous tree that would do well in cultivation. It is rare in Tonga, where it is known in the wild only from Vava'u and Late. A small population of this species is found on the east end of Utungake, and is an easy seed source. A Tongan endemic tree, *Syzygium crosbyi*, should also be propagated, since it is rare on Vava'u. Its seeds can also be collected at the same Utungake site noted above. Another leguminous plant, *Sesbania coccinea*, is known in Tonga only from Maninita Island. This can easily be propagated, and should perhaps be planted on other nearby potentially rat-free islands. Other rare species will be helped by keeping intact what little native vegetation remains in Vava'u.

2.6.2. PROTECTION OF REMAINING NATIVE VEGETATION AREAS

Mt Talau

Foremost of areas that would benefit from recognition and protection is Mt Talau. This hill also has scenic beauty, and is located on the edge of Neiafu, the main city on Vava'u. Mt Talau has a unique shape and geological formation, and has secondary forest covering the top. It is not prime land for agriculture, but the disturbance in the forest shows it has recently been used as agroforest. It is the only know place where *Casearia buelowii* (no Tongan name) is known to occur, as noted above. The best way to preserve this is to give the park formal recognition. Also, it should be possible to rid the forest at Mt Talau of the invasive tree red-bead tree *Adenanthera pavonina* (lopa), which was the second dominant species in the vegetation plot (Plot 1).

Mo'ungalafa

This mountain, similar to Mt Talau, is on the western end of the main island of Vava'u. Parts of it, especially the steep slopes, cliffs and part of the top, are covered with native lowland forest. Because of its topography, it might be easier to preserve compared to other more accessible areas on the island. However much of the top and surrounding area is highly disturbed, and some of it is being used for cattle grazing.

Utula'aina

This area was one of few places where undisturbed lowland forest occurs on flat land. It is a long walk from the nearby village of Holonga situated between the steep coastal slopes and the sea, and perhaps this isolation is what has saved it until now. It appears to be relatively pristine, with only native species present. This would make an ideal reserve because of its proximity to the beautiful bay at the terminus of a trail. Perhaps the two could be linked together into a reserve, especially if the bay has good marine assets.

Utungake

There is a small patch of forest on the south side of the top of the hill leading up from the causeway on the east end of Utungake Island. A number of native trees, perhaps two dozen, can be found along this short stretch of road, including the rare *Serianthes melanesica* (mohemohe) and the endemic trees *Syzygium crosbyi* (no Tongan name) and *Guioa lenticifolia* (no Tongan name). This is a good place to collect seeds for these species, or give a short ecotourism lecture to visiting tourists. Perhaps the best way to preserve it would be to let the village officials know if its existence and importance. The land is not likely to be useful for humans, since it is on the roadside adjacent to a short steep slope leading down to the sea.

Outer islands

Several of the outer islands have promise as protected islands. Maninita is home to many seabirds and is important for these alone, but it is also interesting botanically. Several species found on the island are rare elsewhere in Tonga, including *Sesbania coccinea* (ohai), *Boerhavia albiflora* (a new record for Tonga), *Portulaca lutea* (tamole; a new record for Vava'u), *Sesuvium portulacastrum* (a new record for Vava'u) and *Suriana maritima* (rare in Vava'u). 'Euakafa, which is uninhabited, is a good candidate for protection since the slope and upper regions of the island are covered in good forest. At the time of the visit, however, there was small scale construction going on near the landing site. 'Oto Island is also good, since it is relatively inaccessible. To be valuable from a conservation perspective the goats currently there would have to be removed.

2.6.3. INVASIVE MAMMAL MANAGEMENT

Many of the small uninhabited islands have goats and pigs on them. Apparently villagers put them there to prosper, and later come back to slaughter them for food. Raising livestock this way is very harmful to the vegetationbecause goats and pigs eat everything they can reach. This is visible on many of the small islands, where the only plants growing by the sea are on steep slopes or cliffs where goats and pigs cannot reach them. It could be relatively easy to educate the local population about the damage that goats and pigs do, and perhaps make laws banning the practice. Although goats and pigs are a major source of meat, the damage they cause make them prime targets for removal. Similarly, rats have a major impact on the distribution and abundance of plants and other native biodiversity and rat management should be considered on islands where rats are having serious impacts on important native vegetation as well as potentially also impacting on threatened birds (e.g. ground doves) or where significant seabird populations are found.

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CHAPTER 3 REPTILES OF VAVA'U

ADAM BACKLIN AND ROBERT FISHER

TEAM MEMBERS: TONGAN GOVERNMENT STAFF PARTICIPATED IN REPTILE SURVEYS

3.1. Summary

- The Vava'u Island group of the Kingdom of Tonga was surveyed for terrestrial reptiles from 12 to 27 February 2014.
- During this survey reptile inventories were collected on 13 of 58 islands within the Vava'u island group, five of which had no previous reptile information – Kenutu, Maninita, 'Oto, Taula and 'Umuna.
- Fifteen sticky trap transects spanning 4.2 km and 10 islands were sampled.
- Twenty-four visual encounter surveys were conducted, covering 22.3 km for diurnal and nocturnal species.
- A total of 417 terrestrial reptiles was recorded representing 11 species of lizard.
- The first record of the invasive common house gecko (*Hemidactylus frenatus*) within the Vava'u island group was collected.
- Twenty-nine new island species records for reptiles across the Vava'u island group were collected.
- No snakes or amphibians were detected.
- It is recommended thata survey of the Lau banded Iguana be conducted across the Vava'u island group.

3.2. Introduction

The Vava'u island group within the Kingdom of Tonga is known to support 12 species of terrestrial reptiles, all of which are lizards. Eleven of these species are documented from previous expeditions and research and one is newly documented from this study and represents a recent (last 20 years) arrival to Vava'u. Steadman et al. (1999) compiled much of the prior information on the reptiles of Vava'u which includes several expeditions and research projects (Gill 1990; Gill and Rinke 1990; Zug and Gill 1997). In addition to Steadman's compilation, we have included reptile information from 10 museums and additional research projects (Austin and Zug 1999; Steadman et al. 2002; Pregill and Steadman 2004; Zug et al. 2012).

3.3. Sites and methods

Surveys were conducted for terrestrial reptiles and amphibians from the Vava'u island group within the Kingdom of Tonga between 12 and 27 February 2014. Reptile surveys were conducted on 13 of the 58 islands within the Vava'u Island group (Figures 3.1 and 3.2, Annex3.1). Six sticky trap transects were sampled on the main island of 'Uta Vava'u, nine sticky trap transects were sampled on other islands within Vava'u, and reptiles were recorded by visual encounter surveys from an additional three islands.

The survey effort on Vava'u consisted of three techniques when possible (Fisher 2011). The first technique was daytime visual encounter surveys of the habitats around the island, as possible, with capture of animals by hand. The second technique involved setting up sticky trap transects at various habitats and elevations across the islands (Figures 3.3 and 3.4). Each station consisted of three standard sticky mouse traps, one placed on the ground, one placed on a log off the ground, and the third stapled to a tree (about 1.5 m high). These traps were optimally placed out in the afternoon and then collected the next morning so that they would sample diurnal and nocturnal species. The third technique was night visual encounter transects. These were used to provide additional data on geckos and iguanas and were both time and distance constrained surveys. We also recorded the presence of invasive mammal and ant species, including rats, pigs, goats, cats and yellow crazy ants.

For each sticky trap transect, a sampling station was set up every 20 or 30 m along the transect line . At each sampling station the three sticky traps were deployed: one on the ground (G), one on a log (L) above the ground, and one on a tree

(T) approximately 1.5 m off the ground. The locations of the transects were selected to sample the variety of habitats, elevational gradients and vegetation types across Vava'u. Captured lizards were removed from the traps using vegetable oil by rubbing it along their body and peeling them off the trap. Once the lizard had been removed, the location of the sticky trap was recorded and the lizards were identified, weighed (g), measured snout to vent (mm), and either a tissue sample or the whole lizard was collected as a voucher specimen. Rats, rat fur and rat chew marks were recorded from the traps. Yellow crazy ants were also counted from the traps. The traps and flagging were removed at the end of the survey. Museum vouchers of reptiles were also queried for the Kingdom of Tonga via HerpNet2. org on 14 March 2014 to provide additional information on previous collections from the area.

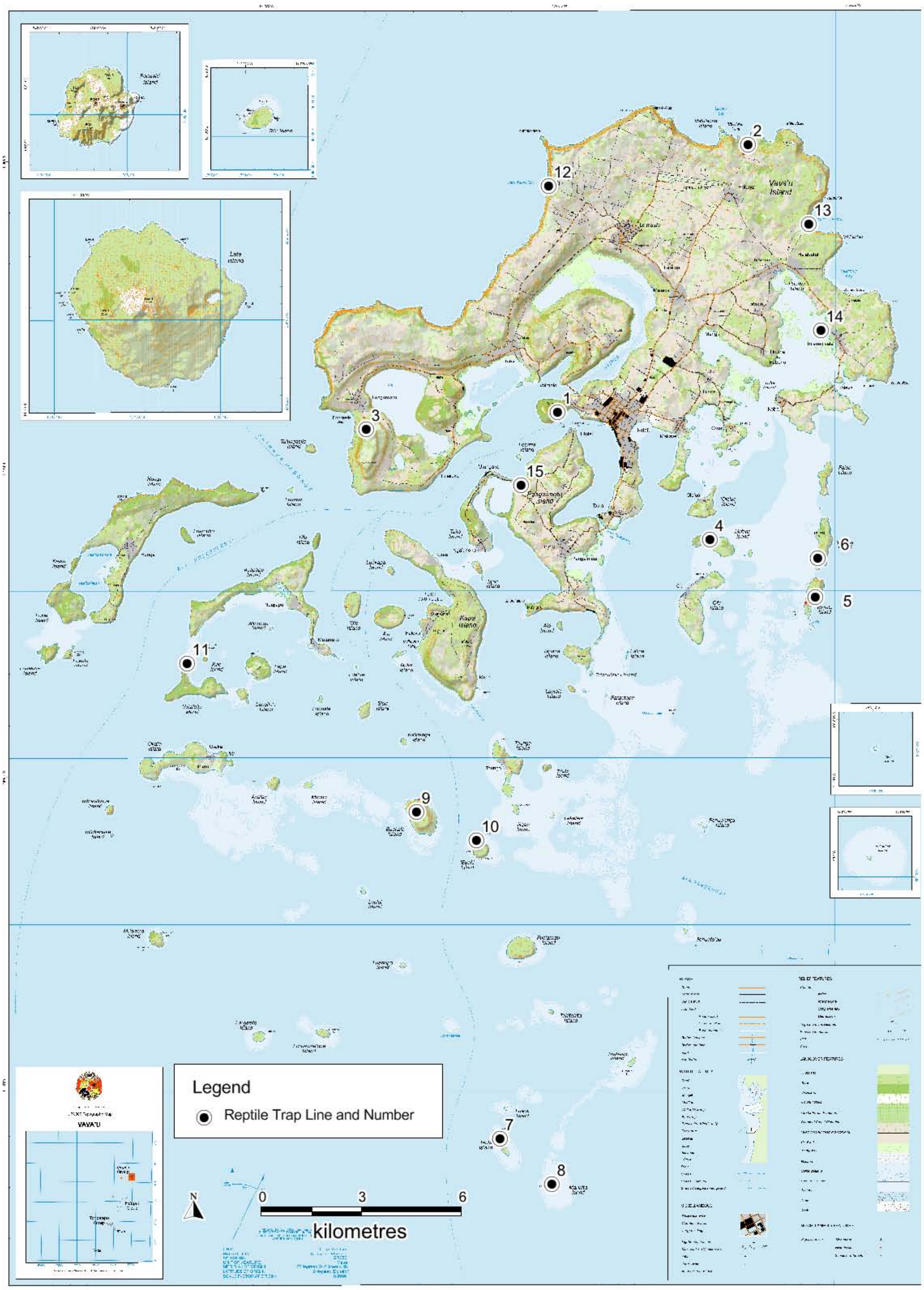

Figure 3.1. Location of reptile trap lines in Vava'u.

Figure 3.2. Location of night and day transects in Vava'u.

Figure 3.3. Sticky trap stations (photos byAdam Backlin).

Figure 3.4. Ana Fekau and Saia Fonokalafi assisting installation and sampling of reptile sticky trap stations (photos by Adam Backlin).

3.4. Results

Overall, 4.2 km of sticky trap transects were sampled. These included 15 transects distributed across the Vava'u island group. These surveys covered a broad variety of habitats and islands across Vava'u, from coastal beaches through Maniltoa forests, secondary forests and mangroves (Figure 3.1). A total of 22.3 km of visual encounter surveys was completed with 15.6 km completed during the day and 6.7 km completed at night (Figure 3.2).

A total of 417 terrestrial reptiles representing 11 lizard species was recorded during this survey (Table 3.1 and Figures 3.5 and 3.6). Six species of skink, one iguana species and four gecko species were detected including the first record of the invasive common house gecko (*Hemidactylus frenatus*) on Vava'u. No snakes or amphibians were detected. Full results from the reptile survey are presented in Annex 3.1.

During this survey we collected reptile inventories on 13 islands, five of which had no previous reptile information – Kenutu, Maninita, 'Oto, Taula and 'Umuna. We collected 29 new island species records for reptiles across the Vava'u Island Group (Table 3.2).

A query of the reptiles from the Kingdom of Tonga from HerpNet2. org on 14 March 2014 revealed 1,413 museum records. Records were located from ten museums: the American Museum of Natural History, NY (AMNH), Bernice P. Bishop Museum, HI (BPBM), the California Academy of Sciences, CA (CAS), Carnegie Museum, PA (CM), Field Museum of Natural History (FMNH), Harvard Museum, MA (MCZ), Osaka Museum of Natural History, Japan (OMNH), San Diego Natural History Museum, CA (SDNHM), Utah Museum of Natural History, UT (UMNH), and the Smithsonian National Museum of Natural History, Washington, DC (USNM). Museum abbreviations follow Leviton et al. (1985). Of the 1,413 records, 1,389 were of terrestrial reptiles. Of those, 200 were terrestrial reptiles from the Vava'u island group representing ten lizard species from seven islands (Table 3.2).

Table 3.1. Lizard species recorded in Vava'u surveys.

Island	Lau banded iguana	Oceania gecko	Mourning gecko	Pacific slender-toed gecko	Common house gecko	Oceanic snake-eyed skink	Pacific moth skink	Undetermined skink	White-bellied copper-striped skink	Dark-bellied copper-striped skink	Tongan robust treeskink[1]	Polynesian slender treeskink[2]	
	Brachylophus fasciatus	Gehyra oceanica	Lepidodactylus lugubris	Nactus palagicus	Hemidactylus frenatus	Cryptoblepharus poecilopleurus	Lipina noctua	Emoia cyanura /impar	Emoia cyanura	Emoia impar	Emoia mokolahi[1]	Emoia tongana[2]	Total captures per island
'Uta Vava'u	1	11	3	8	5	-	4	5	21	35	1	5	99
Pangaimotu	-	-	-	-	-	-	-	3	6	2	1	-	12
Vaka'eitu	-	-	-	-	-	1	-	-	5	8	-	-	14
'Euakafa	-	1	1	-	-	-	-	-	10	12	-	-	24
A'a	-	2	-	-	-	-	-	-	-	3	-	-	5
Mafana	-	2	-	-	-	-	-	-	1	1	-	-	4
'Euaiki	-	-	-	-	-	-	-	-	-	17	-	-	17
Kulo	-	3	-	-	-	-	-	1	-	-	-	-	4
Kenutu	-	5	8	2	-	17	-	12	38	28	-	-	110
Maninita	-	19	11	1	-	-	-	-	2	5	-	-	38
'Oto	-	-	-	-	-	4	-	-	-	31	-	-	35
Taula	-	6	-	-	-	-	-	-	2	13	-	-	21
'Umuna	-	6	3	-	-	1	-	10	3	11	-	-	34
Total islands occupied	1	55	26	11	5	23	4	31	88	166	2	5	417

1 Formerly Dandy skink, *Emoia trossula*.

2 Formerly Murphy's tree skink, ***Emoia murphyi.***

Table 3.2. New island species records in Vava'u.

Island	Lau banded iguana	Oceania gecko	Mourning gecko	Pacific slender-toed gecko	Common house gecko	Indo-Pacific slender gecko	Oceanic snake-eyed skink	Pacific moth skink	Undetermined skink	White-bellied copper-striped skink	Dark-bellied copper-striped skink	Tongan robust treeskink[1]	Polynesian slender treeskink[2]	
	Brachylophus fasciatus	Gehyra oceanica	Lepidodactylus lugubris	Nactus palagicus	Hemidactylus frenatus	Hemiphyllodactylus typus	Cryptoblepharus poecilopleurus	Lipina noctua	Emoia cyanura /impar	Emoia cyanura	Emoia impar	Emoia mokolahi1	Emoia tongana2	Total species/ island
'Uta Vava'u	BR, GR	BR, G, M, S	BR, G, M, S	BR, G, M, S	BR	M	G, M	BR, G, M, S	BR, G, S	BR, M	BR, M	BR, G, M, S	BR, GR, M, ZG	13
Pangaimotu	UV	M	-	-	-	-	-	-	BR, S	BR	BR, M	BR	-	6
Kapa	-	G	-	-	-	-	M	S	G, S	M	-	G	-	6
Hunga	-	S	S	S	-	-	S	S	S	-	-	S	-	7
Koloa	-	-	-	-	-	-	-		-	-	M	G	-	3
'Utungake	-	G	-	-	-	-	-	G	S	-	-	-	-	3
Vaka'eitu	-	S	S	S	-	-	BR	S	BR, S	BR, M	BR, M	-	-	8
Okoa	-	-	-	-	-	-	-	-	-	-	-	-	GR	1
Euakafa	-	BR	BR	M	-	-	-	-	BR, S	BR, M	BR, M	-	-	6
Taunga	-	-	-	-	-	-	-	-	S	-	-	-	-	1
A'a	-	S	-	-	-	-	-	-	BR, S	-	BR	-	-	3
Mafana	UV	BR, S	-	-	-	-	-	-	BR, S	BR	BR	-	-	5
'Euaiki	-	-	-	-	-	-	-	-	BR, S	-	BR	-	-	2
Foelifuka	-	S	S	S	-	-	-	-	S	-	-	-	-	4
Foeata	-	S	S	-	-	-	-	S	S	-	-	-	-	4
Kulo	-	BR, S	S	-	-	-	-	-	BR	-	-	-	-	3
Kenutu	-	BR	BR	BR	-	-	BR	-	BR	BR	BR	-	-	7
Maninita	-	BR	BR	BR	-	-	-	-	BR	BR	BR	-	-	6
'Oto	-	-	-	-	-	-	BR	-	BR	-	BR	-	-	3
Taula	-	BR	-	-	-	-	-	-	BR	BR	BR	-	-	4
'Umuna	-	BR	BR	-	-	-	BR	-	BR	BR	BR	-	-	6
Ofu	-	-	-	-	-	-	-	-	-	-	M	-	M	2
Total islands occupied	3	16	10	7	1	1	7	7	19	10	14	5	3	
New species records/island	2	5	4	2	1	0	4	0	1	4	5	1	0	29

1 Formerly Dandy skink, *Emoia trossula*.

2 Formerly Murphy's tree skink, *Emoia murphyi*.

BR = BIORAP (2014), G =Gill (1990), GR = Gill and Rinke (1990), M = museum record, S = Steadman et al. (1999), ZG = Zug and Gill (1997), UV = unverified.

Figure3.5. *Emoia tongana*, the largest lizard on the right, and *E. cyanura/impar*, the two smaller blue tailed lizards, captured on a sticky trap (photo by Adam Backlin).

Figure 3.6. Juvenile *Emoia tongana* captured on a sticky trap (photo byAdam Backlin).

3.5. Discussion

The BIORAP in 2014 was the most recent assessment of reptiles in the Vava'u Island Group since the Steadman et al. (1999) expedition in 1993 and 1995–1996. All but 30 of the 200 museum specimens from Vava'u were collected since 1985. This indicates that very little was known about the reptiles in Vava'u 30 years ago and since that time only a few collecting expeditions have occurred.

In the past 18 years, little has changed within the reptile community across the Vava'u island group. On our surveys in 2014 we detected all known species of terrestrial reptiles except one, the Indo-Pacific slender gecko (*Hemiphyllodactylus typus*). This species is known from only one specimen collected in 1993 (USNM 333617). This is a small cryptic gecko that is not easily captured on sticky traps. It likely still occurs within Vava'u at low densities. We were able to detect one additional reptile not documented from Vava'u, the invasive common house gecko (*Hemidactylus frenatus*). This is a newly established invasive species arriving within the last 18 years. It is readily detectable on the walls and ceilings of structures and was very common throughout Neiafu. We did not detect this species outside of Neiafu and it was also absent from Mounga Talau which is less than 1 km from structures in Neiafu. This species is continuing to spread throughout the Pacific Basin, as previously suggested by Case et al. (1994), and is not a surprising finding. Biosecurity measures could be implemented to try to limit its movement to all the remaining populated areas of Vava'u.

We did not detect any snakes or amphibians during this survey. We searched for the Pacific tree boa (*Candoia bibroni*) during our night time visual encounter surveys as there is a single museum record from the Kingdom of Tonga with no further locality data from 1906 (USNM 56211). This species also occurs in nearby Fiji and Samoa (Zug 2013). We spoke with numerous villagers regarding their knowledge of this species and no one we spoke with had ever seen or known of a large snake in Vava'u. We also conducted searches for the invasive Brahminy blindsnake (*Ramphotyphlops braminus*), mainly in Neiafu. This is a small, wormlike snake that is also known as the 'flower pot snake' as it has been transported across the Pacific in the soil of nursery plants (Zug 2013). We did not detect any blindsnakes during our searches. Additionally we did not detect any amphibians. No amphibians have ever been detected on Vava'u. Our surveys aimed to confirm that no invasive amphibians have established recently. The most likely invasive amphibian species would be the cane toad (*Rhinella marina*).

The Lau banded iguana (*Brachylophus fasciatus*) is classified as endangered by the IUCN. The only museum specimens from Vava'u were collected in 1969 (Gill 1990). We conducted day and night time visual encounter surveys for the iguana across Vava'u. Although this iguana is diurnal, night surveys are 10 times more likely to detect iguanas compared to day time observations (Harlow and Biciloa 2005). We collected one iguana in the village of Leimatu'a which was from elsewhere (the original capture location was never ascertained) and recently brought to this location (Figure 3.7). In speaking with the local villagers, many were aware of the iguanas and had seen them at some point in their lifetime. Occasionally, locals keep them as pets or sell them. In the areas we surveyed the iguanas, if still present, are at low densities. There may be areas on Vava'u that we did not survey that support large populations of iguanas, but none of the surveys in the 1980s or 1990s detected it. Most of the forest habitats the iguanas require are highly fragmented, manipulated or converted, restricting their ability to access other suitable forest patches. Cat predation seems to be one of the biggest threats to the species in its native range.

Zug (2013) and others (Steadman et al. 2002; Pregill and Steadman 2004) describe the Tongan Lau banded iguana as introduced from Fiji shortly after human colonisation of Tonga. Archaeological studies of the Ha'apai island group of Tonga revealed an extinct species of iguana (*Brachylophus gibbonsi*) that disappeared less than one century after human colonisation (c. 2,850 years ago; Steadman et al. 2002). Not a single bone of *B. fasciatus* has been found in any fossil record in Tonga while there is a fossil record of *B. fasciatus* in Fiji (Pregill and Steadman, 2014). It is likely that *B. fasciatus* was translocated from Fiji approximately 500 years ago to Tonga as a food source (Pregill and Steadman 2004). Further genetic evaluation of the iguanas is recommended to fully resolve their historic distribution (Keogh et al. 2008).

In the short time we were working on Vava'u, there were two separate documented translocations of iguanas. One was the iguana we ultimately captured in the village of Leimatu'a that had been collected from the forest. We were told that two iguanas had been captured, but one died shortly after translocation. The other translocation was an iguana captured on Pangaimotu, near a vanilla farm. A man named Bien came into possession of this iguana and released it on Mafana where he runs an eco-tourist camp. Movement of this species is of concern since we do not know the source of the iguanas or the size of the population. Outreach about reporting the native iguana and not moving them between islands is important.

There is also concern that other species, such as the invasive green iguana (*Iguana iguana*) that is present in Fiji, might be brought to Tonga. In Fiji, movement of the green iguana is leading to major concerns about economic impacts of this species, such as food security issues.

Invasive species are a major threat to the herpeto fauna of Vava'u and elsewhere. Invasive reptiles and amphibians can outcompete and displace native species (Case et al. 1994; Cole et al. 2005; Fisher 2011), and they can also introduce new parasites (Hanley et al. 1995) and diseases. There is also concern over invasive animals such as rats, pigs, goats and ants. Rats are voracious predators and readily eat geckos and skinks. We recorded rats at almost every sampling station on Kenutu and 'Umuna Islands. Pigs and goats are destructive to habitat and vegetation. Pigs dig up the ground and are likely disrupting iguana nests and eating their eggs. Invasive ants such as the yellow crazy ant (*Anoplolepis gracilipes*) are already widespread across Vava'u and have been implicated in major losses of biodiversity on other island systems (Smith et al. 2012; Fisher et al. 2012). 'Euaiki had much greater densities of yellow crazy ants than elsewhere across Vava'u although they were detected at most sampling areas in lower densities. Fisher et al. (2012) found no overlap between three large skink species and invasive ants on Savai'i (Samoa). The invasive ants have invaded all areas of Savai'I below 900 m. These three large skink species are now only found above 900 m where the ants have been unable to colonise.

We compiled all the available data for reptiles from the Vava'u island group and present it in Table 3.2. This table includes work from recent expeditions (Gill 1990; Gill and Rinke 1990; Zug and Gill 1997; Steadman et al. 1999; and this study) and records obtained from ten museums dating back to 1899. There is information available for reptiles from 22 of the 58 islands within Vava'u representing 12 species of lizard. From this data it appears that many of these species are widespread across Vava'u, including *Emoia cyanura*, *E. impar*, C*ryptoblepharus poecilopleurus*, *Lipina noctua*, *Gehyra oceanica*, *Lepidodactylus lugubris* and *Nactus pelagicus*. Other species appear to be more common on the larger islands or may simply have not been detected on other islands they occupy. Clearly the main island 'Uta Vava'u has the highest diversity with all known species being detected. This is the only island where three species have been detected– *Brachylophus fasciatus*, *Hemidactylus frenatus* and *Hemiphyllodactylus typus*. For the Lau banded iguana (*B. fasciatus*), we know that there is a recently translocated individual on Mafana and it was captured from Pangaimotu so this species is likely more widespread than the data represent. The common house gecko (*H. frenatus*) is an aggressive invasive that will likely spread to other islands. It likely arrived in Vava'u within the last 20 years and may already be present on other islands. The Indo-Pacific slender gecko (*H. typus*) is also a recent arrival to Vava'u. This is a small cryptic gecko that can be difficult to detect. It may be more widespread and species specific surveys may help to better understand its distribution on Vava'u. The Tongan robust treeskink (*Emoia mokolahi*) is endemic to Tonga and is widespread across the archipelago from Vava'u to Eua. This species likely occurs on more than five of the islands within Vava'u. Likewise the Polynesian slender treeskink (*Emoia tongana*) occurs from Vava'u south through the Ha'apai island group and north into Futuna and Samoa. This species is also likely more widespread in Vava'u than our data suggest. Since these last two species can be difficult to detect, all three sampling techniques need to be utilised since they have low detection generally, so that the distribution of the species can be better defined.

3.6. Conservation recommendations

The reptile community in Vava'u has remained mostly intact despite almost 3,000 years of human occupation. To ensure the persistence of these species into the future we outline several recommendations here.

The main island of 'Uta Vava'u has the most reptile diversity compared to the other islands in this group and is the highest priority island for reptile conservation in Vava'u. This island's forests are highly fragmented except on the steepest slopes. We recommend creating management areas that would allow for large intact sections of forest and also linking of forest patches. We also recommend inventories of invasive species across the islands that will provide baseline data to initiate conservation actions working towards control, removal and biosecurity protocol development.

The Lau banded iguana (*Brachylophus fasciatus* – Figure 3.7) is the only reptile from Vava'u that has a classification on the IUCN Red List. It is classified as endangered, with a decreasing population trend. It is persisting on Vava'u but almost nothing is known about this species in Tonga. Iguana specific surveys should be conducted across the Vava'u island group to understand their current distribution and abundance. This information is required to make informed management decisions on proposed locations of forest management areas or where restoration projects should occur. Compiling a checklist of iguana occupied islands is important as many of the islands have more intact forests than the main island. These islands could serve as refugia populations in the event of a catastrophic loss of the species within Vava'u, the rest of Tonga, or Fiji.

Figure 3.7. Lau banded iguana (*Brachylophus fasciatus*) captured in the village of Leimatu'a (photo by Adam Backlin).

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CHAPTER 4 BIRDS AND BATS OF VAVA'U

DAVID BUTLER AND MARK O'BRIEN

TEAM MEMBERS: ALMOST ALL TONGAN GOVERNMENT STAFF PARTICIPATED IN BIRD SURVEYS ON ONE OR MORE DAYS

4.1. Summary

- Bird observations were made in the Vava'u Group from 13 to 26 February 2014.
- Twenty sites were visited, six on 'Uta Vava'u and 13 on other islands. Ten other islands were observed while passing by boat. Automatic bird recorders were set out at a few sites to supplement the team's observations. Five days of boat surveys were carried out at sea alongside the marine mammal programme.
- A total of 38 species was recorded.
- The Tongan whistler (*Pachycephala jacquinoti*), endemic to the Vava'u group, was widespread in and near to areas of primary forest and is not considered under immediate threat.
- The blue-crowned lory (*Vini australis*) which had not been recorded on Vava'u for over 100 years was found at two sites.
- The friendly ground dove (*Gallicolumba stairii*) which had been found at only one site during surveys in 1995/96 was located on three islands this survey.
- Islands in the south of the group were found to hold very large numbers of seabirds, particular nesting noddies (*Anous* spp.) and white terns (*Gygis alba*).
- At least two of the three islands subject to rat control programmes in 2002 appeared to be free of these mammals though a further follow-up is recommended.
- One invasive species was recorded, the red-vented bulbul (*Pycnonotus cafer*), but it seems to be confined to 'Uta Vava'u and has not reached significant numbers there.
- The avifauna team also made observations of bats. No sightings were made of the endangered Polynesian sheath-tailed bat (*Emballonura semicaudata*). Small colonies of the insular or Pacific flying fox (*Pteropus tonganus*) were seen on many of the small forested islands and larger colonies were seen on 'Uta Vava'u with up to 250 bats present.

4.2. Introduction

Tonga's avifauna is a reflection of its relatively isolated location, over 800km from Samoa or Fiji, small size, and somewhat limited range of habitats with no high mountains. The flora and vegetation are very similar to those of Samoa and Fiji and the three countries share many bird species. Currently there are 74 bird species recorded from Tonga – 28 breeding land and freshwater birds, 24 breeding seabirds and 22 migrants or vagrants (Watling 2001). Two species, the Tongan megapode (*Megapodius pritchardii*) and the Tongan whistler, are endemic to the country.

The Vava'u group is lacking a few land and freshwater bird species found in other parts of the country, but its chain of around 40 islands supports very large numbers of some seabird species. A detailed survey of 16 of the islands was carried out by an American and New Zealand team in 1995/96 (Steadman and Freifeld 1998; Steadman et al. 1999) and this provided some baseline data for the current survey. An effort was made to visit all the islands that they identified as particularly significant for birdlife.

Bats are also included in this avifauna section. There are two species recorded in Tonga, the Insular or Tongan Flying-fox (*Pteropus tonganus)* and the small insectivorous Polynesian Sheath-tailed Bat (*Emballonura semicaudata)* which is endangered.

4.3. Avifauna survey schedule

The terrestrial BIORAP team arrived in Vava'u on the afternoon of 12 February 2014. The team included David Butler and Mark O'Brien (Figure 4.1), who led the avifauna aspect. This schedule identifies where they undertook observations, supported by Tongan members of the team (see also Figure 4.2).

Thursday 13 Feb

Mt Talau

Butler and O'Brien visited from 12pm with full team. Made species list and set out two recorders.

Friday 14 Feb

Mt Talau

O'Brien conducted 5-minute bird counts and retrieved recorders.

Holonga Bay/Utula'aina Point

Butler conducted 5-minute counts and set out one recorder.

Saturday 15 Feb

Mo'ungalafa

Butler and O'Brien visited, did 5-minute bird counts, set up recorder and walked length of the site.

Monday 17 Feb

Eastern Islands – Kenutu, 'Umuna, Mafana

Butler and O'Brien visited Kenutu, 'Umuna – made species list, set out recorder on Kenutu and glue traps baited for rats on both islands. O'Brien overnighted on 'Umuna and Butler on Mafana where a recorder was set out and glue traps set.

Tues 18 Feb

Return from Eastern Islands;to 'Oto and A'a Islands

O'Brien ashore on 'Oto and Butler on A'a for brief observational surveys.

Wednesday 19 Feb

Southern Islands – Maninita, Taula, Lualoli

O'Brien to Taula, Butler to Lualoli (x2), both to Maninita – two recorders set up, and glue traps and snap traps for rats. Butler overnight on Maninita, O'Brien to Blue Lagoon for seabird/marine mammal surveys, observing chain of islands from Fonua'one'one en route.

Thursday 20 Feb

Butler returned from southern islands observing Luatefito and chain of islands from there to Lua'ui. O'Brien carried out seabird/marine mammal surveys on seas to the west and northwest of Vava'u.

Friday 21 Feb

'Euakafa and 'Euaiki

Butler to Euakafa (including setting glue traps for rats, collected after dark) and 'Euaiki. O'Brien carried out seabird/marine mammal surveys to the south and southeast of Vava'u.

Saturday 22 Feb

Western Islands – Vaka'eitu, Kulo

Butler to Vaka'eitu, Kulo and very briefly Langito'o islands. O'Brien carried out seabird/marine mammal surveys to the northwest of Vava'u.

Monday 24 Feb

Butler carried out seabird/marine mammal surveys largely off northern coast of Vava'u. O'Brien to Mo'ungalafa– retrieved recorder and conducted 5-minute counts; set recorder at Utula'aina Point.

Tuesday 25 Feb

Butler carried out seabird/marine mammal surveys of southern islands and out to 'trench' to south west. O'Brien to 'Oto Island and survey of inner bay, Vava'u.

Wednesday 26 Feb

Butler to Toafa and Utula'aina Point (retrieved recorder). O'Brien to Mt Talau and completed 5-minute counts.

Figure 4.1. Mark O'Brien above Vai utu Kakau(photo by D. Butler).

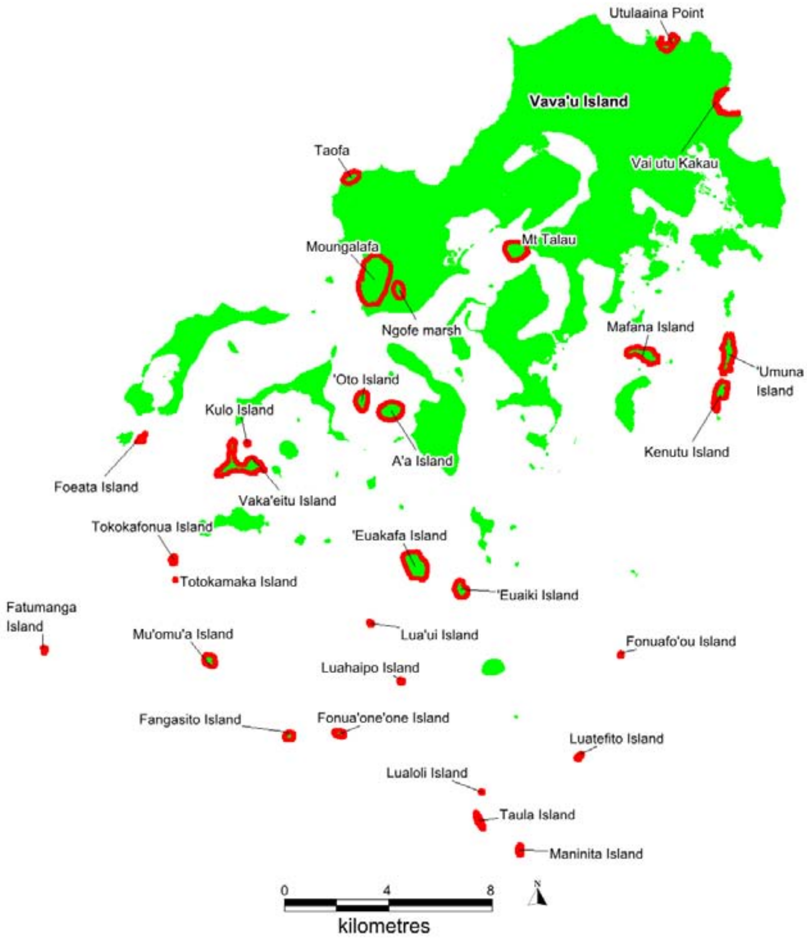

Figure 4.2. Bird observation sites, 2014.

4.4. Results: Species accounts

Species are listed in the order adopted by Watling (2001) which he identified as a more natural grouping for non-specialists than standard taxonomic classifications. Common, Tongan and scientific names are provided in that order using those in Watling (2001).

4.4.1 SPECIES RECORDED DURING THE SURVEY

Eastern reef heron, motuku, *Egretta sacra*

Occasional birds were seen on rocky shorelines of several islands, the majority of them of the grey (G) phase with fewer white (W) [Kenutu 1G, 'Umuna 1G 1W, Maninita 1G, Lualoli 1W, Euaiki 3G, Vai-'utu-kakau 2G, Fonua'one'one 1G1W].

White-faced heron, motuku, *Ardea novaehollandiae*

Twelve birds were seen on grass beside the runway at Vava'u airport on 28 February. This is a first record for Vava'u of this species.

Pacific black duck, tolo'a, *Anas superciliosa*

Several were reported by Atherton at the Ngofe Marsh to the east of Mo'ungalafa, a site where Steadman et al. (1999) saw three birds in the 1960s.

Junglefowl, moakaivao, *Gallus gallus* (Polynesian introduction)

It is difficult to determine which birds are true junglefowl and which are domestic chickens. However we located birds at a remote site at Mo'ungalafa which are unlikely to have been domestic.

Raptor (unidentified) (Order: Falconiformes)

Kate Walker reported to the team seeing a raptor coming into land on Fatamaunga Island within the past year which she considered to be buzzard-like in its wing shape. It seems most likely to have been a Pacific harrier or tiseni (*Circus approximans*), a species recorded elsewhere in Tonga but not apparently the Vava'u group before.

Buff-banded rail, veka, *Gallirallus philippensis*

Recorded in small numbers at several sites and perhaps most numerous or conspicuous on the sandy island of Maninita. We saw very few from the road on Vava'u compared to other places like Upolu, Samoa and Niue suggesting that breeding density is relatively low on Vava'u.

Purple swamphen, kalaē, *Porphyrio porphyria*

Birds were reported by others at Ngofe Marsh, Vava'u , Euaiki and Mafana islands utilising damper areas.

Friendly ground dove, tū, *Gallicolumba stairii*

Small numbers of friendly ground doves were seen and heard at Mo'ungalafa, Vava'u and on A'a and 'Oto islands.

Pacific pigeon, lupe, *Ducula pacifica*

Pigeons were recorded at most sites where there were significant areas of native forest.

Crimson-crowned fruitdove, kulukulu, *Ptilinopus porphyraceus*

Fruitdoves appeared to be more widespread and numerous than pigeons, occupying more modified areas including plantations.

Blue-crowned lory, hengehenga, *Vini australis*

Birds were seen on 'Euakafa (two individuals) and heard at Mo'ungalafa and also detected there by an automatic recorder.

Long-tailed cuckoo, kaleva, *Eudynamis taitensis*

One bird was seen in flight on Vaka'eitu.

Barn owl, lulu, *Tyto alba*

One was seen in the evening on 'Euakafa when checking rat traps and another alongside the road on the main island.

White-rumped swiftlet, pekapeka, *Aerodramus spodiopygius*

Swiftlets were encountered at almost all sites except the southernmost sand islands. About 50 empty nests were seen in a coastal cave on Euaiki, birds were seen to enter a cave on 'Umuna at dusk (28 birds entered the cave in a 45-minute period), and many flew in the vicinity of Swallows Cave, Kapa Island.

White-collared kingfisher, sikota, *Todiramphus chloris*

Kingfishers were a noisy presence in almost all forested areas but not recorded on the southernmost islands.

Polynesian starling, misi, *Aplonis tabuensis*

Starlings were widespread and relatively common at most sites except the southernmost islands.

Red-vented bulbul, fuiva, *Pycnonotus cafer* (European introduction)

Small groups were seen in Neiafu and a couple of individuals at other sites on 'Uta Vava'u but they were not common and seemed confined to this island.

Tongan whistler, hengehenga, *Pachycephala jacquinoti*

Whistlers were generally found at all sites with significant areas of native forest as well as in some patches of secondary forest with some connectivity to primary forest.

Polynesian triller, sikiviu, *Lalage maculosa*

Trillers were widespread on the main island in areas of modified habitat. They appeared absent from some of the smaller forested islands and the southernmost ones.

Wattled honeyeater, fuleheu, *Foulehaio carunculata*

Wattled honeyeaters were the most widespread of the landbirds, found fairly commonly at all sites.

Petrel (unidentified species), lafu, *Pterodroma* spp.

A single bird was seen flying to the north of Vava'u, while on a whalewatching boat. It showed all the signs of a small, dark-winged *Cookilaria* type petrel, but views were insufficient to determine whether it was a collared or black-winged petrel.

Wedge-tailed shearwater, manu'uli, *Puffinus pacificus*

Shearwaters were encountered in small numbers during the seabird surveys, particularly in areas of deep water around the island group. One hundred and fifteen individuals were recorded during 34 hours of surveys on the whale-watching boat.

White-tailed tropic bird, tavake, *Phaethon lepturus*

White-tailed tropicbirds were encountered along the coasts of many of the islands, particularly where there were sections of cliff. Just 16 individuals were recorded during 34 hours of surveys on the whale-watching boat.

Brown booby, ngutulei, *Sula leucogaster*

Brown boobies nested in small numbers on the ground above cliffs on several islands including 'Uta Vava'u, Kenutu, 'Umuna, Tuapapa and 'Oto. Eighty birds were present on the outlying rock at Fatamaunga – it was unclear from the views whether these were breeding, or roosting, individuals. A further 77 individuals were recorded during 34 hours of survey on the whale-watching boat.

Red-footed booby, ngutulei, *Sula sula*

Most red-footed boobies were found on the southern islands with young seen on Laula. Thirty to fifty birds were seen at Maninita and Laula but numbers had been reduced by Cyclone Ian which passed the Vava'u group on 10 January 2014. More than 200 were estimated during turtle surveys of the islands in December 2013, the majority on Laula (Kate Walker, personal communication). Fifteen individuals were recorded during 34 hours of survey on the whale-watching boat, all of which were to the south and east of Maninita. Juveniles of this species were present at the dock at Neiafu, where they were kept as pets.

Great frigatebird, lofa, *Fregata minor*; lesser frigatebird, lofa, *Fregata ariel*

Both species were recorded but most observations were at a distance when the identity of individual birds could not be determined. The largest numbers of birds were seen at Taula and Lualoli islands in the south of the group – counts were 14 Taula, 15 Lualoli, 1 Fonuafo'ou, 5 Mafana, and 3 above Mt Talau. Only four individuals were recorded during 34 hours of survey on the whale-watching boat.

Crested tern, 'ekiaki, *Sterna bergii*

Pairs of birds were seen at four sites during boat journeys south of the main island –by Vava'u Beach Resort, Kenutu, Euaiki and Vaka'eitu.

Black-naped tern, 'ekiaki, *Sterna sumatrana*

Small numbers were recorded at sea between Neiafu and 'central' islands such as 'Oto and Nuapapa. Few were seen further offshore, with only 21 individuals recorded during 34 hours of survey on the whale-watching boat.

Bridled tern, 'ekiaki, *Onychoprion anaethetus*

Twenty-six bridled terns were recorded during 34 hours of survey on the whale-watching boat, with a further nine observations of individuals noted on the crossing between the ferry terminal and A'a Island.

Blue noddy, *Procelsterna cerulea*

One was seen from a boat between Neiafu and Kapa Island.

Brown noddy, ngongo, *Anous stolidus*

Common and widespread nesting in small numbers on many islands and in larger numbers on southern ones. Four hundred and seventyone individuals were recorded during 34 hours of survey on the whale-watching boat.

Black noddy, ngongo, *Anousminutus*

The most numerous and widespread tern seen in sizeable feeding flocks at sea and nesting in large numbers on southern islands (Figure 4.3). Four thousand six hundred individuals were recorded during 34 hours of survey on the whale-watching boat.

White tern, tala, *Gygis alba*

Common and widespread with similar distribution to black noddy but in smaller numbers. Six hundred and four individuals were recorded during 34 hours of survey on the whale-watching boat.

Pacific golden plover, kiu, *Pluvialis fulva*

One was seen in Longomapu village near Mo'ungalafa, two on 'Umuna, one on A'a, five on Maninita Island, up to three on the school playing fields at Neiafu and thirty five at the Vava'u airport.

Bristle-thighed curlew, fata, *Numenius tahitiensis*

One was seen to fly off the shoreline of Fonua'one'one when we approached in the boat. It flew off toward the neighbouring Fangasito Island.

Wandering tattler, kiu, *Heteroscelus incanus*

Seen in small numbers on rocky shores on several islands including Kenutu, 'Oto and 'Umuna.

Ruddy turnstone, kiu, *Arenaria interpres*

One was seen on Euaiki Island on 21 February and at least one was present at Vava'u airport on 28 February.

4.4.2. Species previously recorded on Vava'u but not detected during the survey

Many-coloured fruitdove, *Ptilinopus perousii*

This species apparently died out in Vava'u in the 19thcentury (Steadman and Freifeld 1998). There was however a sighting reported in 2006 (John Mittermeier, personal communication) so this species should be considered as possible in future surveys.

Pacific swallow, *Hirundo tahitica*

Watling (2001) lists Vava'u as a location for this species.

Lesser (Fiji) shrikebill, *Clytorhynchus vitiensis*

The only record of this species on Vava'u was in the 1860s (Steadman and Freifeld 1998).

Black-winged petrel, lafu, *Pterodroma nigripennis*

A colony of more than 200 burrows was located on the southern part of Taula Island in March 2003 (Watling 2003) with a few nests at the northern end. In the limited time ashore on Taula during this survey (because of tidal conditions) a rapid assessment was made of the approximate area that the birds were thought to burrow, but there were no obvious signs of occupancy. A more complete assessment should be made at the next available opportunity.

4.5. Results: Landbirds by site

Table 4.1 summarises the landbird species found at the 16 sites visited by O'Brien or Butler –five on the main island and 11 on other islands – alongside the results of the 1995/96 surveys (Steadman et al. 1999).

There is a range of common landbird species that we would expect to be present at times on all the islands, just as Steadman et al. (1999) concluded, and others with particular habitat requirements like the purple swamphen which will be found wherever there are significant wetter areas. The exceptions are the introduced red-vented bulbul which has apparently not reached beyond the main island, and some of the rarer native species, which can be used to identify priority sites for conservation. These rare native species are as follows:

- Friendly ground dove –found only at Mo'ungalafa, 'Uta Vava'u Island in 1965/66 and observed there and on 'Oto and A'a islands this survey.
- Blue-crowned lory – not detected in 1965/66 but observed at Mo'ungalafa and 'Euakafa this survey.
- Tongan whistler – detected at a significant number of sites but requiring native forest of some extent and quality. This species has additional significance as endemic to Vava'u.

Table 4.1. Summary of land bird observations from 2014 Vava'u survey, alongside the results of the 1995/96 surveys (Steadman et al. 1999).

Species	'Uta Vava'u Island						Other islands										
	Mt Talau	Moung-alafa	Taofa	Utula'anina Pt	Vai utu Kakau	All sites combined	'Umuna	Kenutu	Mafana	'Euakafa	Euaiki	Taula	Maninita	'Oto	A'a	Vaka'eitu	Kulo
Buff-banded rail		*				*+			*+			*	*			*	
Purple swamphen						*+			*	+	*+					*	
Friendly ground dove		*				*+								*	*		
Pacific pigeon	*	*	*		*	*+	*		*+	*+	+			*	*+		*+
Crimson-crowned fruit dove	*	*	*			*+	*	*	*+	*+	*+			*	*+		*+
Blue crowned lory		*				*				*							
Long-tailed cuckoo																*	
Barn owl						*				*+							
White-rumped swiftlet	*	*	*		*	*+	*	*	*+	+	*+			*	*+		*
Collared kingfisher	*	*	*	*		*+	*	*	*+	*+	*			*	*+	*	*
Polynesian starling		*	*	*		*+			*+	*+	+			*	*+	*	+
Red-vented bulbul						*+											
Tongan whistler	*	*	*	*		*+	*	*	*	*+	+			*	*+	*	
Polynesian triller		*		*	*	*+	*	*	+	+	+			*	*+	*	+
Wattled honeyeater	*	*	*	*	*	*+	*	*	*+	*+	*+		*		+	*	

Key: *Recorded this survey;+recorded in 1995/96 survey.

Five-minute counts

Five minute point counts were undertaken at the three important sites on the main island of 'Uta Vava'u (Table 4.2). The most frequently recorded species were wattled honeyeater and Tongan whistler. Surprisingly few doves and pigeons were recorded – perhaps because February may be the wrong time of year for birds to be displaying.

Table 4.2. The birds and numbersrecorded for each of the 5 minute point counts at each of the key sites on 'Uta Vava'u.

Latitude	Longitude	Date	Start time	Brown noddy	White tern	Crimson-crowned fruit dove	Pacific imperial pigeon	White-rumped swiftlet	Collared kingfisher	Wattled honeyeater	Polynesian triller	Tongan whistler	Polynesian starling
Mo'ungalafa													
−18.6542	−174.052	15/02/2014	08:55						1	2		2	
−18.6625	−174.052	24/02/2014	09:16						2	2			
−18.6552	−174.051	15/02/2014	09:06	1					2	1	1	3	
−18.6556	−174.052	15/02/2014	09:19						1	2			
−18.6569	−174.050	24/02/2014	08:08				1			1		2	
−18.6578	−174.050	24/02/2014	08:20						1	1		1	
−18.6589	−174.050	24/02/2014	08:32									2	
−18.6598	−174.050	24/02/2014	08:44			1	1			1		1	
−18.6608	−174.050	24/02/2014	08:55						2	2		1	
−18.6615	−174.051	24/02/2014	09:07							2			1
Mt Talau													
−18.6473	−173.998	14/02/2014	06:32					2		6			
−18.6480	−173.996	26/02/2014	06:53				1			1		2	
−18.6487	−173.997	26/02/2014	07:06		1		1			1			
−18.6491	−173.998	26/02/2014	07:26		1					3		2	
−18.6476	−173.995	26/02/2014	07:43				1		1	1		1	1
−18.6473	−173.995	26/02/2014	07:51				1					1	1
−18.6480	−173.998	14/02/2014	06:40		1			6	1	3			2
−18.6484	−173.999	14/02/2014	06:49							2		2	1
−18.6476	−173.999	14/02/2014	07:03					4		2			
−18.6487	−174.000	14/02/2014	07:24					2	2	2		1	
−18.6489	−174.001	14/02/2014	07:32							4			3
−18.6481	−174.002	14/02/2014	04:42							1		1	
−18.6471	−174.002	14/02/2014	07:54		2				2	3		1	
−18.6473	−174.000	14/02/2014	08:07			1		2	2	2	1	3	
Utula'aina Point													
−18.5785	−173.947	14/02/2014	08:12							3			1
−18.5776	−173.947	14/02/2014	08:23		1					2		4	1
−18.5766	−173.947	14/02/2014	08:35						1	3		4	
−18.5753	−173.946	14/02/2014	08:56							1		4	
−18.5745	−173.945	14/02/2014	09:08		1				1	2		2	
−18.5743	−173.944	14/02/2014	09:20						2	1		1	
−18.5748	−173.942	14/02/2014	09:35						2	1		2	
−18.5753	−173.942	14/02/2014	09:53		1				1	2		3	
−18.5760	−173.941	14/02/2014	10:10						2			1	1
−18.5757	−173.940	14/02/2014	10:22							2	3	1	1

Automatic sound recorders

Three automatic sound recorders developed by the New Zealand Department of Conservation were set out at three locations on 'Uta Vava'u (Talau, Utula'aina Point and Mo'ungalafa), and three outer islands (Table 4.3).

Table 4.3. Details of use of automatic sound recorders.

Date	Machine	Location	Timing	Waypoint or code	Latitude	Longitude
14/2	ar3	Talau	am	52	–18.64849	–173.99925
14/2	ar4	Talau	am	Audio2	–18.64879	–174.00370
15/2	v1	Holonga	am	23	–18.57460	–173.94499
17/2	ar4	Kenutu	pm	43	–18.69958	–173.92636
18/2	ar4	Kenutu	am	43	–18.69958	–173.92636
17/2	v1	Mafana	pm	52	–18.68176	–173.95600
18/2	v1	Mafana	am	52	–18.68176	–173.95600
19/2	v1	Maninita	pm	60	–18.85860	–173.99513
20/2	v1	Maninita	am	60	–18.85860	–173.99513
19/2	ar4	Maninita	pm	57	–18.85737	–173.99523
20/2	ar4	Maninita	am	57	–18.85737	–173.99523
16/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
17/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
18/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
19/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
20/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
21/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
22/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
23/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
24/2	ar3	Mo'ungalafa	am	Fgd	–18.65475	–174.05223
24/2	v1	Holonga	pm	86	–18.57742	–173.94708
25/2	v1	Holonga	am	86	–18.57742	–173.94708
25/2	v1	Holonga	pm	86	–18.57742	–173.94708
26/2	v1	Holonga	am	86	–18.57742	–173.94708

4.6. Results: Seabirds and shorebirds by site

Maninita Island (5.2ha)

Bull *et al* (2002) report a survey, undertaken in 2001, estimating a population of 2,664 noddies and 233 white terns at the time of visit. They do indicate that this might not be the most appropriate time to survey seabirds. A followup survey in November/December 2001 (Watling 2002), estimated that there were 7,500 black noddy nests, 850 brown noddy nests and 550 white tern nesting sites present after sampling 19% of the island. These reflect population sizes of around 22,500, 2,550 and 1,650 individuals, respectively.

During our visit there was insufficient time to conduct an equivalent survey. Also, birds seemed to be at all stages of breeding from incubating eggs to fledged, independent young, making any counts very difficult. This was possibly due to Cyclone Ian which may have disrupted some initial nesting attempts. However it was clear that large numbers of the three species were present and there was no evidence of a significant decline in numbers since Watling's survey (2002).

Watling (2002) observed 12 red-footed boobies nesting and about 50 roosting on the island whereas we only observed about 15 birds around the island with no apparent nesting, again a likely impact of Cyclone Ian.

Figure 4.3. Tongan team leader Lupe Matoto with black noddy chick (photo by D. Butler).

Taula Island (7.0ha)

Watling (2003) reports surveys of Taula in March 2003 that estimated numbers of occupied nests for the main species as 5,780 black noddies and 675 brown noddies, noting that most white terns had finished breeding so no counts were possible. This would suggest total populations of around 17,340 and 2,025 individuals for the two noddies, respectively. Significant numbers of all three species were present when we visited but it was only possible to spend an hour ashore so no counts were made. In March 2003 38 pairs of red-footed boobies were considered nesting and about 100 birds roosted on the island at night. We observed a small number of young boobies and approximately 20 birds in all.

Lualoli Island (0.3ha)

During two brief visits we confirmed high densities of breeding noddies and the presence of white terns, 15 frigate birds and small numbers of red-footed boobies including fledglings.

Other southern islands

A number of southern islands were observed while passing by boat. In some cases the boat passed close enough for seabirds to take flight allowing some assessment of numbers, but others were surrounded by shallow reefs so this was not possible. Table 4.4 should be treated as indicative only, but it does confirm that there are many islands of significance for seabirds in addition to the Maninita group.

Table 4.4. Observations of seabirds on other islands made from boat.

Island	Noddies	White tern	Red-footed booby	Frigatebird	Brown booby
Luatefilo	c.100 (60:40 black/brown)	10	1		
Fonuafo'ou	Few hundred	20	1	1	
Luahaipo	2000+ (mostly black)	50			
Lualui	Several thousand	20			
Totokafonua	55	1			
Totokomaka	20				
Muomua	30 black, 2 brown	8			
Fangasito	150 black, 10 brown	120	4		
Fatumanga	2 brown			15	80
Fonua'one'one	400 (300 black, 100 brown)	40		3	

4.7. Results: Surveys of seabirds at sea

The whale-watching boat searched the seas around Vava'u for sightings of whales and dolphins. The bird survey data were collected by recording the number and species of all birds passing within 300m of the boat every minute (Figure 4.4). The flight direction and/or behaviour of the birds were also recorded (although this component has yet to be analysed). For the purposes of presentation these data were then summarised into 10 minute sections, which represented transects averaging about 1mile in length. Approximately 50 transects were collected per day on each of 20, 21 and 22 of February; 26 on 23 February; and 33 on 24 February. In addition any opportunistic boat trips to islands within the lagoon were also used to record 10 minute transect lengths. All data for 20–22 February have been used to produce the maps for the four species below. Additional maps can be output from eBird by setting the location to Vava'u, the month of survey to February, and the year of survey to 2014.

Figure 4.4. Juvenile red-footed booby landing on the survey boat (photo by M. Donoghue).

Wedge-tailed shearwater

This species was regularly seen from whale-watching boat, whenever we left the reef area and headed out to the deep oceans (Figure 4.5). Up to five birds were present in any one 10 minute time slot.

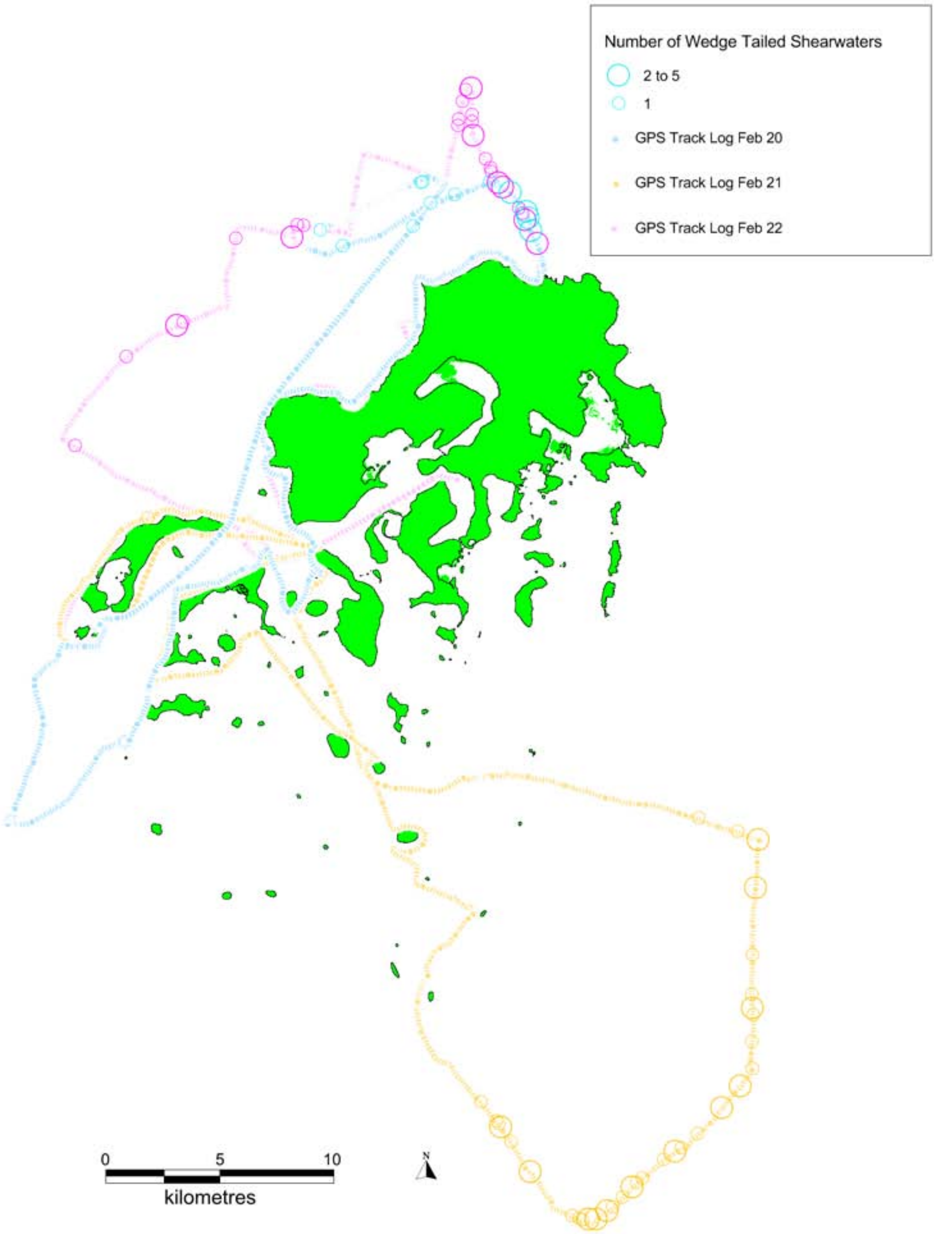

Figure 4.5. Map showing wedge-tailed shearwater sightings, 20–22 February 2014.

Black noddy

Black noddies were recorded both within the reef areas and the deeper ocean (Figure 4.6). The main colonies are in the south of the island group, while the main foraging areas appear to be to the north and west of the study area.

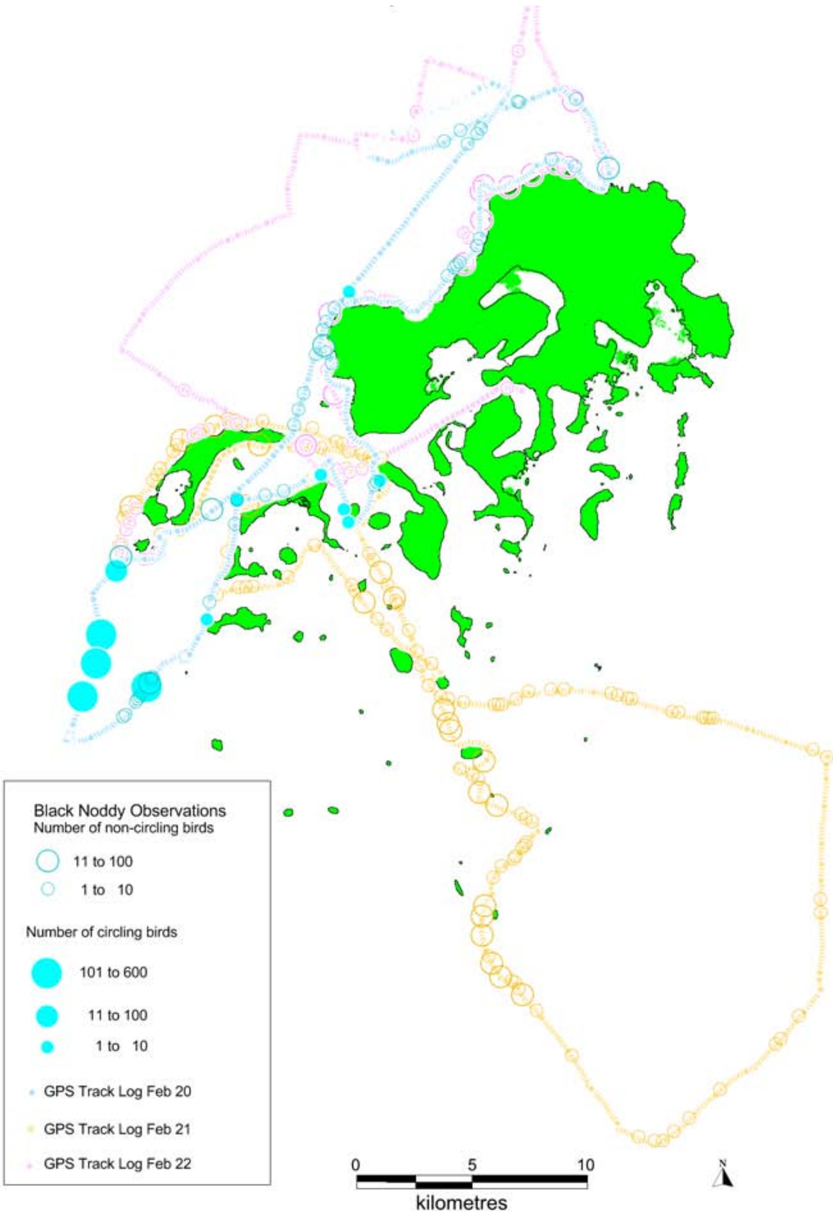

Figure 4.6. Map showing black noddy sightings, 20–22 February 2014.

Brown noddy

Brown noddies were recorded almost exclusively within the reef area and/or close to land. While the main breeding areas were on the southern islands, brown noddies were also thinly distributed around the island group (Figure 4.7).

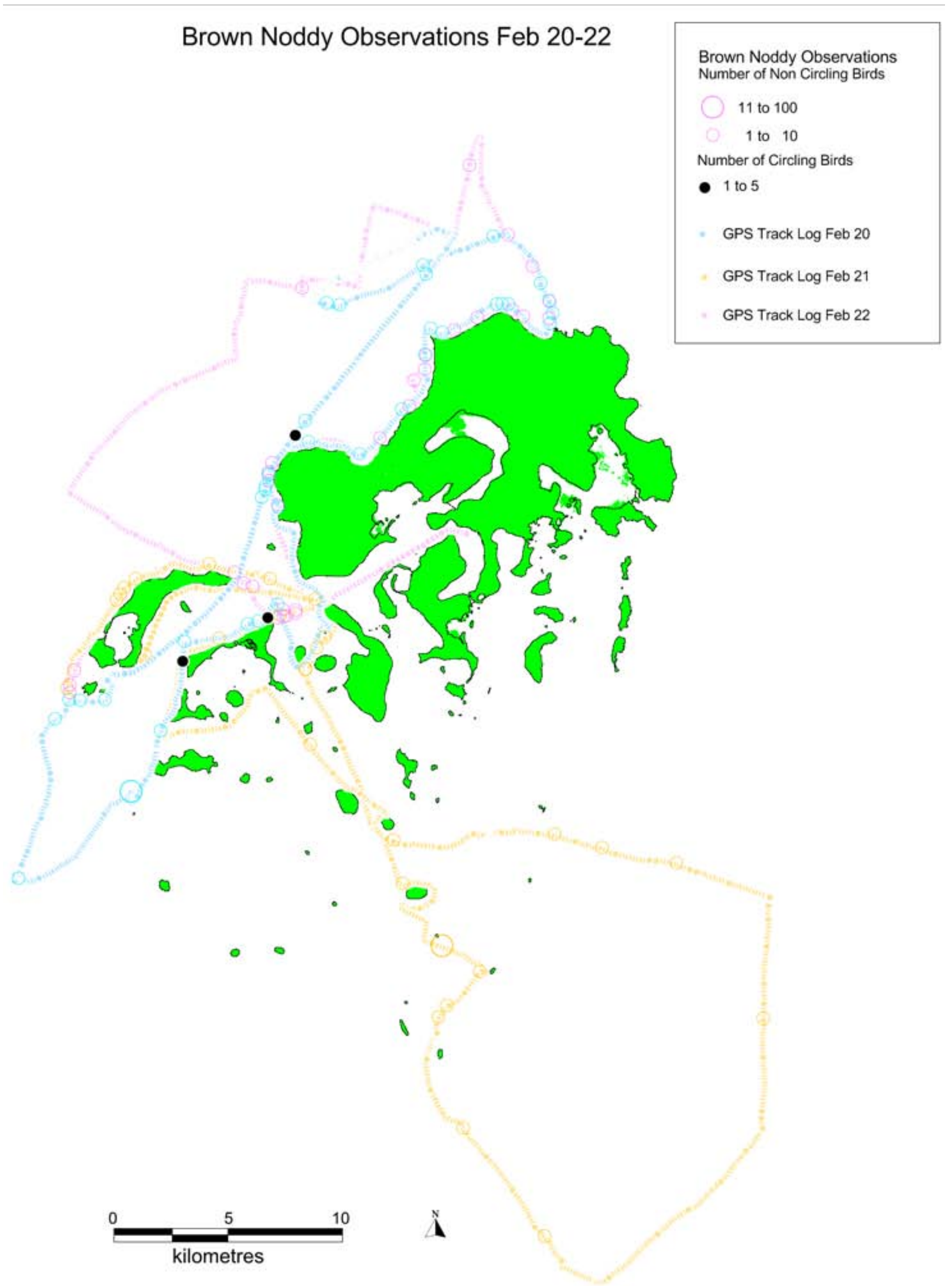

Figure 4.7. Map showing brown noddy sightings, 20–22 February 2014.

Bridled tern

The vast majority of bridled tern sightings were recorded within the Vava'u island group, and within the reef areas with just a few sightings further out to sea (Figure 4.8).

Figure 4.8. Sightings of bridled tern, 20–22 February 2014.(Map courtesy eBird and Google Earth.)

4.8. Discussion

The results show that the Vava'u group retains a diverse avifauna and our findings in 2014 were similar to those of a 1995/96 survey with the addition of a new species, the blue-crowned lory, not seen here for over 100 years.

It is interesting to note that the sites that Steadman et al. (1999) identified as holding the largest continuous areas of forest and the most forest birds 20 years ago, Mo'ungalafa and Liku Holonga (named here as Utula'aina Point), still have that status today. They noted that the former was being logged in 1995 and were concerned that the friendly ground dove would not survive there as a result, but it has done so and a large area of forest still remains there. That these sites remain of significant value for conservation is an indication that their topography and possibly land ownership offer them some ongoing protection.

Key discussion points are detailed below.

4.8.1. PRIORITY SITES FOR BIRD CONSERVATION – RARE LANDBIRDS

The key to retaining the group's landbirds is to conserve their forest habitat at all sites where this remains. Four sites have been identified as priority sites based on the presence of rare species or advocacy opportunities.

Mo'ungalafa, 'Uta Vava'u

This was the most significant forest area on Vava'u for birdlife with both the friendly ground dove and blue-crowned lory present. During the survey there were plenty of honeyeaters and whistlers but few pigeons and doves, perhaps because it was a time of year when few called.

A'a and 'Oto islands

Both these islands held friendly ground doves and were heavily grazed by goats and other livestock including pigs.

'Euakafa Island

'Euakafa was the second site at which blue-crowned lories were detected. It also appears to be free of ship rats as we caught none in a night's trapping (26 traps, snap and glue, four Pacific rats were caught), and Steadman et al. (1999) also detected none.

Mt Talau

This site on the edge of Neiafu holds good numbers of Tongan whistlers and more common forest birds and is an excellent site for advocacy and education.

4.8.2. SITES SIGNIFICANT FOR BIRD CONSERVATION – SEABIRDS

Maninita, Taula and Lualoli islands

These three islands identified by Birdlife International as the Maninita Important Bird Area (IBA) are a major breeding site for black and brown noddies and white terns, with smaller numbers of red-footed boobies and frigatebirds (Figure 4.9).

Figure 4.9. Picking up the survey team from Taula Island, with circling seabirds (photo by D. Butler).

Other southern islands

Table 4.3 shows that other southern islands support thousands of nesting seabirds, particularly black noddies.

Fatamaunga Island

This high rock, the westernmost island of the Vava'u group, recorded high numbers of brown boobies (c.80 individuals). It was unclear from observations whether these were nesting or roosting birds.

4.8.3. STATUS OF THE BLUE-CROWNED LORY

Steadman and Freifeld (1998) noted that there had been no record of this species in Vava'u in the 20th century, though by referring to its 'absence or extreme scarcity' they apparently did not rule out its presence. Birds were seen on 'Euakafa (two individuals) and heard at Mo'ungalafa and also detected there by automatic recorders. It seems most likely that the species has recolonised Vava'u recently. It is apparently only present in low numbers and at widely dispersed sites, and so its long-term future in Vava'u is uncertain. This same species is close to extinction in Niue and the reasons for this are uncertain, though rat predation and competition for nectar sources by introduced honeybees have been suggested. It is quite a common bird on the most northerly Tongan island of Niuafo'ou which interestingly has no ship rats (only Pacific rats) or honeybees.

4.8.4. INVASIVE SPECIES

Invasive species are the second most important threat to a number of birds, after habitat loss. Rats, bulbuls and yellow crazy ants are discussed here but continuing vigilance is needed to make sure that other damaging species do not reach the group, such as myna birds.

Rats are known to be major predators of birds and their nests and also impact on reptiles, invertebrates and the whole forest system through eating seeds and fruit. Three species were recorded on the islands – Norway rats (*Rattus norvegicus*), ship rats (*Rattus rattus*; the most damaging of the three), and Pacific rats (*Rattus exulans*).

Status of rats on Maninita, Lualoli and Taula islands

Programmes were carried out to eradicate Pacific rats from Maninita Island in June/July 2002 (Houston 2002) and Taula and Lualoli islands in December 2002 (Houston 2003) using baits containing brodifacoum placed in bait stations on the ground. Rat traps set on Maninita during December 2002 caught no rats and there was no sign of them on the island, indicating that the eradication might have been successful. Three nights of trapping on Taula at the end of December 2002 also caught no rats. No rats were detected on Lualoli either before the operation (June) or after it (December). Further follow-up monitoring was recommended but did not take place.

The current survey found the following.

Maninita

No rats were detected using the following techniques:

- Glue traps and two types of snap traps baited for rats;
- Surveys of fallen fruit (no rat bites) (Figure 4.10);
- Four person-hours of night time searches (many rats were seen during similar searches on 'Uta Vava'u Island);
- Beach footprint survey (around most of island);
- Unbaited glue traps set for lizards;
- Inspection of dead birds found on the ground showed no evidence of scavenging;
- Trapping around camp at night(with lots of food left around).

Lualoli

No rats were detected based on:

- Glue traps baited for rats;
- Surveys of fallen fruit;
- Noddy chicks in nests on ground (Figure 4.11).

Taula

One of the team thought they saw a rat during one of two brief daytime visits. Ten sticky traps were deployed on the island for 24 hours, but no rats were caught.

Figure 4.10. Fallen fruit on Maninita with no sign of rat feeding (photo by D. Butler).

Figure 4.11. Noddy chick at nest on ground on Lualoli (photo by D. Butler).

There was abundant food on the three islands in the form of the eggs and chicks of noddies and terns which could have reduced the attractiveness of baits for rats. However it is considered that there is a high likelihood that rats are absent from Maninita and Lualoli and if they are present on Taula their numbers must be very low. Watling (personal communication) noted that Maninita and Taula were overrun with rats, which were seen everywhere when baseline assessments were undertaken (Watling 2002, 2003).

If rats are currently on Taula it seems highly unlikely that the population survived the eradication programme but have not increased in numbers since. It would be more likely that another very recent colonisation has taken place.

Further monitoring is needed, particularly on Taula, ideally outside the birds' breeding seasons when any rats present are more likely to be short of food and drawn to baits. This could be undertaken as part of the regular turtle monitoring programme carried out by VEPA. Equipment required would be sticky traps/breakback traps or, if nothing else, chewsticks. If they are detected on Laula then an eradication programme would be needed as soon as possible, to prevent the numbers building up to the point that recolonisation of Maninita is likely. In addition a biosecurity programme, primarily aimed at people who visit the islands to harvest seabirds or who stay the night while on fishing expeditions, should be developed and implemented as soon as possible. If rats have returned to Taula, and if no action is now taken to eradicate them, it would undo all the effort that was put in over a decade ago and undermine the important positive results that this has achieved in terms of maintaining high numbers of seabirds on the southern island group.

Rats on other islands

Norway rats were seen at the Neiafu wharf but not on offshore islands. Ship rats were recorded on all the inner islands where trapping was carried out with the exception of 'Euakafa, and Pacific rats were seen on all of these.

Further work is needed to determine the distribution of the different species across different islands to determine where rat control or eradication should be attempted. In particular, it should be determined whether rats are present, and which species, on the other southern islands of most significance for seabirds, and 'Oto and A'a islands where the friendly ground dove occurs. Some islands such as 'Umuna hold so many rats that their natural values have already been compromised and action is not worthwhile. Others, if they are beyond the swimming range of rats from a neighbouring source (c. 1.5km), could be candidates for eradication programmes if rats are present, or for biosecurity programmes to keep them rat-free. Efforts are needed to prevent rats reaching islands where they are not present, including stopping ship rats getting to 'Euakafa.

Status of red-vented bulbul

Steadman et al. (1999) observed this species in Neiafu in 1995 and suggested that the small population should be eradicated before it spread, noting that in Nuku'alofa it had become one of the two most common species. No such programme was initiated. Now almost 20 years later, bulbuls continue to be limited in both distribution and numbers. Small groups were seen in Neiafu, up to six birds at a time, one 2km out of town on Tu'i Road by the Kings Road store, one onthe road between Neiafu and the Tongan Beach Resort, and one at Tefisi Village. None was seen while driving several times north to Holonga Village and west to Longomapu. It is unclear why the species has failed to increase and spread as expected.

Threat posed by the yellow crazy ant (Anoplolepis gracilipes)

This species had arrived in Tonga by the 1860s and has been present in Vava'u since at least the 1920s (Wetterer 2002). It can exist in two states, one in which individual colonies are separate entities with single queens competing for resources, and the other in which supercolonies are formed with multiple queens covering large areas with very high densities of workers. The species can persist in the first state for many years and then apparently switch to form supercolonies. On Christmas Island in the Indian Ocean, for example, it was present from the 1930s with little impact until the first supercolony was detected in 1989 and since then it has devastated red crab populations (O'Dowd et al. 2003). Only on one island, 'Euaiki, were yellow crazy ants found in huge numbers suggesting supercolony formation (Figure 4.12), and this is apparently a recent development as they were not a major issue for a family who lived there for 6 months in 2010 (Kate Walker, personal communication). They were detected on 'Uta Vava'u at Utula'aina Point, and several other islands including 'Umuna and Foeata, but were apparently absent from others such as Kenutu, Maninita, Taula and Lualoli.

Figure 4.12. Sticky trap with yellow crazy ants (photo by A. Backlin).

4.9. Recommendations

The following recommendations are proposed.

- Work with communities to conserve the key sites identified for landbirds and seabirds.
- Develop management plans for these key sites to address the key threats to their birdlife and other biodiversity values.
- Confirm rat-free status of Maninita, Taula and Lualoli (particularly Taula). If any rats are detected on any of these islands this should be reported to the government and to others such as the Pacific Invasives Partnership, BirdLife Pacific and others, with requests for a rapid response.
- Whether or not there are rats on Taula now, there should be a biosecurity programme to ensure that all users of the islands are aware of the threats and understand how to minimise those threats when they visit. This will involve identifying key users, developing community-related plans and events, and carrying out training exercises.
- Assess rat status of the other southern islands, such as Fonua'one'one and Fangasito. If feasible, consider an eradication programme for these islands as well.
- Monitor the black-winged petrel colony on Taula to assess whether it is still active and productive.
- Monitor the forest extent, and particularly understorey cover, at Mo'ungalafa, 'Oto and A'a. It is likely that the friendly ground dove is associated with relatively sparse understorey cover.
- Survey the forests on the northern parts of Kapa and Nuapapu, to search for the friendly ground dove.
- Assess the rat status of all the sites where the friendly ground dove is recorded. Consider whether rat control/eradication is appropriate.
- Assess the pig status at the sites where the friendly ground dove is recorded. Consider whether pig removal from these sites is sensible/feasible.
- Monitor the extent of native forest across the island group. Set up regular point count plots to count numbers of Tongan whistler (e.g. at Mt Talau) as a simple means of monitoring trend in numbers.
- Review the possibility of extending the rat-free zone still further north in the Vava'u group, to buffer the seabird islands at Taula and Maninita and also to create islands suitable for future colonisation by seabirds.
- Monitor the spread of yellow crazy ants and link into programmes in other countries to identify opportunities for their management.

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CHAPTER 5 MOTHS, BUTTERFLIES, ANTS & DRAGONFLIES OF VAVA'U

ERIC EDWARDS

TEAM MEMBERS: ALMOST ALL TONGAN GOVERNMENT STAFF PARTICIPATED IN INSECT SURVEYS ON ONE OR MORE DAYS

5.1. Summary

- One hundred and ninety two moths and butterflies (Lepidoptera), 19 ant species (Hymenoptera) and seven dragonflies (Odonata) were recorded in the survey. Micro-moth species remain unanalysed with many being cryptic undescribed species. Many macro-moth species (in 14 families) are new records for Tonga of moths known widely in the region.
- Four ant species are new records signalling exotic ant invasion is ongoing for Vava'u since last reported in 2002.
- Exotic yellow paper wasp (*Polistes olivaceus*) occupies the entire archipelago and during the survey appeared likely to be impacting species and ecosystem values as reported elsewhere for invasive social wasps.
- The Tongan leafwing butterfly (*Doleschallia tongana tongana*) was not recorded in this survey or in another recent survey for Vava'u. Likely host plant *Graptophyllum insularum* (Acanthaceae) status and potential range contraction and threatened species status should be reviewed for leafwing in Tonga.
- The Fiji glasswing (*Acraea andromacha polynesiaca*) is said to be a regional endemic subspecies hosted on native *Passiflora.* Neither the butterfly nor its plant host have been recorded for many years in Fiji, Tonga or Samoa. The butterfly may well be extinct in Tonga and its threat status could be tentatively assigned extinct. The native passionvine should also have its threat status assessed.
- On the basis of native insect and also snail values (Chapter 6) some sites of remnant natural character on 'Uta Vava'u are worthy of conservation. Sites are associated with slopes, northern coastal bluffs, coastal littoral sites and exposed roughened limestone surfaces.
- Maninita Island has some distinctive insect associations likely associated with both its abundance of seabirds and current lack of rodents. This and other seabird dominated islands, particularly those without rodents, have additional conservation value for the invertebrate component of ecosystems.

5.2. Introduction

Vava'u, at around 18° south of the equator, is the northernmost of four island groups of the Kingdom of Tonga.'Uta Vava'u (the main island) has a land area of almost 90 km^2 and a complex coastline, particularly to the south. There are numerous closely associated islands of all sizes spanning approximately 20 km west–east and 20 km to the south, mostly in shallow coral seas. The archipelago also includes rarely visited and more remote islands to the east and north including Late and Fonualei islands. The main island includes Neiafu, the second biggest town in the Kingdom with a population of about 3,900, and the archipelago has an overall dense population of over 15,000 residents. The topography of most islands is raised and eroded limestone platforms of relatively young geological age with an overlying sticky soil derived from aerial volcanic deposition (Roy 1990). Apart from Late Island (which was not visited), there are no hills or mountains over about 160 m above sea level. No areas of permanent flowing water or streams are present but two freshwater lakes (on Late and 'Uta Vava'u; Figure 5.1) and several brackish water areas are present. The small southern islands are sand cays perhaps less than ten thousand years old.

Vava'u's low and recent geology coupled with its oceanic position east of Fiji and south of Samoa means its fauna is largely derived with a low proportion of endemism. The butterfly and moth fauna is believed to be strongly linked to that of the Fijian archipelago and Melanesia as well as including a few species of Samoan association.

Historical works published on Tongan insects are mostly centred on Fijian or Samoan insects but discussing records from Tonga. Key among these are the 'Insects of Samoa' series, including 'Butterflies of Samoa and some neighbouring island-groups' (Hopkins 1927), 'Micro-Lepidoptera'(Meyrick 1927), 'Geometridae'(Prout 1928) and 'Heterocera (exclusive of the Geometridae and Microlepidoptera)' (Tams 1935). For the large bodied moths and butterflies, 'Macrolepidoptera of Fiji and Rotuma: A taxonomic and geographic study' (Robinson 1975) gathers sufficient information to show biogeographic insight on Tongan butterflies and moths. Dugdale (1978) documents Lepidoptera of Lakeba and Moce in the Fiji Lau islands group. These have perhaps a geographical association with Vava'u being the closest 'upwind islands' to the west. As for Fiji, Tonga's fauna includes many moths associated with Asia, Indonesia, New Guinea, Solomon Islands, Vanuatu and Queensland, Australia. A small amount of endemism in Tonga appears to extend to Fijian examples that include Tonga in their range or a few Samoan examples extending to Tonga. Upland fauna noted in Fiji (Robinson 1975) and Samoa (Edwards 2012) would not be expected to occur in Vava'u. A detailed list of the butterflies of Melanesia, Micronesia and Polynesia by Tennent (2006) and publications on butterflies of the South Pacific by Patrick and Patrick (2010, 2012) provide context for the Vava'u fauna.

Wetterer (2002) describes 53 ant species for Tonga. Ten are considered local endemics to the Samoa–Tonga–Fiji region and 21 are wide-ranging Pacific natives. The 22 remaining ant species are considered pan-tropical exotics. One species of ant recorded from Vava'u is tentatively considered to be regionally endemic. Eighteen ants out of 34 species known in 2002 from Vava'u are invasive exotics (Wetterer 2002).

Marinov (2012, 2013) documents five dragonflies for Vava'u. This contrasts with a much greater richness on 'Eua and Tongatapu, and a total 17 species for the Kingdom. Some local endemism is recognised at the subspecies level for Tongatapu and at the species level for 'Eua. However, the remainder of the dragonfly species are Pacific-wide in their occurrence or have a pan-tropical distribution. In contrast with moths and ants, all might be considered 'self introduced' and therefore native.

In the Kingdom of Tonga as elsewhere in the Pacific the number of exotic insects and other invertebrates is continually increasing through human introductions. Habitat management is in the context of a rich Tongan culture that retains strong association with the land and sea. Conservation as an industry is still in the phase of developing opportunities.

Under the BIORAP, the insect work focused on butterflies and moths to gain insight on invertebrate biogeography and ecological associations with vegetation. To interpret invertebrate invasion, ants and some wasps were targeted. Dragonflies are poorly documented for Vava'u. A range of other insects was also noted or curated for further interpretation. An attempt was made to choose sites representative of the range of semi-natural and natural areas and islands present. The results of this work combine with the vegetation assessment and other faunal assessments to establish the value of indigenous ecosystems and their vulnerabilities. Opportunities to retain and conserve ancient, intrinsically valuable habitats are also assessed. This report focuses on terrestrial invertebrate values, landscape ecology and threats, and suggests management implications that can be shared with local community leadership.

5.3. Survey sites and methods

5.3.1. SURVEY SITES

Figure 5.1 shows the sites visited by the insect survey team.

Three representative sites were chosen for intensive sampling by a team assembled from local and national expertise. These were:

- Mount Talau (National Park) near to Neiafu township – a site of invaded secondary forest and pig ranching. Soils comprised a thin litter cover on leached loam or clay and limestone rubble.
- Utula'aina – coastal forest at a secluded northern beach, with an intact sequence of coastal shrub and tree species. Soils were sandy with some litter, woody debris or coarse grasses.
- Mo'ungalafa – at 135 m above sea level, at the toe of a limestone bluff under secondary forest remnants and bluff relict forest. Soils had deep litter and woody debris but underlain by clay causing episodes of surface storm-water flow.

Figure 5.1. Location of sites visited by the insect survey team.

5.3.2. SAMPLING METHODS

Four methods were used for butterfly/moth, ant and dragonfly sampling – insect Malaise trapping, pitfall trapping, insect light trapping and hand collecting.

Insect Malaise traps (Figure 5.2) are suitable for sampling a great range of mobile insects during the day or night in relatively sheltered but open areas associated with forest margins. The trap is made from a fine mesh in a tent shape and is similar in size to a two person tent. Insects fly into the mesh and then walk up through a mesh funnel where they fall and accumulate in a preservative solution. Malaise traps were set in place for several days with sampling jars replaced as necessary.

Pitfalls were created using eight plastic cups (c. 13 cm in diameter) dug into the soil adjacent to a Malaise trap at each site. Each was filled with water to 4cm and 5ml detergent added to aid retention of invertebrates. Every few days the sample was retained on a sieve and then preserved in 80% ethanol to be sorted later. Ground dwelling invertebrates sampled in this way can include landsnails, ants, spiders, centipedes, beetles and many other invertebrates (Figure 5.3).

Insect light trapping began at dusk and continued for about three hours. A powerful 240 volt 120 watt mercury vapour ballasted ultraviolet light powered by a portable generator was used to attract moths, queen and drone ants, beetles, flies, bugs and other winged insects. A large white sheet was placed on the ground and the light was placed in the middle (Figure 5.4). Expedition team members captured specimens of as many species as possible individually in small plastic jars to be later preserved and identified.

Simple hand collecting techniques were based on observing insects in a range of habitats and capturing samples in small plastic jars for later curation. A sweep net was also used aerially or through vegetation to capture moths, butterflies, ants, dragonflies beetles, bugs and flies. Hand collecting was done during the night as well as in daylight.

5.3.3. COLLECTIONS

While ants and moths were the key target, a general collection of invertebrates was made including beetles, flies, wasps, bugs, spiders and smaller invertebrate orders for later analysis and reporting elsewhere (Figure 5.6). Collections will eventually be housed in the New Zealand Arthropod Collection (NZAC) in Auckland with most material presently held by the author for analysis and determination of new species. NZAC is an institutional insect collection with a strong representation of collections from many Pacific Islands, particularly of Lepidoptera (i.e. moths and butterflies). Some of the material can potentially be studied in association with other institutions with Pacific collections such as the Bishop Museum in Honolulu.

Figure 5.2. Insect Malaise trap at Mt Talau (photo by E. Edwards).

Figure 5.3. Pitfall sample of insects at Mt Talau (photo by E. Edwards).

Figure 5.4. Light trapping on the beach at Maninita (photo by E. Edwards).

Figure 5.5. Hand collecting with nets showing crow butterflies (photo by E. Edwards).

Figure 5.6. 'Lika' and Nani' assisting with insect curating (photo taken by E. Edwards).

5.3.4. IDENTIFICATION OF ANTS AND MOTHS

Identification of taxa curated from the expedition was carried out by comparison with other collections and by use of published works for Fiji, Samoa, French Polynesia, Hawaii and Australia (see the list of references but some of the key sources include):

- NZAC, Wetterer (2002) and 'Antkey' for ants;
- NZAC, Tams (1935), Robinson (1975), Dugdale (1988), online resources Herbison-Evans and Crossley (accessed 2014), Clayton (accessed 2014), McCormack 2007 (accessed 2014) and keys to Lepidoptera families (Dugdale 1988; Nielsen and Common 1991).

Many 'species' might only be determined by detailed genitalia dissections and comparison with original Type specimens and in some cases would be new to science. Such 'species' have been listed as indeterminate taxa (Indet.) in Annex 5.1. For moths, some caterpillar host plant associations were drawn from the literature (including those listed above, as well as online databases Herbison-Evans and Crossley (2012) and Robinson et al. (2012)). Family nomenclature for moths follows Van Nieukerken et al. (2011).

5.4. Results

We experienced settled weather for the entire survey including mild nights with little wind and good light trapping conditions. The team sampled a good range of habitats including slope forests, Mo'ungalafa plateau forest and fen, secondary forest and farm, exposed slopes of casuarina (toa) and pandanus (fafa) on bare limestone, lake marsh, rocky shrubland, sandy shoreline–shrubland, sheltered littoral forests and mangrove, and sandy seabird-dominated cays.

5.4.1. MOTH AND BUTTERFLY RESULTS

We found 18 species of butterfly, and identified 88 moth species (Table 5.1 and Annex 5.1) with around another 86 species of micro-moths (in many families) to be identified. This totals approximately 192 Lepidoptera species. Many new records for Tonga are noted (Annex 5.1); most of these are species occurring elsewhere in the Pacific, Asia and Queensland, Australia. The 'larger bodied' moths and butterflies identified at the time of reporting include the following 14 families: Crambidae, Arctiinae-Erebidae, Geometridae, Hesperidae, Lycaenidae, Noctuidae, Nolidae, Nymphalidae, Peridae, Psychidae, Pyralidae, Sphingidae, Thyrididae and Uraniidae (Annex 5.1).

The richest light trap catch of larger bodied moths was from Pangiamotu Island, western causeway. The site was at sea level in a sheltered embayment surrounded by mangrove, relict scarp forest, horticultural plantations, market garden and roadside herbs and grasses. Forty five moths and five butterflies were noted here with many micro-moths (yet to be assessed). On the northern coast at 110 m above sea level Utula'aina scarp forest, plantation and cropping land yielded 30 larger bodied moth species. Mount Talau, 'Euakafa Island and 'Umuna Island yielded 22, 17 and 15 species of identified moths, respectively. Under ideal conditions ten larger bodied moth species were recorded at Maninita Island indicating the small island size and simplicity of vegetation sequences and habitats. However, at the Maninita Island coral cay we recorded a number of individuals of Pisonia hawkmoth (*Hippotion velox*), clearwings (hummingbird) hawkmoth (*Cephonodes armatus*), and the large noctuid (*Thyas coronata*). None of these large moths was recorded at other sites (Annex 5.1).

Table 5.1. Summary species richness in the survey and for Tonga, Samoa and Fiji (number of taxa).

Insect group	Vava'u BIORAP	Published record Vava'u	Published record Tonga	Samoa	Fiji	New records for Vava'u
Butterflies (Lepidoptera)	18	23	28	29	48	0
Ants (Hymenoptera)	19	34	53	68	187	4 (3 new for Tonga)
Dragonflies and damselflies (Odonata)	7	2	16	30	43	6
Moths (Lepidoptera)	88 (plus c. 86 micro-moth spp.)					

We recorded 18 of the 23 butterflies species known for Vava'u (Table 5.1) and found no new records for the island group or Tonga. Of note perhaps was the absence of the Tongan leafwing butterfly (*Dolleschallia tongana tongana*). Tongan leafwing is common in Samoa (e.g. Edwards 2008, 2010) but was noted at only one locality on 'Eua during a butterfly survey of the Kingdom in 2010 (Patrick and Patrick 2010). Also historically, Fiji glasswing butterfly (*Acraea andromacha polynesiaca*) has been recorded from Tonga (at Tongatapu – Tennent 2006) but was not found in this survey. Its caterpillars are hosted on native *Passiflora* species which are possibly also extinct among the Vava'u islands (e.g. not noted in Whistler and Athertonthis survey). The forest glade inhabiting big eye blue butterfly (*Nacaduba dyopa*; Figure 5.7) was seen in many semi-natural sites among the islands.

Figure 5.7. Big eye blue butterfly (*Nacaduba dyopa*) (photo by Mark O'Brien).

During the survey a tree of disturbed forests, *Micromelum minutum* Rutaceae, was common in a few localities (see Whistler and Atherton this study). Saplings of this tree are host to swallowtail butterflies in Fiji (*Papilio schmeltzi*) and in American Samoa (*P. godeffroyi*). However, neither swallowtail species has ever been recorded in Vava'u or elsewhere in Tonga.

5.4.2. ANTS RESULTS

We recorded 19 ant species (Table 5.1 and Annex 5.1). One, an undetermined species of *Strumigenys* from the higher elevation slope forest 135 m above sea level at Mo'ungalafa, may possibly be native but widespread and exotic species are also known in this genus (Wetterer 2002). Thirty four of the 53 species of ants known from the Kingdom of Tonga were known from Vava'u (Wetterer 2002). In this survey we verified none of the regional endemics known, found four of the 16 wide ranging Pacific natives previously recorded, and found ten of the 18 exotic ants known for Vava'u (Annex 5.1). In addition we discovered two global invasive ant species not previously known from any Tongan islands. These were cf. *Tetramorium calderum* from moderately remote Taula Island coral cay, and *Camponotus maculatus* grp. from the main island and inner associated islands of Vava'u (Annex 5.1). *Nylandera vaga*, an ant from the Western Pacific margin regions, was also noted from the main island and inner associated islands of Vava'u. Another wide ranging Pacific native ant *Tetramorium insolens* previously only known from 'Eua in Tonga was newly recorded at Mt Talau.

Two notorious Pacific invasive ants – bigheaded ant (*Pheidole megacephala*) and yellow crazy ant (*Anonplolepis gracilipes*) (see Holway et al. 2002; Ward and Wetterer 2006) – were widespread and common during the survey. Bigheaded ant was often in high numbers even on the moderately remote Maninita Island. On 'Euaiki Island at the main landing/resort area yellow crazy ant had formed a continuous supercolony so that only the beach itself could be rested on. By contrast to this, tropical fire ant (*Solenopsis geminata*), which also has a damaging reputation, has been present since at least 1956 but was only recorded at one site, the Pangiamotu Island causeway (Holway et al. 2002).

Yellow paper wasp (Polistes olivaceous)

This exotic large bodied wasp was widespread and abundant during the survey. Guarded nests were suspended in vegetation near ground level or more frequently at head height in all types of shrubland and forest with reasonable shade. The density of nests was perhaps 'several' per hectare. Wasps could be seen actively hunting and disturbing winged insects particularly on common flowering coastal shrub ngingie (*Pemphis acidula*). They may also have been gathering pollen and nectar resources from the flowers. Members of the team were repeatedly stung.

5.4.3. DRAGONFLY RESULTS

Prior to this survey six dragonflies were reported for Vava'u. One species –*Macrodiplax cora*– was not seen during the survey but two new species records for Vava'u were noted bringing the total for Vava'u to eight species (Annex 5.1.). This is only half the total for Tonga (Table 5.1) and likely more can be documented in future. All are most probably native and Pacific wide species.

5.4.4. OTHER INSECTS RECORDED AND CURATED

Malaise trapping, pitfall trapping and light trapping all caught a typical range of insects curated for further study including Blattodea roaches, Isoptera termites, Mantodea praying mantis, Dermaptera earwigs, Orthoptera crickets and grasshoppers, Phasmatodea stick insects, Psocoptera booklice, Hemiptera true bugs (many families and species), Thysanoptera thrips, Neuroptera lacewings, Coleoptera beetles (many families and species), Strepsiptera parasitic (one adult) and Diptera (many families and species). Some Araneae spiders, one Scorpiones scorpion and some Acari mites are also to be deposited in the New Zealand Arthropod Collection/spirit collection.

5.5. Discussion

Semi-natural and natural faunal habitats are present in some parts of the main island of Vava'u, which have survived fragmentation and disturbance processes. These harbour distinct assemblages of insects and other invertebrates that are dependant on the dominance of indigenous plants, bats and birds. These sites were the focus of the biodiversity survey.

5.5.1. ROUGHENED LIMESTONE PLATFORM AREAS –BIOLOGICAL REFUGIA FOR VAVA'U

Where volcanic tuff derived soils have been stripped off, jagged exposures of limestone may become refugia for native trees and invertebrates alike. Such surfaces were found in areas of 'Umuna, Kenutu, 'Euakafa and small Kulo Island as well as on some parts of the raised pitted limestone platform of Mo'ungalafa. The top of Mo'ungalafa (c. 160 m above sea level) includes areas seasonally or episodically cultivated as well as the rough exposed limestone areas (Figure 5.8) and in contrast, some areas of grass, sedge and fern fen/wetland (Figure 5.9). The steep escarpments bounding this top also retain some native vegetation adding value to the site. While pigs are farmed here and there is some cultivation and harvest, there are no dwellings present. Understorey fern and litter dwelling moths such as *Bradina* species and *Dracaenura* species are among typical day active forest species recorded. In the fern/sedge grass areas longhorned grasshoppers, Delphacidae and other true bugs are abundant and the satin coloured day active moth *Cydalima laticostalis* was also recorded here.

Figure 5.8. Rough limestone refugia atop Mo'ungalafa (photo by E. Edwards).

Figure 5.9. Deeper soils under fernland at 160 m above sea levelon Mo'ungalafa (photo by E. Edwards).

5.5.2. UTULA'AINA POINT AND ADJACENT AREAS

The flat cultivated land of 'Uta Vava'u island is bounded to the north by extensive coastal bluff systems and slopes dropping often over a hundred metres to the sea or narrow beach (Figure 5.10) which offers a significant site for conservation. The northern bluffs are mainly clothed in forest right to the water or to active beaches, and there are no dwellings or roads at sea level. The native vegetation observed on back beach sands, slopes and rocky bays, which includes a fruit bat roost, are likely to support anciently associated and broadly typical invertebrates. Caper white butterfly was common around the Vava'u islands during the survey and its caterpillars were found feeding here on the native coastal rock dwelling shrub *Capparis cordifolia*. The moth *Striglina oecia* previously considered indigenous to Samoa is newly recorded in this survey for Vava'u with several examples from Utula'aina. Its caterpillars are hosted on *Erythrina* and probably other trees of Fabaceae. The common beet webworm *Spoladela recurvalis* was recorded on the beach at Utula'aina probably on a beach dwelling herb of the Amaranthaceae. The continuous band of tohuni (*Tornefortia argentia*) at this beach attracted hundreds of 'male' crow butterflies of all three species present – *Euploea lewinii lewinii, E. tulliosusforsteri* and *E. boisduvalii boisduvalii.*

The abundance of such butterflies reflects the forest *Ficus* species which are hosts for crow butterfly caterpillars. The crow butterfly *E. tulliosusforsteri* was not recorded for tohuni thickets among the outlying islands of Vava'u suggesting additional importance of its host plant and habitat at Utula'aina coast.

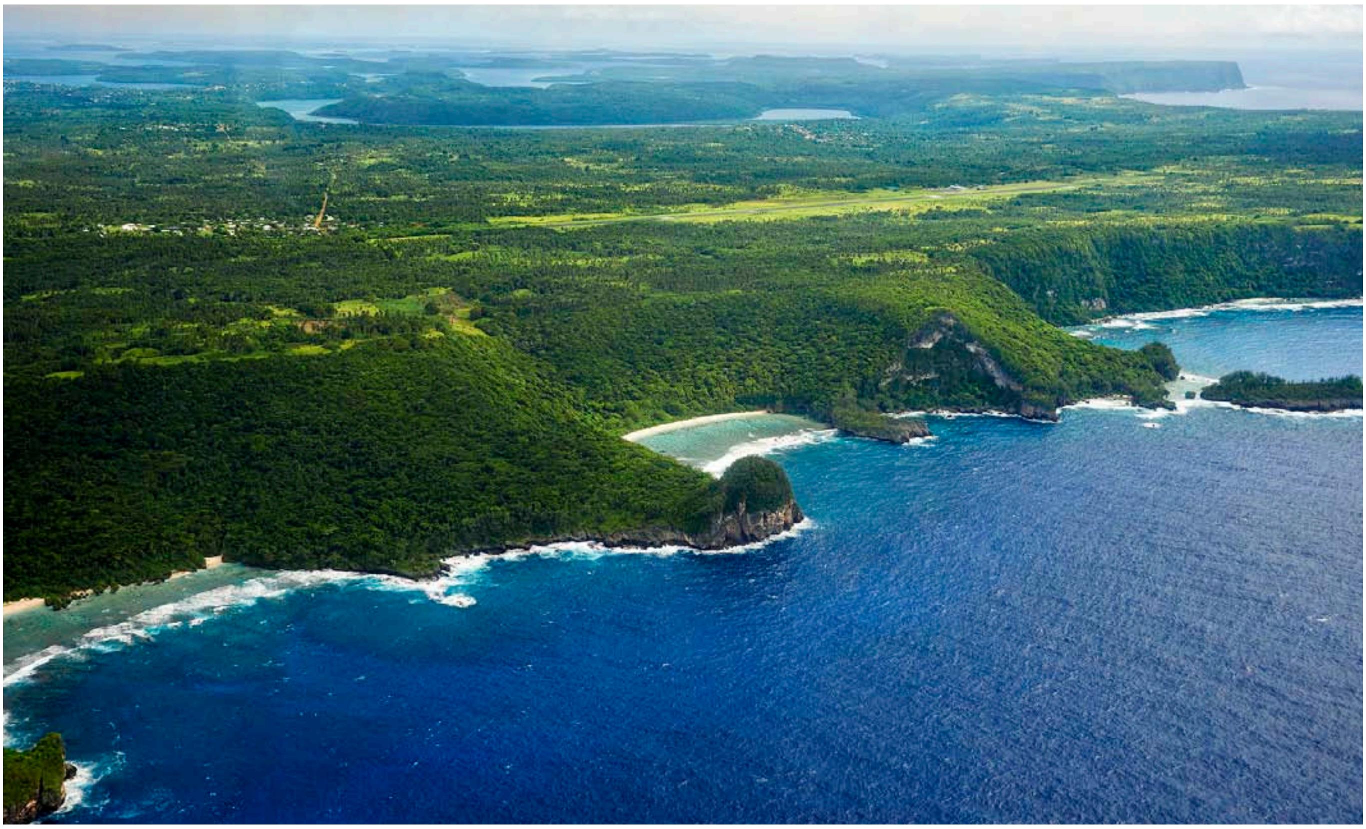

Figure 5.10. Oblique aerial view of Utula'aina coast of 'Uta Vava'u, a significant site for conservation (photo by Stuart Chape).

5.5.3.'UMUNA AND 'EUAKAFA ISLANDS

These islands include sheltered coastal forest with *Terminalia litoralis, Pisonia*sp. and other flowering and fruiting trees. The skipper butterfly *Badamia exclamationis*, white butterfly *Appias athama manaia* and vivid blue butterfly *Jamides carissima thomasi* were commonly seen in the mornings at these sites. On the small-leaved mangrove shrub of rocky headlands the active moth *Piletocera signiferalis* was very common on the flowers. Yellow paper wasps (*Polistes olivaceus*) were also common at such sites. On the exposed eastern scarps and shores, barren-looking *Casuarina* and *Pandanus* groves with deep needle leaved duff on the ground probably suit common litter feeding caterpillars of the moth *Hydrillodes surata*. Adults of large bodied noctuid moths like to hide inside the broad leaf bases of *Pandanus*. Rats, exotic paper wasps and exotic big headed ants probably all impact at least seasonally on the abundance of spiders and insects, especially caterpillars. However, the moth fauna remains rich and light trapping yielded many (as yet undetermined) micro-moths. While bag moth 'bags' were commonly seen, an adult male bag moth *Clania* cf. *ignobilis* was a rare catch at the light trap on 'Umuna Island. This is one of many new species records for Tonga.

5.5.4. MANINITA AND TAULA ISLANDS

These coral cays, home to many seabirds, are distinctive nutrient enriched environments with many insects, amphipods, isopods, earthworms and other species converting guano in the soil or feeding on a plentiful supply of dead birds. Maninita Island was visited 12 years prior to this survey in 2002, where an outbreak of large devastating caterpillars was observed to have stripped much of the forest of its leaves (Houston 2002 and reported on website Pestnet). The dominant tree is *Pisonia grandis*; this was reported to be eaten by caterpillars of the hawkmoth *Hippotion velox*. Another common tree *Guettarda speciosa* was host to another hawkmoth – clearwings (hummingbird) hawkmoth (*Cephonodes armatus*). Both of these moths were still present and several examples of another large moth, *Thyas coronata*, were noted here and nowhere else in the survey. It appears that the ecology of these and probably similar islands includes episodes of defoliation followed by tree recovery or regeneration –adding to the distinctiveness and value of these small ecosystems.

5.5.5. ANT INVASION

The data from Wetter in 2002 and from this survey show that ant invasion is ongoing for Tonga and Vava'u, with new species arriving and established species spreading around the moderately remote and small islands. Their impact on the native snails and insects of Vava'u islands is not measured here but is reported elsewhere to be significant (Hoffman et al. 1999; Holway et al. 2002). The 'supercolony' of yellow crazy ants on at least part of Euaiki Island is a concern for the indigenous values of its ecosystems as well as the increased likelihood of the ant spreading to other sites and islands. This ant is already widespread and well established and its impact may be both seasonal and dependent on interactions with other ants and sources of nectar or honeydew. An improvement in biosecurity and reduction in the rate of arrival of new ants and other invasive insects and snails would be significant for biodiversity on these islands.

5.5.6. YELLOW PAPER WASP

This wasp is very likely seasonally abundant and probably disappears for a few months each year before building up in large numbers again. Yellow paper wasp has been established in some part of the Pacific for so long (Tonga by 1939 (Harris 1979)) that its environmental impacts are no longer being considered. Such social wasp species (family Vespidae) are reported to be quite generalist predators as well as carrion, nectar and pollen feeders (Liebert 2006). Some *Polistes* species typically target Lepidoptera caterpillars and spiders as well as many other insects (Liebert 2006). Problems with seasonal high abundance of social wasps are increasingly being reported in Europe, North America, Asia and New Zealand. While *P. olivaceus* is widespread in the Pacific and in some other countries there is the opportunity to call for collaborative science to develop tools to control or suppress this pest.

5.5.7. TONGAN LEAFWING BUTTERFLY AND FIJIAN GLASSWING

While butterfly lifecycles mean there can be periods of time when adults are hard to find, there are still enough observers and observations to conclude that for these two butterflies there seems to have been a decline. For the leafwing, the absence of records during active searches is evidence with a moderate level of confidence that range contraction has occurred within its Tongan range. Any confirmed sightings or captures of leafwing in Vava'u would be of value. An assessment of its caterpillar host plants may provide some insight. The evidence for disappearance of glasswing butterfly from Tonga and Samoa and likely much of Fiji is also accumulating with time (see Tennent 2006; Patrick and Patrick 2010, 2012). This glasswing is said to be a regional endemic subspecies hosted on native *Passiflora*. It is interesting to note that native *Passiflora* species are no longer on botanical lists for Tonga (e.g. Whistler and Atherton this survey) or Samoa (Whistler 2010) and perhaps concern should also be extended to these native *Passiflora* species. The author proposes that the status for *Acraea andromacha polynesiaca* glasswing is extinct for Samoan islands and the Kingdom of Tonga, and should be reviewed for Fiji.

5.6. Conservation recommendations

We recommend a set of conservation actions be agreed among local experts, land owners and the Tongan government, with a ten year funding plan and an annual programme of work. The work should be led locally and supported by a fund raising team to maintain financial support for the programme. This is justified by the often short term nature of conservation work and the need to develop further capacity where presently conservation capacity is in the membership of the non-government organisation VEPA. An example would be a programme of annual biosecurity visits to Maninita Islands and its associated islands monitoring their pest rodent status, pest plant status and pest wasp status.

We recommend the information from this BIORAP be developed into a resource for both teachers and school children in Tonga. Messages could include the nature of the present harvest ethic, and importance to livelihoods and for future generations in relation to marine and land management approaches.

While some land or islands are vested nationally not locally, local conservation leadership should explore and understand the administration of Crown lands and what would be required to manage an active relationship for long term conservation.

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CHAPTER 6 LAND SNAILS OF VAVA'U

FRED BROOK

TEAM MEMBERS: ALMOST ALL TONGAN GOVERNMENT STAFF PARTICIPATED IN LAND SNAIL SURVEYS ON ONE OR MORE DAYS

6.1. Summary

- In February 2014 the extant land snail fauna of native forest remnants was surveyed at 23 sites in Vava'u, including 15 sites on the largest island, 'Uta Vava'u, and single sites on the smaller islands of 'Euaiki, 'Euakafa, Kulo, Maninita, Pangaimotu, Taula, Tuita and Vaka'eitu.
- Live snails and/or fresh empty shells of 41 terrestrial snail species were found, including two species endemic to Vava'u, three species endemic to Tonga, seven regionally endemic species known from Tonga and one or more adjacent island groups in the tropical southwest Pacific, 12 widely distributed Pacific species, and 12 extra-Pacific species native to Africa, Asia or the Americas.
- One endemic species, *Sinployea paucicosta*, was relatively widely distributed and locally common in native forest remnants on 'Uta Vava'u, and is assessed here as having anInternational Union for Conservation of Nature (IUCN) threat ranking of Critically Endangered. A second endemic species, *Sturanya culminans*, was common locally at a few sites only. It has evidently undergone a marked recent decline on 'Uta Vava'u, and is also assessed as having an IUCN threat ranking of Critically Endangered.
- No live snails or fresh shells were found of three other land snail species endemic to Vava'u, namely *Lamprocystis vavauensis*, *Thaumatodon vavauensis* and *Tuimalila infundibulus*. These species presumably now have highly restricted distributions on Vava'u and are Critically Endangered, or have gone extinct.
- Four areas of native forest that are of particular importance for land snail conservation on 'Uta Vava'u are identified: bluffs on Mo'ungalafa; coastal cliffs at Talehele northwest of Leimatu'a village; coastal flats, terraces and hillslopes east of Utula'aina Point; and the coastal flat and adjacent hillslopes at Vai-utu-kakau on the northeastern coast.
- Other important forest remnants on 'Uta Vava'u that were not surveyed during the present study, and which may contain relict populations of endemic land snail species, include: steep coastal slopes and inland bluffs north of Longomapu village; coastal slopes northeast of Longomapu; coastal cliffs west and north of Leimatu'a village; steep coastal slopes on the western and eastern sides of Utula'aina Point; steep coastal slopes on the western side of Mata'utuliki Point; and the southern end of the peninsula south of Makave village. It is recommended that land snail surveys be carried out in these areas, as well as on the small, relatively unmodified cliff-girt islands of Kitu and Luamoko, and the outlying volcanic islands of Late, Fonualei and Toku.
- Effective biosecurity controls will be necessary to prevent highly invasive, exotic agricultural and ecological pest species such as the giant African snail *Achatina fulica* and the rosy wolf snail *Euglandina rosea* from becoming established in Vava'u and elsewhere in Tonga.

6.2. Introduction

During this survey, the species composition and richness of land snail assemblages were determined at 15 forested sites on 'Uta Vava'u, and at single sites on the smaller islands of 'Euaiki, 'Euakafa, Kulo, Maninita, Pangaimotu, Taula, Tuita and Vaka'eitu (Figure 6.1). This chapter of the BIORAP describes the preliminary findings of this survey, and identifies priority areas for land snail conservation on 'Uta Vava'u and adjacent islands.

Figure 6.1. Locations of land snail survey sites in Vava'u.

6.2.1. PREVIOUS WORK ON THE LAND SNAILS OF VAVA'U

Land snails collected during the visits of the French ships *Astrolabe* and *Zélée* to Vava'u in 1838 were described and illustrated by Hombron and Jacquinot (1841, 1852), Le Guillou (1842) and Rousseau (1854). Mousson (1871) described further new land snails from Vava'u and elsewhere in Tonga, and compiled an annotated species list based on previously published work and extensive collections made in the Kingdom by Edouard Graeffe. Mousson (1871) recorded a total of 24 terrestrial gastropod species from Tonga, including 17 from Vava'u. Two species of land snails collected on Vava'u during the visit of the British ship HMS *Curacoa* in 1865 were described by Baird (1873), and Wagner (1907–1911) described a subspecies of Helicinidae from Vava'u.

Further collections of land snails made on Vava'u between 1921 and 1933 by W. E. Fisher, D. S. Gifford, E. S. Handy, J. E. Hoffmeister and L. H. MacDaniels were deposited in the Bishop Museum, Honolulu (BPBM). Baker (1938, 1941) revised the taxonomy and summarised distribution data for zonitoid land snails from the tropical Pacific region, including Tonga.

In 1965–1966 Laurie Price collected land snails at 11 sites in Vava'u, including ten sites on 'Uta Vava'u and one on Pangaimotu, for the Field Museum of Natural History, Chicago (FMNH). Solem (1976, 1983) revised the taxonomy of tropical Pacific species of Endodontidae and Charopidae, respectively, listing four taxa, including a new species and subspecies from Vava'u.

6.2.2. AIMS OF THIS STUDY

The main aims of the February 2014 land snail survey on Vava'u were to obtain information on the biogeographic composition and richness of extant land snail assemblages in native forest remnants on 'Uta Vava'u and adjacent smaller islands, assess the population status of Vava'u and Tongan endemic land snails, and identify priority areas for land snail conservation on Vava'u.

6.3. Sites visited and methods

Twenty three forested sites on islands in the Vava'u group were surveyed for land snails. These included 15 sites at five locations on the large island of 'Uta Vava'u (i.e. at Mo'ungalafa, Talehele northwest of Leimatu'a village, east of Utula'aina Point, Vai-utu-kakau and Mt Talau), and single sites on each of 'Euaiti, 'Euakafa, Kulo, Maninita, Pangaimotu, Taula, Tuita and Vaka'eitu islands (Figure 6.1 and Annex 6.1). The geographic coordinates (WGS 1984) of sites were determined using a Garmin Etrex GPS unit. At each site the sampling protocol involved between one and three people spending at least one hour searching for snails and empty shells by eye over an area of c. 100 m^2. This involved looking for snails and shells on the ground in leaf litter and under stones and fallen wood, and on the leaves of ground-layer plants, shrubs, small trees and vines. In addition, at each site a series of spot samples of leaf litter and humus with a combined volume of several litres were collected, and later dried and sorted under a binocular microscope for live snails and empty shells. This sampling regime was aimed at qualitatively covering as great a variety of microhabitats at each site as possible.

Fossil land snail assemblages were also collected at several sites on Vava'u, to obtain information on the former composition of the fauna and species distributions. An account of this fossil material, and of patterns of faunal changes within and among sites on Vava'u, will be reported elsewhere.

Identifications of the land snail species found during this study were mostly based on published literature, but a few of the species found are new to science and unnamed, and are here identified to genus only. Information on the geographic distributions of named landsnail species was obtained from published literature, museum databases, and field observations made during the present study. Species were assigned to the following biogeographic categories, based on available distributional and historical information: local endemics (i.e. known from the Vava'u archipelago only); Tongan endemics (present in two or more island groups within Tonga); regional endemics (present in Tonga and one or more adjacent island groups); widespread Pacific species; and alien species (i.e. not native to the Pacific region). Five species were listed as distribution unknown.

For each of the 23 survey sites on Vava'u, lists of species that were represented by live snails and/or fresh empty shells were compiled, and the range and mean species richness at sites, and frequency of species at sites, were determined.

The relative importance of sites for land snail conservation was assessed by assigning rankings based on their biogeographic composition. Land snail species in the various biogeographic categories were assigned weighted scores as follows, and these were used to calculate total scores for the land snail assemblages at each of the 23 survey sites: Vava'u endemics (score = 5); Tongan endemics (3); regional endemics (2); widespread Pacific species (1); alien species (0). The five locations surveyed on 'Uta Vava'u (i.e. comprising between two and six sites each) were also assessed in terms of their importance for land snail conservation using the following measures of species richness: range of species richness at sites, excluding extra-Pacific species; range of numbers of locally to regionally endemic species at sites; overall species richness at locations, excluding extra-Pacific species; and the total number of locally to regionally endemic species at locations.

Preliminary assessments of the population status of locally endemic and Tongan endemic land snail species on Vava'u were made using International Union for the Conservation of Nature (IUCN) threat ranking categories (IUCN 2012), based on species distribution and qualitative abundance records obtained during the present survey and historical records from collections of the BPBM and FMNH.

6.4. Results

6.4.1. SPECIES AND DISTRIBUTIONS

Forty one extant species of land snails were found in the Vava'u group in February 2014 (Table 6.1). The majority of these species were found alive, but four species were found only as fresh empty shells (i.e. *Gulella bicolor*, *'Microcystina' gerritsi*, *Nesopupa armata* and*Ptychopatula orcula*). Most species were ground dwelling in soil and leaf litter and under stones, fallen wood and ground-layer plants. Some species were found exclusively on the foliage, trunks and branches of shrubs and trees (e.g. *Diastole tongana*, *Elasmias apertum*, *Pacificella variabilis*, *Sturanya multicolor* and *Sturanya* sp. 1), some were found living both on the ground and arboreally (e.g. *Bradybaena similaris*, *Lamellidea pusilla*, *Liardetia samoensis* and *Sinployea vicaria*), and some were predominantly ground dwelling, but were seen crawling on tree trunks after rain (e.g. *Delos gradata*, *Omphalotropis vallata*, *Sturanya culminans* and*Subulina octona*). Two of the species found only as empty shells (*Nesopupa armata* and*Ptychopatula orcula*) were probably arboreal. Seven species were restricted to forest and shrubland on coastal margins (i.e. *Melampus adamsianus*, *M. fasciatus*, *M. luteus*, *M. tongaensis*, *M.* sp. 1, *Pythia scarabaeus* and *Truncatella guerinii*).

Of the 41 land snail species found during the present survey, two were endemic to Vava'u, three were endemic to Tonga, seven species were regional endemics known from Tonga and one or more adjacent island groups in the tropical southwest Pacific, 12 species were widely distributed in the western Pacific, and 12 were extra-Pacific species, native to Africa, Asia or the Americas (Table 6.1). The biogeographic distributions of five unidentified species found during the survey have not yet been determined (Table 6.1). *Georissa* sp. 1, *Georissa* sp. 2, *Nesopupa* sp. 1 and *Sturanya* sp. 1 are probably local or regional endemics, whereas *Melampus* sp. 1 is probably regionally endemic or a widespread Pacific species.

Table 6.1. Land snails found during the survey, and their biogeographic distribution.

Biogeographic distribution	Species
Vava'u endemics	*Sinployea paucicosta*, *Sturanya culminans*
Tongan endemics	*Diastole tongana*, *Omphalotropis vallata*, *Sturanya multicolor*
Regional endemics	*Delos gradata*, *Elasmias apertum*, *Lamprocystis excrescens*, *Melampus tongaensis*, *Nesopupa armata*, *Sinployea vicaria*, *Sturanya musiva*
Widespread Pacific species	*Coneuplecta microconus*, *Discocharopa aperta*, *Gastrocopta pediculus*, *Lamellidea pusilla*, *Liardetia samoensis*, *Melampus adamsianus*, *M. fasciatus*, *M. luteus*, *'Microcystina' gerritsi*, *Pacificella variabilis*, *Pythia scarabaeus*, *Truncatella guerinii*
Extra-Pacific species	*Allopeas clavulinum*, *A. gracile*, *A. micra*, *Bradybaena similaris*, *Gastrocopta servilis*, *Gulella bicolor*, *Laevicaulis alte*, *Opeas hannense*, *Paropeas achatinaceum*, *Ptychopatula orcula*, *Quickiaconcisa*, *Subulina octona*
Distributions not known	*Georissa* sp. [1], *Georissa* sp. [2], *Melampus* sp. [1], *Nesopupa* sp. [1], *Sturanya* sp. [1]

No live snails or fresh empty shells of *Lamprocystis vavauensis* (Baird 1873) (Euconulidae), *Thaumatodon vavauensis*(Solem 1976) (Endodontidae) or *Tuimalila infundibulum* (Hombron and Jacquinot 1841) (Charopidae), all of which are endemic to Vava'u, were found during the 2014 survey. The status of these species is discussed below.

The distributions of land snail species at the sites surveyed during the present study are listed in Annex 6.2. The most frequent extant species, present at more than half the sites surveyed, were: *Georissa* sp. 1 and *Sturanya multicolor* (21 sites each); *Liardetia samoensis* and *Paropeas achatinaceum* (19 sites each); *Subulina octona* (18 sites); *Sturanya* sp. 1 (16 sites); *Laevicaulis alte* (15 sites); *Gastrocopta pediculus* (13 sites); and *Sinployea vicaria* (12 sites). The least frequent species, found at one or two sites only, were *Allopeas clavulinum*, *Georissa* sp. 2, *Gulella bicolor*, *Lamprocystis excrescens*, *Melampus adamsianus*, *Pacificella variabilis*, *Quickia concisa* and *Truncatella guerinii*.

6.4.2. SPECIES RICHNESS AT SITES AND LOCATIONS

Overall land snail species richness at the 23 sites surveyed ranged from four to 25 species per site (Table 6.2), with a median of 14 and mean of 14.04 + 5.16 SD. The highest numbers of species were on the sea track at Talehele (sites 4 and 5), at Vai-utu-kakau (site 13), at Mo'ungalafa (site 2), and the bay east of Utula'aina Point (site 6). Three of these sites were in coastal forest inhabited by supralittoral species of the families Ellobiidae and Truncatellidae (i.e. sites 4, 6 and 13), whereas sites 2 and 5 were further inland and lacked the coastal-restricted taxa. The least rich land snail assemblages were at Taula and Maninita islands (sites 22 and 23), with four and five species, respectively.

Table 6.2. Biogeographic composition of land snail species assemblages at survey sites on Vava'u, and weighted site ranking scores.

Site Number	Total number of species per site	Number of species endemic to Vava'u (score = 5)	Number of Tongan endemic species (score = 3)	Number of regionally endemic species (incl. unidentified species of *Georissa, Nesopupa, Sturanya*) (score = 2)	Number of widespread Pacific species (incl. *Melampus* sp. 1) (score = 1)	Number of extra-Pacific species (score = 0)	Weighted site ranking score
Site 1	15	1	3	3	4	4	24
Site 2	19	1	3	7	2	6	30
Site 3	13	1	3	4	2	3	24
Site 4	25	2	2	9	9	3	43
Site 5	19	2	3	7	1	6	34
Site 6	19	1	2	5	7	4	28
Site 7	8	0	1	3	1	3	10
Site 8	12	1	1	4	2	4	18
Site 9	13	1	2	5	1	4	22
Site 10	11	1	1	5	1	3	19
Site11	11	0	1	3	3	4	12
Site 12	17	2	2	6	7	0	35
Site 13	22	2	3	6	5	6	36
Site 14	15	0	2	5	3	5	19
Site 15	12	0	2	4	3	3	17
Site 16	17	0	1	4	4	8	15
Site 17	17	0	2	4	5	6	19
Site 18	7	1	1	2	1	2	13
Site 19	15	1	2	3	4	5	21
Site 20	14	0	2	5	3	4	19
Site 21	13	1	1	4	3	4	19
Site 22	4	0	0	0	2	2	2
Site 23	5	0	0	1	2	2	4

One of the sites surveyed lacked extra-Pacific species (i.e. site 23, Vai-utu-kakau), but land snail assemblages at the other sites surveyed contained between two and eight species each (Table 6.2). If extra-Pacific species are excluded from the assemblage totals, land snail species richness at sites ranged from two to 22 species per site, with a median of 10 and mean of 10.09 + 4.56 SD. The richest assemblages, excluding extra-Pacific species, were all at sites on 'Uta Vava'u, at Mo'ungalafa, coastal cliffs at Talehele, on the northern coast east of Utula'aina Point and at Vai-utu-kakau: site 4 (22 species); site 12 (17 species); site 13 (16 species); site 6 (15 species); and sites 2 and 5 (13 species each). Several of these sites also had the highest diversities of locally to regionally endemic land snail species: site 4 (13 species); site 5 (12 species); sites 2 and 13 (11 species each); and site 12 (10 species) (Table 6.2). The lowest numbers of locally to regionally endemic species were found on Maninita Island (site 23, one species), Vaka-eitu Island (site 18, four species), and at two coastal sites east of Utula'aina Point on 'Uta Vava'u (sites 7 and 11, four species each). Taula Island (site 22) lacked endemic species.

The weighted scores that were determined for the 23 sites, based on overall biogeographic composition, ranged from two to 42 (Table 6.2). The sites with the highest scores were all on 'Uta Vava'u, at Mo'ungalafa, Talehele sea track, on the northern coast east of Utula'aina Point and at Vai-utu-kakau: site 4 (43); site 13 (36); site 12 (35); site 5 (34); site 2 (30); site 6 (28); and sites 1 and 3 (24). Other sites had weighted scores of 22 or lower, with site 22 on Taula, and site 23 on Maninita, having the lowest scores (Table 6.2).

Between two and six sites were surveyed at each of the five locations on 'Uta Vava'u. Ranges of species richness at sites excluding extra-Pacific species, ranges of locally to regionally endemic species at sites, combined totals of species richness, and numbers of locally to regionally endemic species recorded at each of the five locations on 'Uta Vava'u are listed in Table 6.3. Talehele sea track, Vai-utu-kakau and Utula'aina Point had the highest overall species richness excluding extra-Pacific species, with totals of 24, 23 and 20 species, respectively. Talehele sea track and Vai-utu-kakau also had the combined highest numbers of locally to regionally endemic species, followed by Mo'ungalafa and Utula'aina Point. Mt Talau had the lowest overall species richness, and the fewest endemic species, of the locations surveyed on 'Uta Vava'u.

Table 6.3. Land snail species richness at sites and locations on 'Uta Vava'u.

Site name and number	Range of species richness at sites, excluding extra-Pacific species	Range of numbers of locally to regionally endemic species at sites	Overall species richness at location, excluding extra-Pacific species	Total number of locally to regionally endemic species at location
Mo'ungalafa (sites 1–3)	10–13	7–11	14	11
Talehele sea track(sites 4, 5)	13–22	12–13	24	15
Utula'aina Point(sites 6–11)	7–15	4–8	20	11
Vai-utu-kakau (sites 12, 13)	16–17	10–11	23	14
Mt Talau (sites 14, 15)	9–10	7–8	11	8

Many land snail species were patchily distributed within the locations surveyed on 'Uta Vava'u. As already noted, *Pythia scarabaeus*, *Truncatella guerinii* and *Melampus* spp. were restricted to coastal fringes (e.g. lower coastal slopes on Talehele sea track, east of Utula'aina Point and on the coastal flat at Vai-utu-kakau), and *Sturanya culminans* was locally common on the coastal fringe and scarce or absent further inland, at the locations surveyed at Talehele and east of Utula'aina Point. Some other species were patchily distributed within and among sites in inland forest habitats, notably: *Delos gradata*, *Elasmias apertum*, *Nesopupa armata*, *Nesopupa* p. 1, *Sinployea paucicosta* and *Sturanya musiva* at Mo'ungalafa; *Discocharopa aperta*, *Elasmias apertum*, *Georissa* sp. 2, *Nesopupa armata* and *Omphalotropis vallata* at Talehele sea track; *Delos gradata*, *Diastole tongana*, *Liardetia samoensis*, *Omphalotropis vallata*, *Sinployea paucicosta* and *Sturanya musiva* east of Utula'aina Point; *Diastole tongana*, *Georissa* sp. 2, *Nesopupa armata*, *Nesopupa* p. 1, *Sinployea vicaria* and *Sturanya* sp. 1 at Vai-utu-kakau; and *Discocharopa aperta* and *Nesopupa armata* at Mt Talau.

6.5. Discussion

All the extra-Pacific species in the Vava'u land snail fauna have been introduced to this island group. *Allopeas gracile* was recorded from Vava'u by Mousson (1871 – i.e. as *Stenogyra novemgyrata*), and was probably introduced in ancient times, as elsewhere in Polynesia (e.g. Christensen and Weisler 2013). None of the other extra-Pacific species were recorded by Mousson (1871). *Ptychopatula orcula* was evidently introduced to some Polynesian islands prior to European contact (Brook 2010), but most if not all of the other extra-Pacific species in the Vava'u fauna were probably introduced to this island after the mid- to late 1800s. Collections made by Laurie Price indicate that several extra-Pacific species were established in Vava'u by the mid-1960s (i.e. *Gastrocopta servilis*, *Opeas hannense*, *Paropeas achatinaceum* and*Subulina octona*). All these species were still extant on Vava'u in February 2014, along with a further six extra-Pacific species that had not been recorded previously from this island group, and which presumably became established there after the mid-1900s (i.e. *Allopeas clavulinum, A. micra*, *Bradybaena similaris*, *Gulella bicolor*, *Laevicaulis alte* and *Quickia concisa*).

Like *Allopeas gracile*, the widespread Pacific land snail *Gastrocopta pediculus* was probably also introduced to Tonga in ancient times (Christensen and Weisler 2013), and it has been suggested that the wide distributions of some other fully terrestrial Pacific land snail species, including *Discocharopa aperta*, *Lamellidea pusilla*, *Liardetia samoensis* and *'Microcystina' gerritsi*, may also have resulted at least in part from synanthropic introductions before or after European contact (Cooke and Kondo 1961; Brook 2010; Christensen and Weisler 2013). Conversely, the widespread supralittoral Pacific species in the genera *Melampus*, *Pythia* and *Truncatella* are probably native to Vava'u.

The Tongan endemics and regional endemics in the Vava'u land snail fauna are most likely all native to this island group, but the possibility that one or more of these species was introduced from other adjacent island groups cannot be discounted on present evidence.

Extra-Pacific land snail species were ubiquitous in native forest remnants on Vava'u in February 2014, and several species were very widely distributed, particularly *Laevicaulis alte*, *Paropeas achatinaceum* and *Subulina octona*. The last two species were also locally abundant in forest habitats, and appeared to be the dominant litter-dwelling species at some sites. The land snail faunas of modified habitats, including agricultural and horticultural areas, domestic gardens and regenerating shrubland and forest, were not surveyed during the present study but were probably also dominated by, or contained only extra-Pacific species.

All the extra-Pacific species in the Vava'u land snail fauna are widely distributed among tropical Pacific islands, but some equally widespread invasive species present in island groups elsewhere in Polynesia and eastern Melanesia, have apparently not yet been introduced to Vava'u. This includes the giant African snail (*Achatina fulica*), *Parmarion martensi* and *Sarasinula plebeius*, all of which are serious agricultural pests and potential carriers of human diseases, and the predatory snail *Euglandina rosea*, which has caused the serious decline and extinction of many native snail species on other tropical Pacific islands. Effective biosecurity measures will be needed to prevent the introduction and establishment of these and other invasive species on Vava'u and other Tongan islands.

6.5.1. POPULATION STATUS OF LAND SNAIL SPECIES ENDEMIC TO VAVA'U AND TONGA

Two land snail species endemic to Vava'u – *Sinployea paucicosta*and *Sturanya culminans*– had a sparse distribution on 'Uta Vava'u, and were very scarce on adjacent islands, in February 2014. No live snails or fresh empty shells of three other land snail species endemic to Vava'u (*Lamprocystis vavauensis*, *Thaumatodon vavauensis* and*Tuimalila infundibulus*) were found during the 2014 survey. Extant populations of two species of land snails endemic to Tonga, *Diastole tongana* and *Omphalotropis vallata*, were sparsely distributed in native forest remnants on 'Uta Vava'u and very scarce on adjacent islands in February 2014, whereas a third species, *Sturanya multicolor*, was comparatively widespread. More information on these species is given below.

Sinployea paucicosta (Figure 6.2e)

Extant populations of *Sinployea paucicosta* were found at 11 of the sites surveyed, including ten on 'Uta Vava'u and one on Vaka-eitu. This taxon was originally described as a subspecies of *S. vicaria*, but was found living syntopically with that species at several sites on 'Uta Vava'u (Annex 6.2), and is here treated as a separate species. *Sinployea paucicosta* was locally common but very patchily distributed in native forest on bluffs and limestone pinnacle karst at Mo'ungalafa, and was uncommon on steep coastal slopes at Talehele, on a coastal terrace E of Utula'aina Point and on the beach flat at Vai-utu-kakau. It was very scarce in low forest on a coastal hillside at the northern end of Vaka-eitu Island. Sites where this species was recorded in 1966, but which were not visited during the present survey, included forest on coastal cliffs north-northwest of Longomapu village, a forested coastal flat southeast of Toula, and forest near the end of the peninsula south of Makave village. These sites should be resurveyed to see if the local populations of *S. paucicosta* are still extant. The nearshore islands of Kitu and Luamoko, and outlying volcanic islands of Late, Fonualei and Toku, should also be surveyed to see if *S. paucicosta* is present.

In 2014, *S. paucicosta* was evidently very sparsely distributed in native forest remnants on 'Uta Vava'u and Vaka-eitu. Under IUCN threat ranking criteria (IUCN 2012) it qualifies as Critically Endangered, based on the very small area of occupancy (<10 km^2), severely fragmented population, and an inferred historical and ongoing population reduction. The main threats to the continued survival of this species are forest clearance, and probably also predation by introduced species (e.g. ants, planarians and snails).

Sturanya culminans (Figure 6.2b)

Extant populations of *Sturanya culminans* were found at very few sites on Vava'u in February 2014. This species was locally common in the supralittoral zone at the base of coastal cliffs at Talehele, in the bay east of Utula'aina Point, and at Vai-utu-kakau, and was very scarce on upper coastal slopes at Talehele, and on 'Euaiki and Kulo islands (Annex 6.2). *Sturanya culminans* has evidently undergone a marked decline and has died out at some locations since the mid-1900s, including at some of the sites surveyed during the present study. Database records from the FMNH indicate that in 1966 this species was extant in forest at the northern and southern ends of Mo'ungalafa (i.e. in the vicinity of sites 1–3 of the present survey) and on a limestone knoll on the east side of Pangaimotu (i.e. site 16 of present survey). No live snails or fresh empty shells of *S. culminans* were found at these localities in 2014, suggesting that the respective local populations are now extinct. Other sites where *S. culminans* was found alive in 1966, and which were not surveyed during the present study, included forest on coastal cliffs north-northwest of Longomapu village, a forested coastal flat southeast of Toula, and forest near the end of the peninsula south of Makave village. These sites should be resurveyed to see if the local populations of this species are still extant. The nearshore islands of Kitu and Luamoko and outlying islands of Late, Fonualei and Toku should also be surveyed to see if *S. cuulminans* is present on any of these islands.

Available information suggests that *S. culminans* was formerly widely distributed on 'Uta Vava'u but is now largely restricted to forested near-coastal sites on this island, and that it is very sparsely distributed and scarce on the smaller islands. The causes of the recent decline, particularly at forested inland sites, are not known but predation by introduced species (e.g. possibly ants, planarians, rodents) was most likely a key factor. Under IUCN threat ranking criteria (IUCN 2012) *S. culminans* qualifies as Critically Endangered, based on the very small area of occupancy (< 10 km^2), severely fragmented population, and documented historical population reduction.

Lamprocystis vavauensis

Other than the type material described by Baird (1873), the only known museum records of *Lamprocystis vavauensis* are of snails collected at c. 60 m elevation on cliffs in a valley near Holonga in 1928 (Baker 1938: 88; BPBM database), and two shells collected at c. 120 m elevation on a forested hillslope at the northern end of Mo'ungalafa in 1966 (FMNH database). The scarcity of records suggests that this species was rare on 'Uta Vava'u during the early to mid-1900s, and the lack of sightings during the present survey indicates that it now either has a highly restricted distribution on this island (i.e. with an IUCN threat ranking of Critically Endangered), or has gone extinct. Forested areas on 'Uta Vava'u that were not surveyed during the present study, and which should be searched for relict populations of *L. vavauensis*, include the bluffs on the western and northwestern sides of Mo'ungalafa, inland bluffs and coastal slopes northwest of Longomapu village, coastal slopes west and north of Leimatu'a village, steep coastal slopes on the eastern side the gully east of Utula'aina Point, and steep coastal slopes at the northern end of Vai-utu-kakau. The nearshore islands of Kitu and Luamoko and outlying islands of Late, Fonualei and Toku should also be surveyed for this species.

Thaumatodon vavauensis

This species was evidently also rare on 'Uta Vava'u during the last century, with the only known museum records being of a single shell collected at c. 60–105 m elevation on a cliff at Liku, near Holonga on the northern coast in 1928 (Solem 1976: 461; BPBM database), and a few empty subadult shells found near Toula and on coastal cliffs west of Leimatu'a village in 1966 (Solem 1976; FMNH database). It presumably now has a highly restricted distribution on this island (i.e. an IUCN threat ranking of Critically Endangered), or has gone extinct. The key forested areas on 'Uta Vava'u that were not surveyed during the present study and which should be searched for *T. vavauensis* are the same as those listed for *Lamprocystis vavauensis*, along with the islands of Kitu, Luamoko, Late, Fonualei and Toku.

Tuimalila infundibulus

This species was evidently formerly widespread and common in Vava'u. In 1965–1966, Laurie Price collected many fresh, empty shells of *T. infundibulus* at several sites on Vava'u and one on Pangaimotu, but did not find any live snails (Solem 1983: 182–183; FMNH database). Several of the same sites were searched during the present survey, including Mo'ungalafa (sites 1–3), Mt Talau (sites 14, 15) and Pangaimotu (site 16), but no snails or fresh shells of *T. infundibulus* were found. This species presumably now has a highly restricted distribution in Vava'u (i.e. an IUCN threat ranking of Critically Endangered), or has gone extinct. Forested areas where *T. infundibulus* was found in 1965–1966, and which were not searched during the present study, include coastal slopes northwest of Longomapu village, coastal slopes west of Leimatu'a village, and the end of the peninsula south of Makave village. All these areas, along with the islands of Kitu, Luamoko, Late, Fonualei and Toku, should be surveyed for *T. infundibulus*.

Diastole tongana (Figure 6.2a)

This species is known from Eua, Tongatapu and Vava'u (Mousson 1871; Baker 1938; FMNH database). In 2014 *D. tongana* was relatively widely distributed in native forest remnants at Mo'ungalafa, on the Talehele sea track, east of Utula'aina Point, Vai-utu-kakau, and at Mt Talau, and was present also at sites on 'Euakafa and Tuita islands (Annex 6. 2). It evidently had a similarly wide distribution on 'Uta Vava'u in the mid 1960s (FMNH database), and there is no evidence of a recent population decline on this island. The status of the *D. tongana* populations on Eua and Tongatapu is not known.

Omphalotropis vallata (Figure 6.2d)

This species has been recorded from 'Eua, Tongatapu, Ha'apai and Vava'u (Mousson 1871; FMNH database). In 2014 it was sparsely distributed but locally common within native forest remnants at Mo'ungalafa, on the Talehele sea track, east of Utula'aina Point, and at Vai-utu-kakau, and was scarce on Kulo Island (Annex 6.2). A local population of *O. vallata* on Pangaimotu that was extant in 1966 (FMNH database) was apparently extinct in 2014 (i.e. at site 16), and the very patchy distribution of *O. vallata* within areas of contiguous native forest on 'Uta Vava'u suggests that local populations on this island are also in decline. The status of the *O. vallata* populations on 'Eua, Tongatapu and Ha'apai is not known.

Sturanya multicolor (Figure 6.2c)

This species has been recorded from Tongatapu and Vava'u (Gould 1847; Wagner 1907–1911). In 2014 it was widely distributed and locally common in native forest remnants on 'Uta Vava'u, and on all the smaller limestone islands that were surveyed, but was absent from the 'atoll-like' islands of Maninita and Taula. The status of *S. multicolor* populations elsewhere in Tonga is not known.

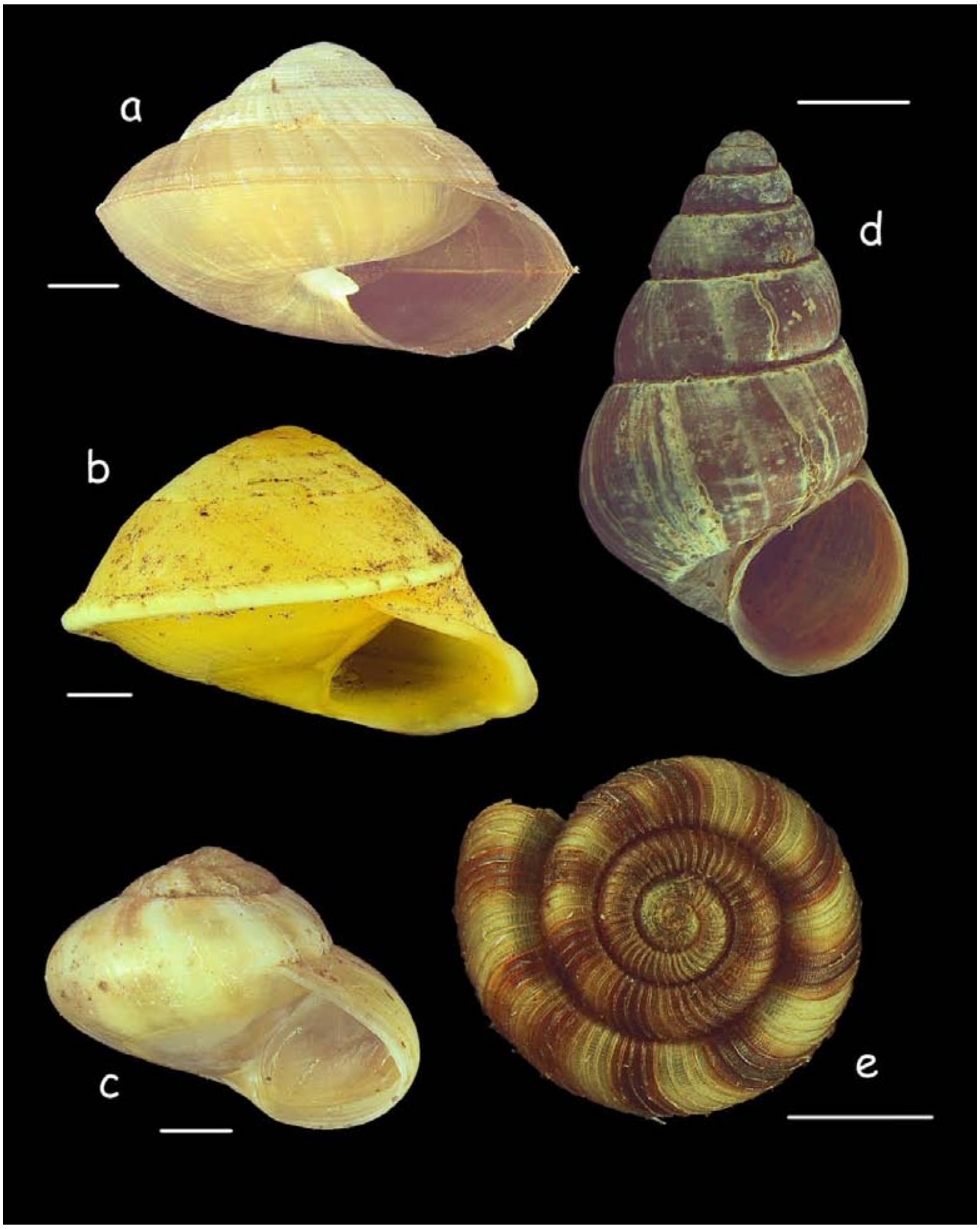

Figure 6.2. Images of some Tongan endemic land snail species.(a) *Diastole tongana*; (b) *Sturanya culminans*; (c) *Sturanya multicolor*; (d) *Omphalotropis vallata*; (e) *Sinployea paucicosta*. Scale bars = 1 mm.

6.5.2. PRIORITY LOCATIONS FOR LAND SNAIL CONSERVATION ON VAVA'U

Of the sites and locations surveyed during the present study, those containing extant populations of land snail species endemic to Vava'u and the richest assemblages of Tongan and regionally endemic species are considered to have key importance for land snail conservation on Vava'u. The four most important locations identified during the present study are all on the main island of 'Uta Vava'u. They are, in order of priority, the native forest remnants at:

Coastal cliffs northwest of Leimatu'a village (*Sinployea paucicosta* and *Sturanya culminans* present; relatively diverse Tongan and regionally endemic species assemblages) (Tables 6.2 and 6.3 and Figure 6.3);

Vai-utu-kakau, northeastern coast of 'Uta Vava'u (*Sinployea paucicosta* and *Sturanya culminans* present; relatively diverse Tongan and regionally endemic species assemblages) (Tables 6.2 and 6.3 and Figure 6.3);

Bluffs encircling Mo'ungalafa (*Sinployea paucicosta* present but patchily distributed; relatively diverse Tongan and regionally endemic species assemblages but with patchy distribution of some species (Tables 6.2 and 6.3, Figure 6.3 and Annex 6.2);

Headland east of Utula'aina (*Sinployea paucicosta* and *Sturanya culminans* present but patchily distributed; low to moderate richness of Tongan and regionally endemic species at sites but moderately high species richness overall) (Tables 6.2 and 6.3 and Figure 6.3).

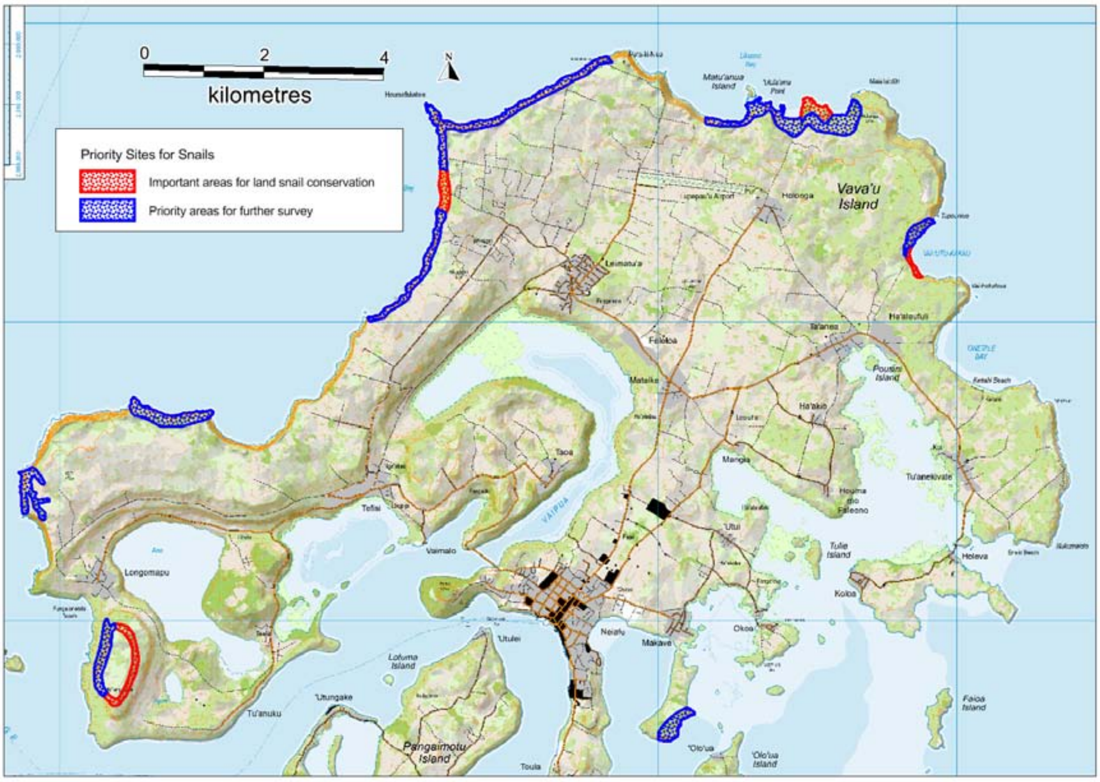

Figure 6.3. Important areas for land snail conservation on 'Uta Vava'u, and priority areas for further land snail surveys.

The smaller islands south of 'Uta Vava'u that were surveyed during the present study had low to moderate species richness, with the most impoverished assemblages on the southernmost islands of Taula and Maninita. These two low islands had typical 'atoll' land snail faunas (sensu Cooke 1928; Harry 1966), consisting mainly or exclusively of species introduced by humans and lacking Vava'u and Tongan endemics. Small and apparently highly localised populations of species endemic to Vava'u were present on Vaka'eitu (*Sinployea paucicosta*), Kulo and 'Euaiki (*Sturanya culminans*), but the sites surveyed on these islands, along with those on 'Euakafa, Pangaimotu, and Tuita, all had low to moderate richness of Tongan and regionally endemic species (Table 6.2 and Annex 6.2).

6.5.3. THREATS TO THE NATIVE LAND SNAIL FAUNA

Existing or potential threats to the native land snail fauna on Vava'u include loss or degradation of key habitats, unsustainable predation of snails and/or their eggs, and possibly also susceptibility of some native snail species to introduced diseases or other pathogens.

Areas of native forest provide key habitats for native land snails on Vava'u. On 'Uta Vava'u and adjacent smaller islands, forest has been extensively cleared in the past, and the surviving remnants are still at risk of destruction or degradation from a variety of causes, including land clearance by people, browsing and trampling by cattle and goats, disturbance of leaf litter and ground-layer vegetation by pigs, weed invasion, and wind damage during cyclones. Forest in low-lying coastal areas (e.g. on beach flats, and the southern atoll-like islands) is also at risk from storm waves, tsunamis and sea-level rise.

Habitat loss during the three millennia or so of human occupation undoubtedly contributed significantly to the fragmentation of populations and the current rarity of endemic land snail species on Vava'u. However, the fact that since the mid-1900s local populations of several endemic species have died out within what appear at least superficially to be areas of intact, relatively unmodified, mature native forest, clearly indicates that a factor or factors other than habitat loss have been the main cause(s) of recent species declines and extirpation.

In the absence of any direct evidence, the most likely causes of the recent marked population declines of locally endemic snails are mortality from predation and/or pathogens. If predation has been a key factor in snail population declines, then the timing suggests that the predator(s) involved became established on Vava'u after European contact, and possibly as late as the early to mid-1900s.

Three species of non-native rodents are known from Vava'u, namely *Rattus exulans*, *R. norvegicus* and *R. rattus* (Twibell 1973; Steadman et al. 1999), all of which are omnivorous and opportunistic predators of land snails. *Rattus exulans* was introduced to Vava'u by early Polynesian settlers, but the other two species were introduced after European contact, probably during the mid- to late 1800s. All these species of rodents probably prey(ed) on the larger bodied endemic land snails on Vava'u, including *Lamprocystis vavauensis*, *Tuimalila infundibulus* and *Sturanya culminans*, and may well have contributed to population declines among these species.

At least ten species of non-native land snails have been introduced to Vava'u since the mid-1800s, including one predatory species (*Gulella bicolor*) and five species of Subulinidae (*Allopeas clavulinum*, *A. micra*, *Opeas hannense*, *Paropeas achatinaceum* and *Subulina octona*) which may or may not be facultative predators of native snails. *Gulella bicolor* was very scarce on Vava'u in 2014, recorded at one site only (Annex 6.2), and is unlikely to have had a significant adverse effect on native snail populations. By contrast, two of the subulinid species, *Paropeas achatinaceum* and *Subulina octona*, were very widespread in native forest remnants on Vava'u and abundant in leaf litter at many of the sites surveyed, so potentially could have had, and still be having, a significant impact on populations of native land snail species.

Predation by introduced ants is known or believed to have caused declines and extinctions of native invertebrate species on other tropical Pacific islands, and it may well have been a significant cause of the declines of native land snail populations on Vava'u. Twenty two species of pantropical exotic ants are known from Tonga, with 18 species recorded from the Vava'u group (Wetterer 2002). Seven exotic species were established in Tonga by the mid-1800s, a further seven had become established by the mid-1900s, and the reminder were apparently introduced subsequently (Wetterer 2002). The early history of establishment of exotic ants on Vava'u is poorly known, but at least six species were present by the mid-1900s, a further seven species were first recorded in 1980, and five species were first recorded in 1995 (Wetterer 2002). Two of the exotic species present in Vava'u are among the most ecologically damaging ants in the tropical Pacific and worldwide: the yellow crazy ant (*Anoplolepis gracilipes*) and the big-headed ant (*Pheidole megacephala*), first recorded there in 1956 and 1980, respectively. Both species are now widespread and locally abundant in anthropogenic habitats and native forest remnants on Vava'u.

Two exotic predatory invertebrate species that have caused serious declines and extinctions of native land snails on some other tropical Pacific islands, namely the rosy wolf snail (*Euglandina rosea*) and the planarian *Platydemus manokwari*, are fortunately absent from Vava'u and other Tongan islands. Effective biosecurity controls will be necessary to prevent these, and other ecological and agricultural pest species such as the giant African snail *Achatina fulica*, from becoming established in Tonga.

6.6. Recommendations for further land snail surveys on Vava'u

The present study provided some preliminary information on the land snail fauna of Vava'u, but further surveys are required to obtain better information on the composition of the fauna; the geographic and ecological distributions, population status, threats and management requirements of endemic species; and the distributions of invasive species. Priorities for further work include the following.

- Surveys of key native forest remnants on the main island of Vava'u that were not visited during the present study, to determine the species composition of land snail assemblages, to search for additional extant populations of the endemic species *Sinployea paucicosta* and *Sturanya culminans*, and to look for any remaining extant populations of the endemics *Lamprocystis vavauensis*, *Thaumatodon vavauensis* and *Tuimalila infundibulum*. Areas of forest to search include (see also Figure 6.3):
    - Bluffs on the western and northwestern sides of Mo'ungalafa;
    - Coastal cliffs and inland bluffs northwest of Longomapu (including c. 18.63575oS 174.06591oW);
    - Coastal slopes northeast of Longomapu, between c. 18.62144oS 174.05088oW and 18.62237oS 174.04121oW;
    - Coastal cliffs west and north of Leimatu'a village;
    - Steep coastal slopes on the western and eastern sides of Utula'aina Point (including c. 18.57606oS 173.94510oW);
    - Steep coastal slopes on the western side of Mata'utuliki Point;
    - Steep coastal slopes at the northern end of Vai-utu-kakau (c. 18.59456oS 173.92834oW);
    - Top of cliffs at the southern end of the peninsula south of Makave village (c. 18.66874oS 173.96449oW).
- Survey of the small, relatively unmodified cliff-girt islands of Kitu and Luamoko to look for extant populations of endemic land snail species.
- Survey of the land snail faunas of the outlying islands of Late, Fonualei and Toku.
- Survey of villages and agricultural areas on the main island of Vava'u, to determine the composition of the invasive land snail fauna, and the distributions of native and invasive species in modified habitats.

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CHAPTER 7

STONY REEF CORALS OF VAVA'U

DOUGLAS FENNER

7.1. Summary

- The reefs of the Vava'u group have a good diversity of stony (hard) corals, with a mean of 55 species per dive site and a total of 206 species in 55 genera observed during 25 dives in this brief survey.
- The number of hard coral species found per dive site was similar to that in New Caledonia, Fiji and American Samoa. The total number of stony corals found in 25 dives was more in Tonga than in American Samoa, higher still in Fiji, and highest in New Caledonia. This is consistent with the well-known longitudinal diversity gradient in the Pacific, and Tonga appears to have exactly the diversity that would be predicted based on its location in the gradient.
- Reef sites which were moderately exposed to waves had the highest number of coral species, followed in descending order by exposed reefs, sheltered reefs, limestone drop-offs and volcanic reefs.
- Two indexes were calculated, one for conservation value, called the "Coral Replenishment Index" and another for diversity, called the "Coral Rarity Index". Site 16 had the highest Coral Replenishment Index, followed by sites 17, 15 and 19 in descending order. Site 1 had the highest Coral Rarity Index, followed by sites 3, 25 and 2 in descending order. Site 16 had the highest combination of these two indices, followed by sites 1, 17 and 26 in descending order.
- A total of 197 species were found that had not been reported before from Vava'u, 95 species were found that had not been reported before from Tonga, and 67 species were recorded that represented extensions of their known biogeographic ranges.
- A total of 33 species were found that have been reported to have an elevated risk of global extinction, 17 species were found which have been proposed for listing under the US Endangered Species Act (ESA), and five species were found which are listed under the ESA.
- Conservation recommendations include the establishment of marine protected areas (MPAs), protecting the largest reef fish species throughout the country, signing the Convention on International Trade in Endangered Species (CITES), protecting sea turtles, and monitoring the reefs by repeating our benthic and fish transects annually.

7.2. Introduction

Stony or hard corals are a critical component of coral reefs worldwide. Coral reefs are the most diverse of the marine ecosystems. Corals contribute to the build-up of the calcium structure of coral reefs (along with certain algae) and are critical to holding reefs together. Further, corals are a primary contributor of habitat diversity used by many species associated with coral reefs, notably fish but also cryptic, sessile and commensal organisms. Corals are highly vulnerable to a range of disturbances, many of which are caused by humans, and are undergoing rapid decline in many parts of the world, though not everywhere. Coral reefs produce many ecosystem services for people, including fisheries that provide critical food security, shoreline protection, and tourism, worth billions of dollars annually around the world.

Many corals can be identified in-situ on coral reefs using field identification guidebooks such as Veron (1986, 2000) and taxonomic revisions such as those by Hoeksema (1989) and Wallace (1999). In situ, one can see the entire colony, and often many colonies, while identification from collected specimens often must be based on small samples that do not show the colony shape or range of morphological variation. Hard coral taxonomy is based on the skeletons. Coral tissue is usually thin, and so some skeletal features can be seen in living corals. Although there are fewer species of coral than fish, identification is more difficult due to greater morphological variation within species (Veron 1995, 2000; Todd 2008). However, field identification is at least possible, compared with groups such as sponges or ascidians which require extensive collecting and laboratory analysis because they cannot be identified in the field. The combination of the critical role of corals for coral reefs, the high diversity of coral reefs, and the ability to identify most coral species rapidly in the field makes them a critical component in any rapid assessment of coral reefs.

The Kingdom of Tonga lies in the South Pacific, east of Fiji and southwest of the Samoan archipelago. There are a total of 174 islands, 37 of which are inhabited (Lovell and Palaki 2000), in a nearly north–south chain, in three main island groups (UNEP/IUCN, 1988). At the north is the Vava'u group of islands, in the middle is the Ha'apai group, and in the south is the Tongatapu group. The largest island is Tongatapu, which is at the southern end of the chain, and which has the capitol city Nuku'alofa. Tonga lies to the west of the Tonga Trench, where the Pacific Plate is subducted under the Indo-Australian Plate. In addition to the islands being in three groups, these islands are also arranged in two parallel chains running north–south. Most of the islands are in the eastern chain, and are flat topped limestone islands on top of old, dead volcanoes. To the west is a parallel chain of a much smaller number of young volcanoes, some of which are periodically active. The Vava'u group is an oval group of limestone islands, with the largest and highest island by far at the northern edge, and smaller islands scattered on a shallow plateau that is continuous with the largest island. The flat layers of limestone that compose the smaller islands can be seen from a distance. Many of the small islands are surrounded by reefs, and there are other reefs on the plateau. There are barrier reefs on the south and southeast edges of the plateau (Holthus 1996). This survey also extended to two volcanic islands west of the main Vava'u Group of islands.

There has been relatively little research on the coral reefs of Tonga, with only a few reports of individual coral species. Holthus (1996) presented the results of a coral reef survey programme conducted in 1990 in the Vava'u group. In addition to describing the reef sites surveyed, the report provided a list of coral genera and species found. The list includes 73 taxa consisting of one family (Fungiidae), several genera, lifeform groups and 39 species, including non-scleractinian corals. Lovell and McLardy (2008) present a list of 189 species of coral reported from Tonga. Most were recorded by van Woesik (1997) from the island of Tongatapu at the southern end of Tonga, but a few were obtained from a World Conservation Monitoring Centre (WCMC) online database. The van Woesik (1997) report was not available, including from the author. Adjeroud et al. (2013) recorded 37 coral genera in Tongatapu. They provide the names of the 20 most common genera.

The following is a report of the reef corals of the 25 dive sites and one snorkel site surveyed (refer to Figure 7.1 and Table 7.1) around the Vava'u group and two volcanic islands during the BIORAP in February 2014. The principle goals of the coral survey were to provide an inventory of the coral species growing on the reefs and associated habitats, to compare the coral fauna at different sites, to compare the diversity of corals with other areas, and to look for species that have not been reported in Tonga or would be outside their known range or which have a heightened risk of extinction. The primary group of hard corals on coral reefs is the zooxanthellate scleractinian corals, that is, those that contain single-cell algae and which contribute to building the reef. Also included are a small number of zooxanthellate non-scleractinian coral species which also produce large skeletons which contribute to the reef (e.g. fire coral, *Millepora* and organ pipe coral, *Tubipora*), and two azooxanthellate non-scleractinian corals (*Distichopora* and *Stylaster*). All produce calcium carbonate skeletons that contribute to reef building to some degree.

Most of the world's reef coral species have now been evaluated for their level of risk of global extinction (Carpenter et al. 2008) based on criteria developed by the IUCN (IUCN 2012). The status of individual species is now available from the IUCN (www. iucnredlist. org), and species with a heightened risk of extinction found in Tonga are reported here. Also, 66 coral species have been proposed for listing under the US Endangered Species Act. Species found in Tonga in this study which are proposed for such listing are also reported here.

7.3. Methods

Coral diversity and abundance were surveyed at 25 sites while scuba diving for 60 minutes per site, using a 'roving diver' search method. Coral species were also recorded on one snorkel in shallow water. Sites 6 and 7 were not surveyed, as it was too rough to safely exit and enter the dive boat on the day those sites were visited. A direct decent was made in most cases to the lower limit of abundant coral, which was always less than 30 m deep. The bulk of the dive consisted of a slow ascent along the reef in a zigzag path to the shallowest depth that could be reached with a scuba tank, or the shallowest depth safe from heavy surge, or the depth at which the slope was so near to horizontal that time did not allow searching additional area. The roving diver search method detects more of the species present than belt transects because it covers a larger area. It also distinguishes differences in diversity at different sites as well as belt transects (Holt et al. 2013).

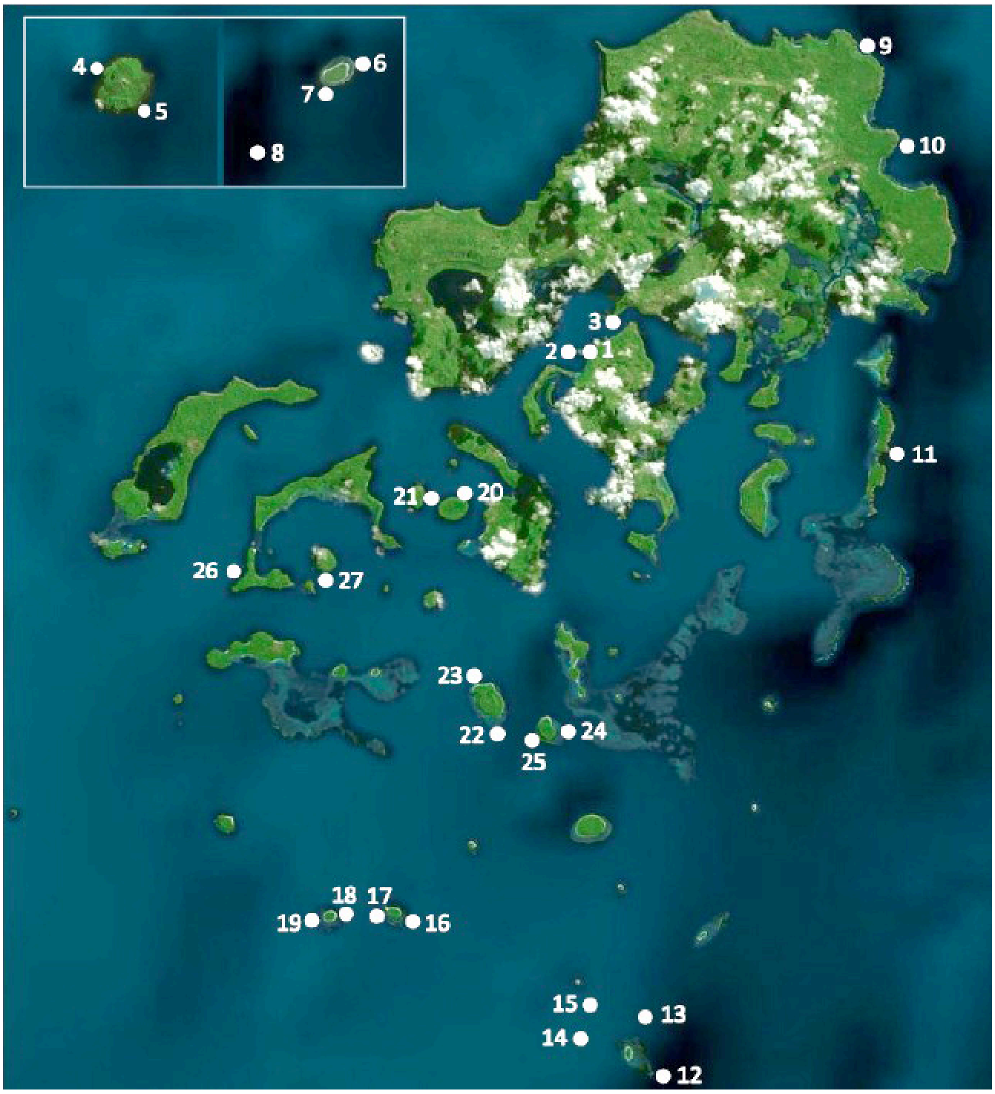

Figure 7.1 Map of Vava'u showing locations of sites surveyed (Map courtesy of Andrew Bauman).

Table 7.1. Site details (courtesy of Andrew Bauman in chapter 8)

Site No.	Site name	Reef type
Site 22	'Euakafa Island, south	Fringing (moderately exposed)
Site 21	'Oto Island	Drop-off (wall)
Site 12	Maninita Island, inside	Fringing (moderately exposed)
Site 7	Toku Island, north	Fringing (moderately exposed)
Site 25	'Euaiki Island, west	Fringing (moderately exposed)
Site 20	A'a Island	Drop-off (wall)
Site 13	Maninita Island, outside	Fringing (exposed)
Site 23	'Euakafa Island, north	Fringing (moderately exposed)
Site 6	Toku Island, south	Fringing (moderately exposed)
Site 18	Fangasito Island, south	Fringing (moderately exposed)
Site 9	Mata'utuiliki, Vava'u lahi Island	Fringing (exposed)
Site 14	Taula Island, inside	Fringing (moderately exposed)
Site 26	Vaka'eitu Island	Fringing (exposed)
Site 17	Fonua'one'one Island, north	Fringing (moderately exposed)
Site 8	Toku Island, Joe's Spit	Exposed oceanic platform
Site 16	Fonua'one'one Island, south	Fringing (moderately exposed)
Site 19	FangasitoIsland, north	Fringing (moderately exposed)
Site 24	'Euaiki Island, east	Fringing (moderately exposed)
Site 11	'Umana Island	Fringing (exposed)
Site 1	Lotuma Island	Lagoon (sheltered)
Site 2	Lotuma Island Channel	Lagoon (sheltered)
Site 3	Mount Talau, Vava'u Lahi Island	Lagoon (sheltered)
Site 15	Taula Island, outside	Fringing (moderately exposed)
Site 10	'Onetale Bay, Vava'u lahi Island	Fringing (exposed)
Site 27	Langito'o Island	Fringing (moderately exposed)
Site 5	Fonualei Island, south	Fringing (volcanic reef)
Site 4	Fonualei Island, north	Fringing (volcanic reef)

At a few sites, there was too little slope to reach the lower limit of coral, in which case an area of a safe size and depth was searched. Corals were usually identified insitu, however where an identification could not be made rapidly, a photograph was taken. An attempt was made to take at least a few photographs of all species. Coral species and their abundance were recorded on a printed form on an underwater slate. Species abundance was recorded using the DAFOR scale, where D stands for dominant, A for abundant, F for frequent, O for occasional and R for rare (Mumby et al. 1996). Rare was defined as only one or two colonies seen, and dominant was defined as over half of all corals or coral cover. Other studies of corals which have used this sort of scale include DeVantier et al. (1998, 2006), Fenner (2006, 2007, 2011), Richards et al. (2008) and Richards and Beger (2013). Abundance categories were next given a numerical value, by assigning R = 1, O = 2, F = 3, A = 4, and D = 5.

Many corals can be identified to species with certainty in the water and a few must be identified alive since they cannot be identified without living tissues. In addition, there are some that are easier to identify alive than from skeletons. However, there are some species that normally require collection for verification. Samples of corals that could represent new species were collected at a few sites. Samples were later bleached in a household bleach solution then rinsed in freshwater and dried, but could not be taken into the US for study because of CITES (Convention on the International Trade of Endangered Species) restrictions. Tonga is not a signatory to CITES so the US will not allow imports of listed species (and all corals are listed) from Tonga. The species collected are listed in Table 7.2.

Table 7.2. List of species collected with number of samples.

	Species	No. samples		Species	No. samples
1.	*Acropora* sp. 1 'globiceps-like'	1	5.	*Acropora* sp. 5 'thin'	1
2.	*Acropora* sp. 2 'flat'	1	6.	*Acropora* sp. 6 'bushy'	1
3.	*Acropora* sp. 3 'club shape'	2	7.	*Alveopora* cf. *Viridis*	1
4.	*Acropora* sp. 4 'pharaonis-like'	3	8.	*Alveopora* cf. *Exselsa*	1

Several comprehensive guides assisted identification (Hoeksema 1989; Wallace 1999; Veron 2000). The nomenclature of Veron (2000) has been followed for fungiids, though the illustrations and descriptions in Hoeksema (1989) were the primary source for actual identification. The nomenclatures of these two authors differ primarily at the level of genera and sub-genera, not species. Additional references used in identifying corals were Randall and Cheng (1984), Veron (1986, 2002), Glynn et al. (2001), Ditlev (2003), Razak and Hoeksema (2003), Wolstenholme et al. (2003), Richards and Wallace (2004), Fenner (2005), Benzoni (2006), Benzoni et al. (2007), Wallace et al. (2007, 2011), Foresman and Birkeland (2009) and Turak et al. (2012).

DeVantier et al. (1998) used an index for evaluating reef sites for conservation, called the 'coral replenishment index' or CI. The presence of high diversity, abundance and cover of coral can increase the ability to replenish or restock local reefs in the case of a major disturbance. The CI is based on the abundance of each species and the total cover at a site, to get a measure of the local population of the species at the site.

$$CI = \sum AiHi/100$$

where Ai is the abundance score of each species at the site on the 0–5 scale used in this study, and Hi is the coral cover at the site where 0% cover = 0, 1–10% cover = 1, 11–30% cover = 2, 31–50% cover = 3, 51–75% cover = 4, and 76–100% = 5. The mean site coral cover from Chapter 11 was used for this purpose.

DeVantier et al. (1998) also used an index called the 'coral rarity index' (RI). This is a measure of how many relatively rare species are found on a site and how abundant they are.

$$RI = \sum Ai / 6Pi$$

where Ai is the abundance score and Pi is the proportion of sites in which the species was present. The constant '6' was picked to make the resulting index roughly equivalent to the CI, to facilitate comparison and adding these indices.

7.4. Results

7.4.1. CORAL SPECIES DIVERSITY

A total of 206 species in 55 genera of stony corals (including 199 species in 51 genera of zooxanthellate Scleractinina) were found in this survey. Almost all of these species are illustrated in Veron (2000), most *Acropora* are illustrated in Wallace (1999), and fungiids are illustrated in Hoeksema (1989). The total of 206 species in 55 genera is slightly more than the 189 species and 41 genera reported by Lovell and McLardy (2008; based mainly on a study by van Woesik (1997) from Tongatapu Island). Together, the present study, the Lovell and McLardy list, plus a report by Holthus (1996) reported a total of 287 species of coral in Tonga. The total found in this study was also less that the number of species found on six other Pacific rapid assessments using the same methodology and the same identifier, ranging from 253 species in Fiji (Fenner 2006) to 333 species in New Caledonia (Fenner 2011). Each study included a different number of sites, but all had more sites than this study. The number of species found increases with increasing numbers of sites, so these numbers of species are not comparable measures of diversity.

The number of species found on the average per dive is much more comparable between areas than the total number of species found in a rapid assessment, because the amount of effort in a single dive (60 minutes) is much more equivalent between studies than the total effort (number of dives), which differs greatly between studies. Figure 7.2 shows the mean number of coral species found per 60-minute roving search dive in four similar rapid assessments by the same author in the South Pacific. The mean number of coral species per dive does not differ greatly between locations, and there does not appear to be any systematic trend. This is somewhat surprising, since the Pacific has a strong longitudinal gradient, with coral diversity declining towards the east (Veron 2000), and the locations shown in Figure 7.2 are shown in order from west to east going left to right. A term for the number of species at individual locations is 'alpha diversity'.

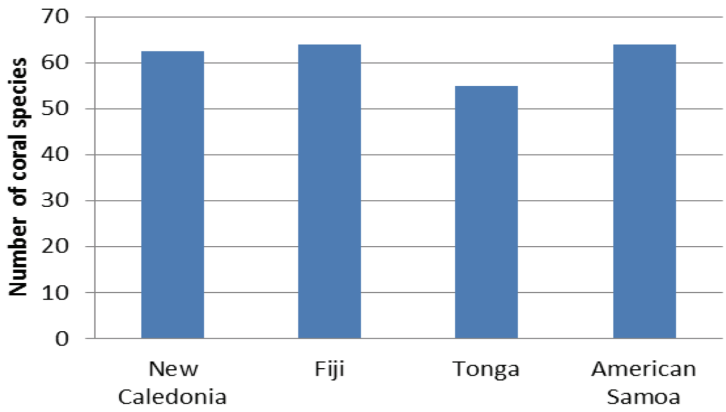

Figure 7.2. The mean number of coral species per dive at four locations in the South Pacific.

The total number of species found in a larger number of dives may be a more sensitive measure of the total biodiversity in an area, since additional effort always increases the total number of species found. With greater effort the total number of species should be closer to the total that occurs at the area, even though that total is unknown. Figure 7.3 shows the total number of coral species found in twenty five 60-minute roving search dives, for the same four South Pacific locations, based on the same data set as in Figure 7.2. The total number of coral species in 25 dives differs consistently between locations, showing a longitudinal gradient in diversity consistent with the overall pattern for the Pacific (Veron 2000). The total number of species in 25 dives decreases towards the east similar to the decrease across the entire Pacific. A term for the differences in species assemblages between sites within a region is 'beta diversity'. It would appear in this case that alpha diversity (Figure 7.2) does not show a longitudinal diversity gradient, however beta diversity does. This is because the difference between the number of species at one site and the total number found at 25 sites is produced by beta diversity; if beta diversity is zero then all sites have the exact same compliment of species, so that the total number of species in 25 sites is the same as the number of species at one site.

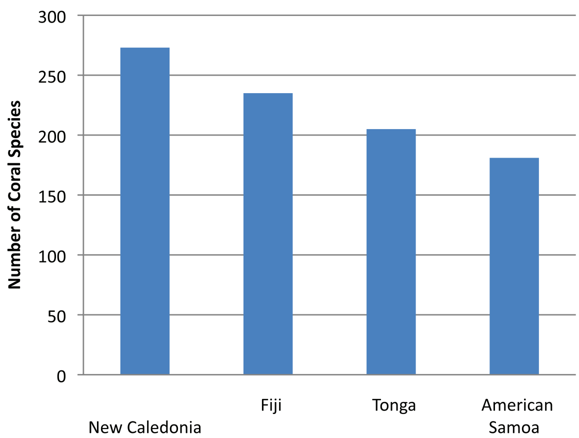

Figure 7.3. The total number of coral species recorded by the author in 25 dives at each of four different South Pacific locations.

The number of coral species at individual sites ranged from 16 to 80 species. The sites with the greatest numbers of coral species were sites 26, 16, 25, 18 and 15, and the sites with the fewest species were sites 4, 5, 8, 21 and 20. The number of species found at each site is shown in Table 7.3. The species found at each site and their abundances are shown in Annex 7.1. Figure 7.4 shows a high diversity site.

Table 7.3. The total number of coral species recorded at each site. Sn1 is the one snorkel site in shallow water.

Site	Species	Site	Species	Site	Species
1.	51	12.	63	21.	33
2.	47	13.	63	22.	69
3.	39	14.	56	23.	49
4.	16	15.	70	24.	60
5.	28	16.	79	25.	74
8.	29	17.	67	26.	80
9.	61	18.	72	27.	60
10.	61	19.	63	Sn1.	17
11.	44	20.	36		

Figure 7.4. High coral diversity and cover at site 16 (photo by Douglas Fenner).

Several different habitats were distinguished: sheltered reefs, limestone drop-off reefs, moderately exposed reefs, exposed reefs, other reefs and volcanic reefs. The number of coral species at each site grouped by habitat locations is shown in Figure 7.5. Sheltered reefs had a mean of 45.7 coral species, limestone drop-off reefs had a mean of 34.5 species, moderately exposed reefs had a mean of 65.2 species, exposed reefs had a mean of 61.8 species, the one other reef had 26 species, and volcano reefs had 21.5 species. Thus, moderately exposed reefs had the highest number of coral species, followed in descending order by exposed reefs, sheltered reefs, limestone drop-off reefs and volcanic reefs. Volcanic reefs also clearly had the lowest coral cover, with very low cover.

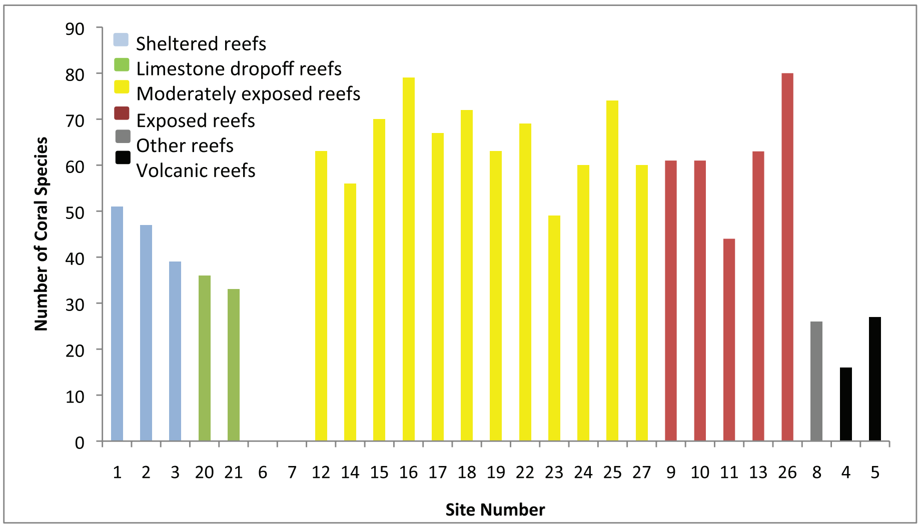

Figure 7.5. The number of coral species for each site grouped by habitat. No data were collected from sites 6 and 7.

The cumulative number of coral species found as a function of the number dives is shown in Figure 7.6. The cumulative number of species found increased rapidly at first, and then the rate decreased gradually to low levels, which is a typical pattern.

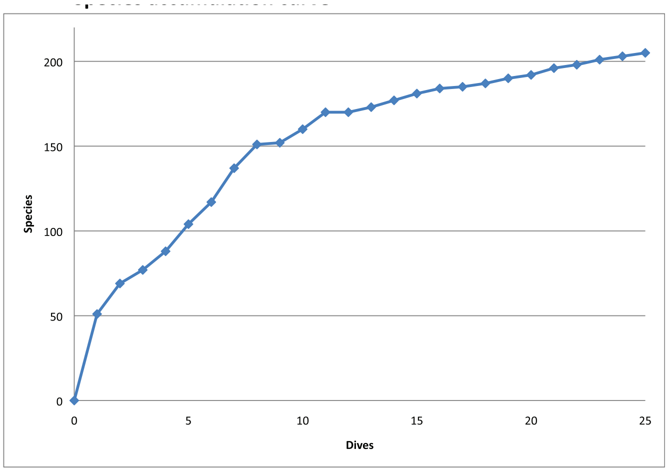

Figure 7.6. Cumulative number of coral species found with increasing numbers of dives.

7.4.2. CORAL REPLENISHMENT AND CORAL RARITY INDICES

The results for the CI for all sites are shown in Figure 7.7. The sites with the highest CI were (in order starting from the highest) sites 16, 17, 15 and 19. Figure 7.8 gives the values of the RI calculated for each site. The highest values were found at sites 1, 3, 25 and 2 (in decreasing order).

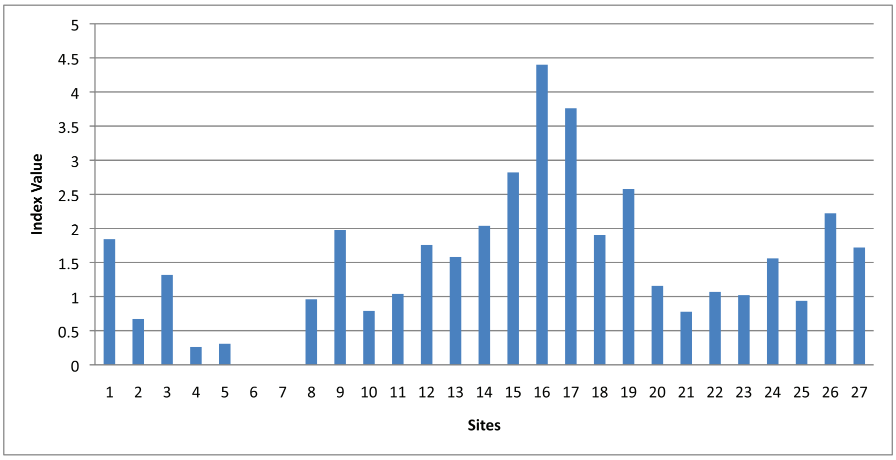

Figure 7.7. The coral replenishment index (CI) for each site using the method of DeVantier et al. (1998). No data were collected from sites 6 and 7.

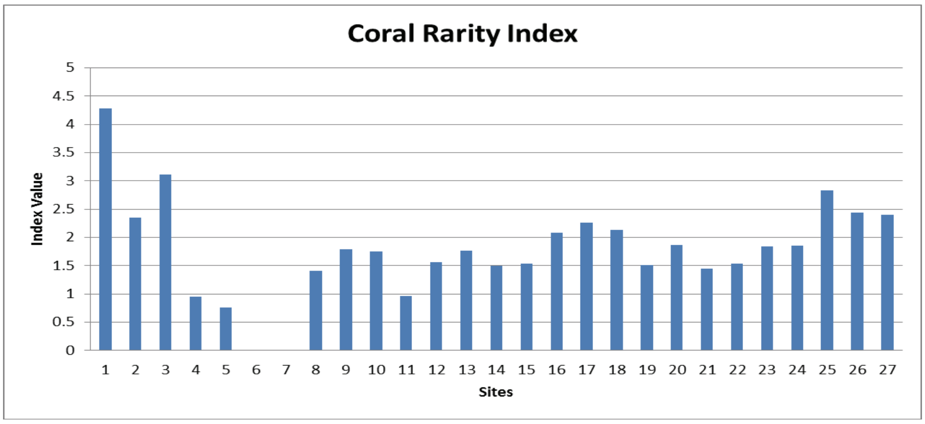

Figure 7.8. The coral rarity index (RI) for each site using the method of DeVantier et al. (1998). No data were collected from sites 6 and 7.

The two indices, CI and RI, can be added together to produce a single score for each site, which provides a ranking of sites. Figure 7.9. presents the combined score for each site. The sites with the highest scores were 16, 1, 17 and 26, in descending order.

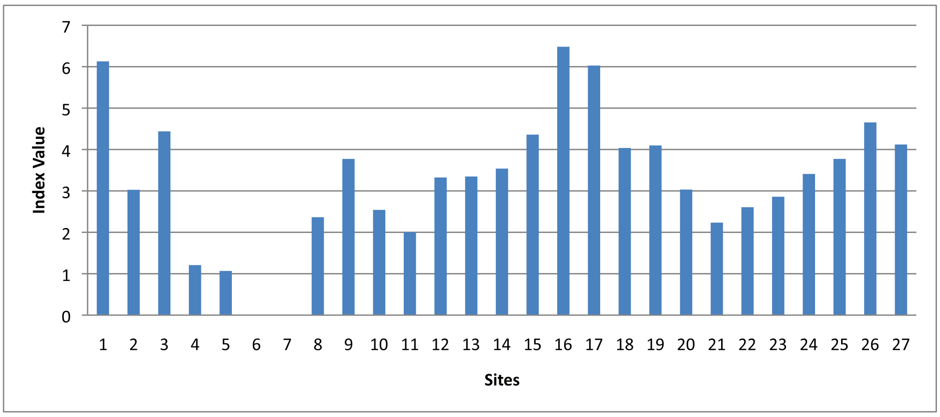

Figure 7.9. Combined index derived from adding the coral replenishment index (CI) and the rarity index (RI) by site. No data were collected from sites 6 and 7.

7.4.3. GENERAL FAUNAL COMPOSITION

The coral fauna consists mainly of zooxanthellate Scleractinia with 199 species, and only seven species that are not zooxanthellate Scleractinia (*Tubipora musica*, *Millepora dichotoma*, *Millepora exaesa*, *Millepora intricata*, *Millepora* cf. *platyphylla*, *Stylaster* sp. and *Distichopora violacea*). Zooxanthellate Scleractinia are the main reef builders, but *Millepora* species are also significant reef builders because they are also zooxanthellate and have large skeletons. There were a total of 204 zooxanthellate species and just two species that were not zooxanthellate (*Distichopora violacea* and *Stylaster* sp.). This pattern is typical of most reefs.

The genera with the most species were *Acropora* with 41 species, *Montipora* with 13 species, *Porites* with 11 species, *Pavona* with 11 species and *Fungia* with nine species. In the Indo-Pacific as a whole, *Acropora* has the most species, followed by *Montipora, Porites* and *Fungia* in that order.

The species that occupied the highest percentage of sites were *Coscinaraea collumna*, *Goniastrea pectinata* and *Pavona chiriquensis* which were present at 80% of the sites; *Leptoria phyrgia* and *Oulophyllia crispa* which were present at 72% of the sites; *Favia stelligera, Herpolitha limax*, *Isopora cuneata*, *Millepora cf. platyphylla*, *Montastrea curta*, *Pocillopora eydouxi* and *Porites vaughani* which were present at 68% of the sites; and *Acropora globiceps*, *Lobophyllia hemprichii*, *Montipora capitata* and *Mycedium elephantotus* which were present at 64% of the sites.

The species that had the highest mean abundance ratings for the sites where they were present were *Montipora hispida* (mean rating = 3, based on only one site), *Acropora* sp. 3 (2.75, 5 sites), *Porites rus* (2.4, 9 sites), *Stylophora* cf. *subseriata* (2.3, 8 sites), *Montipora turgescens* (2.3, 12 sites) and *Acropora hyacinthus* (2.3, 11 sites). The lowest possible mean abundance score for sites where a species is present is 1.0, with 1 = rare, 2 = uncommon, and 3 = common.

7.4.4. SPECIES OF PARTICULAR INTEREST

Holthus (1996) reported 35 species of coral from the Vava'u group of islands. Twenty-seven of those 35 species were also reported in the present study. Thus, 197 species in the present report are new reports for the Vava'u group. Lovell and McLardy (2008) listed coral species which had been reported in Tonga by van Woesik (1997) and others which were listed as being in Tonga by the WCMC database. Lovell and McLardy (2008) listed a total of 189 species of coral present in Tonga. The present study found 95 species not previously reported in either Holthus (1996) or Lovell and McLardy (2008), as indicated in Annex7.1. A total of 287 species of hard corals have been reported from Tonga so far in these three studies.

Several authors have provided range maps or locations where coral species have been found around the world (Randall and Cheng 1984; Hoeksema 1989;Wallace 1999; Veron 2000;Razak and Hoeksema 2003). That information was used to determine if the present records of species in Tonga were outside the known range of the species. In total, 67 species were found to be outside their known biogeographic ranges, as indicated in Annex7.1.

Several coral species have been designated as having an elevated risk of extinction according to the IUCN and/or the US Endangered Species Act. Carpenter et al. (2008) reviewed all of the world's coral species using the criteria of the IUCN Red List of endangered species, and came to the conclusion that a third of the world's reef coral species have an elevated risk of extinction. Table 7.4 lists species found in this study that have an elevated risk of extinction under the IUCN Red List criteria, and the category of risk that was assigned to it by Carpenter et al. (2008) and adopted by IUCN. Table 7.4 also lists which of the corals found in this study were proposed for protection under the US Endangered Species Act, and the listing category proposed. Finally, Table 7.4 lists the species designated in the final listing of the US Endangered Species Act, and the listing category proposed. A total of 33 species were found in this study which were considered under IUCN Red List criteria to have an elevated risk of extinction, one of which (*Alveopora excelsa*) was categorised as Endangered and the rest were categorised as Vulnerable. One species (*Acropora jacquelineae*) was proposed for designation as Endangered under the US Endangered Species Act, and a total of 17 species were proposed for designation as Threatened. Recently, the final decision under the US Endangered Species Act was announced, and five of the species found in this study were designated as Threatened as listed in Table 7.4.

Although the coral referred to as '*Acropora* cf. *jacquelineae*' bears some resemblance to the species of that name, it also appears to have some differences and might be *Acropora speciosa* or some other species. The species referred to as '*Pavona* cf. *diffluens*' appears very similar to *P. diffluens* from the Red Sea and western Indian Ocean, illustrated in Veron (2000), but Veron (2014) states that it is likely to be another, similar species. Examination of skeletal samples will be required to resolve these.

Table 7.4. IUCN Red List category assigned by Carpenter et al (2008), and proposed and final listings under the US Endangered Species Act, for species reported in this study

	Species	IUCN Red List category	Proposed listing, US Endangered Species Act	Final listing, US Endangered Species Act
1.	*Pocillopora ankeli*	Vulnerable		
2.	*Pocillopora danae*	Vulnerable	Threatened	
3.	*Montipora caliculata*	Vulnerable	Threatened	
4.	*Montipora cebuensis*	Vulnerable		
5.	*Isopora crateriformis*	Vulnerable	Threatened	Threatened
6.	*Isopora cuneata*	Vulnerable	Threatened	
7.	*Acropora carolineana*	Vulnerable		
8.	*Acropora globiceps*	Vulnerable	Threatened	Threatened
9.	*Acropora* cf. *jacquelineae*	Vulnerable	Endangered	Threatened
10.	*Acropora palmerae*	Vulnerable	Threatened	
11.	*Acropora paniculata*	Vulnerable	Threatened	
12.	*Acropora retusa*	Vulnerable	Threatened	Threatened
13.	*Acropora solitaryensis*	Vulnerable		
14.	*Acropora verweyi*	Vulnerable	Threatened	
15.	*Astreopora cucullata*	Vulnerable	Threatened	
16.	*Euphyllia cristata*	Vulnerable	Threatened	
17.	*Galaxea astreata*	Vulnerable		
18.	*Pavona bipartita*	Vulnerable		
19.	*Pavona cactus*	Vulnerable		
20.	*Pavona* cf. *Diffluens*	Vulnerable	Threatened	Threatened
21.	*Leptoseris incrustans*	Vulnerable		
22.	*Pachyseris rugosa*	Vulnerable	Threatened	
23.	*Acanthastrea brevis*	Vulnerable	Threatened	
24.	*Acanthastrea hemprichii*	Vulnerable	Threatened	
25.	*Acanthastrea ishigakiensis*	Vulnerable	Threatened	
26.	*Symphyllia hassi*	Vulnerable		
27.	*Caulastrea curvata*	Vulnerable		
28.	*Porites horizontallata*	Vulnerable	Threatened	
29.	*Alveopora excelsaexcels*	Endangered		
30.	*Turbinaria mesenteria*	Vulnerable		
31.	*Turbinaria peltata*	Vulnerable		
32.	*Turbinaria reniformis*	Vulnerable		
33.	*Turbinaria stellata*	Vulnerable		

Several species of coral appear to be new species, such as *Acropora* sp. 1-5, and *Psammocora* sp. 1, *Acropora* sp. 2 and *Psammocora* sp. 1 have also been found in American Samoa by the author, who plans to describe these new species.

A few species were of interest for other reasons. Several colonies of *Euphyllia cristata* were found, all of which had multiple branches and polyps. This species seems to only have been illustrated in photographs of living colonies as young colonies with only one corallite (Veron 2000). Although a skeleton with multiple branches has been figured (Veron and Pichon

1979, Fig. 611), Veron (2000) states that small colonies are more common than larger colonies. All colonies found in Tonga were large for this species, with multiple branches and a colony diameter of about 10 cm. The tentacles were much shorter than on *Euphyllia glabrescens* which has similar shaped tentacles. Branches and polyps were also much larger than has been reported on *Euphyllia baliensis* (Turak et al. 2012). Septa could be seen through the tissues, which is a characteristic feature of this species (Veron 2000), so the identification appears to be secure even though a sample was not collected.

Figure 7.10. *Euphyllia cristata* (photo by Douglas Fenner).

Echinomorpha nishihirai (Veron 1990) was described from Japan in 1990 as *Echinophyllia nishihirai*, but later placed in its own genus (Veron 2000). It is rare in most places, but distinctive enough to be relatively easily recognised. The author has encountered only one colony in the Philippines, where the author has recorded coral species from over 200 dive sites. In American Samoa where the author has worked for 10 years and has been diving on all seven islands, he has only been able to find three of these corals. This species was more common in Fiji (Fenner 2006, 2007), however it was even more common in Tonga than Fiji, and thus Tonga appears to currently have the most abundant populations known of this rare species. In Tonga, photos of 34 of these corals were taken.

Figure 7.11. *Echinomorpha nishihirai*. This species comes in a variety of colours (photo by Douglas Fenner).

7.5. Discussion

The coral reefs in Vava'u host a moderately diverse community of hard corals relative to other areas of the Indo-Pacific. The coral diversity is consistent with Vava'u's location and the fact that coral diversity shows a longitudinal gradient in the Pacific, which is supported by the author's data on the total number of coral species found in 25 dives in four areas of the South Pacific: New Caledonia, Fiji, Tonga and American Samoa. Thus, the diversity of corals appears to be controlled primarily by the distance from the centre of diversity, located in the 'Coral Triangle' area of the Philippines, eastern Indonesia, northern Papua New Guinea and the Solomon Islands (Veron 2000; Veron et al. 2009, 2011).

A total of 197 species were found that had not been reported before from Vava'u, 95 species were found that had not been reported before from Tonga, and 67 species were recorded that represented extensions of their known biogeographic ranges. Thus this study contributes a significant amount of new information about an understudied area of coral reefs. Further study of Tongan reefs is likely to reveal additional species, particularly in the Ha'apai group, since corals in the Ha'apai group have not been studied. Further studies of Tongan reefs are likely to find additional coral species to add to the total for Tonga, but will eventually show diminishing returns for the additional effort.

The reefs of the Vava'u group are quite varied, from exposed reefs to very sheltered reefs to limestone cliffs to volcano slopes. The differences between the habitats at individual reef sites contributes to the diversity of coral species, since individual coral species are often more common in specific habitats or even completely restricted to specific habitats. Surveying more habitats increases the number of coral species found. Reef flats were not extensively surveyed in this study, and additional surveys in shallow habitats like reef flats may add to the total number of species found.

It appears that the amount of wave exposure accounts for little of the differences in coral diversity, since reefs with different wave exposure had similar coral diversity. Sheltered reefs had somewhat fewer species, but exposed and moderately exposed reefs had similar numbers of species. Corals on volcanic substrate have very low coral cover and fewer species than in other habitats. The low apparent diversity is likely to be partly due to the low number of coral colonies found, and additional searching may find more species. The corals were attached to boulders of volcanic rock, but most of the surface of the boulders had no corals on them. The situation was essentially the same at the two sites, which were on different volcanoes. The habitat and coral populations appeared very similar to those on a volcanic island named Pagen in the Northern Marianas Islands observed by the author in 2013. Low coral cover could be due to the volcanic surface being so young that the boulders have not had time yet to be colonised by corals. However, the boulders had rounded corners indicating time for erosional rounding of sharp edges, there was black volcanic sand between boulders, and the terrestrial slopes of the volcano were well vegetated. Thus, it appears this was not the reason for low coral cover. Other volcanoes in the Tongan archipelago have high coral cover (K. Stone, personal communication). It may be that exposed volcanic boulders are sand blasted by the loose sand during heavy wave action, which damages the corals and keeps coral cover low.

The fairly diverse coral community in the Vava'u group is a very attractive asset for dive tourism. There are reefs with high coral cover and high enough diversity to make a beautiful reef. Other corals are large and unusual (*Acropora* sp. 2), several species appear to be new species, and others are more common in Vava'u than elsewhere (such as *E. nishihirai* and *E. cristata*). Several species found are on lists of threatened species. All this supports the conservation value of the living corals in Vava'u and Tonga as a whole.

The information in this report detailing the number of coral species on individual sites, the coral replenishment and rarity indices for each site, and the threatened species, provides information to assist in the selection of sites for protection as marine protected areas.

The reefs appeared to be in relatively good condition, without large numbers of dead corals, coral bleaching, coral disease, invertebrate coral predators (no crown-of-thorn starfish were seen by the author and few *Drupella* snails), storm damage, abundant algae, or visible terrestrial sediments. However, large fish and predatory fish were not sighted, indicating that fishing pressure is significant. The healthy coral communities provide a strong basis for dive tourism, which would be strengthened by increased populations of large fish, which usually appeal to divers.

7.6. Conservation recommendations

Tonga has many healthy coral reefs. These are a national treasure, and a world treasure. Many of the world's coral reefs are now in very poor condition. Healthy coral reefs can support a growing dive industry that can help the economy grow. The coral reefs of Vava'u are easily accessed and safe to dive, have lots of variety, and are beautiful, all very attractive features for divers, and there is thus great potential for increasing dive tourism in Vava'u. Diving is one of the most sustainable uses of coral reefs, when conducted in an eco-friendly fashion with divers controlling their buoyancy. At the same time, resorts, restaurants, businesses and agriculture need to minimise their impacts on the reefs, for example by reducing nutrient runoff from fertilisers and sewage, or terrestrial sediment runoff from roads and cleared fields. Luckily, most of the islands are limestone, which usually has much less sediment runoff than non-limestone islands.

The attractiveness of the reefs to divers would be greatly increased if there were more fish, particularly large fish. The lack of large fish is almost certainly caused by overfishing (Fenner 2014). There are at least two different ways to increase the numbers of large fish. One is to establish marine protected areas (MPAs), and in particular 'no-take areas' where fishing and other extractive activities such as collecting coral are forbidden. There are a number of studies documenting the increase in larger fish with time within such MPAs (Fenner 2012). The sustainable management of reef fish for dive tourism can produce much more economic benefits for the local community than fishing the reefs. Divers often pay about US$75 a day for diving from small boats, plus more money for hotel, food, airfare and purchases. All that money other than airfare and foreign-owned hotels enters the local economy. The MPAs can also provide increased fish catches. Some of the fish that grow larger and more numerous in the MPA will swim outside the MPA, where fishermen can catch them. In a sense, an MPA is a natural fish farm which can provide moderate fisheries benefits as well as great conservation benefits.

The choice of sites for protection as MPAs will likely depend on a variety of factors. The diversity of corals was highest at sites 26, 16, 25, 18 and 15, and the coral replenishment and rarity indices together were highest at sites 16, 1, 17 and 26. So sites 26 and 16 would be particularly good choices, as would be 25, 18, 1, 17 and 15. Social acceptance and support by the local residents would be a critically important factor for the success of the selected protected area.

A second way to increase the population of large fish species is to ban the taking of those species throughout an island group or the entire country. This has the advantage that people can still catch other fish, but protects the large fish so they increase in size and number. Alternatively, this could be spatially targeted, where the take of large fish species is prohibited in areas that divers use. The more targeted or restricted any closure, the less opposition there is likely to be from fishermen, so the more likely it is to be acceptable and therefore effective. One problem with closing only relatively small areas is that some large fish such as sharks swim over much larger areas than small MPAs, and can be taken while outside the small MPA, so the MPA provides only limited protection.

There are a variety of other measures that can help protect the reefs and strengthen them. The Government could consider signing the CITES convention, which would help it to control anypresent or future international trade in organisms that might threaten biodiversity on land or in the sea, while allowing trade that is not a threat. Finally, either the Fisheries Department or Department of the Environment should begin a coral reef monitoring programme, repeating our benthic transects each year. A monitoring programme could provide early warnings of any problems with the reef that might develop.

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CHAPTER 8

MARINE MACRO INVERTEBRATES OF VAVA'U

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8.1. Summary

- A list of marine macroinvertebrate species was compiled for 27 coral reefs sites surrounding select islands in the Vava'u Archipelago. The survey involved approximately 27 hours of scuba diving to a maximum depth of 35m.
- The survey included a separate rapid assessment of three commercially valuable marine invertebrate species (sea cucumbers, giant clams and trochus) conducted by representatives from the Tonga Ministry of Agriculture and Food, Forests and Fisheries.
- A total of 249 species from 146 genera were identified in the survey. This included representatives from 101 families, 39 orders and 17 classes across seven phyla.
- Phylum Mollusca accounted for the highest number of species recorded for all 27 sites assessed in the survey (96 species), while the Phylum Annelida accounted for the lowest number of species (two species).
- Species richness among sites ranged from 15 at site 4 (Fonualei island, north) to 38 species at site 22 ('Euakafa Island, south), with an average of 28.7 (± 0.95 SE).
- Alcyoniidae and Holothuriidae were the two most prevalent families, occurring at 85% of the sites (23 of 27 sites).
- The most common species were two species of soft coral (Family Alcyoniidae):*Sarcophyton* sp. (23 sites) and *Lobophyton* sp. (22 sites).
- A total of 279 sea cucumbers was counted and 14 species of sea cucumbers were identified, with a maximum of eight species identified at site 21 ('Oto Island).
- The abundance of high and very high commercial value sea cucumber species was low, accounting for only 17% of the 279 individuals.
- Four species of giant clam (*Tridacna maxima, T. squamosa, T. derasa* and *T. crocea*) were recorded in the survey. The boring giant clam (*Tridacna crocea*) is a new species record for Tonga.
- The highest densities of clams were found on three sites around Toku Island (sites 6, 7 and 8). These sites accounted for nearly 60% of all clams counted in the survey.
- A total of 59 trochus (*Tectus nilotocus*) were recorded in the survey.
- Strong indications of overexploitation of both sea cucumbers and giant clams were noted across sites in the survey.

8.2. Introduction

Coral reefs are one of the world's most complex and productive ecosystems with the highest biodiversity of any marine ecosystem (Sebens 1994; Gray 1997). Estimates of the number of species found on coral reefs range from 170,000 to over 9 million (Reaka-Kudla 1997; Ruppert et al. 2004). The enormous uncertainty in species estimates is largely because like in most marine ecosystems, coral reef biodiversity is dominated by highly diverse invertebrate taxa that are understudied and incompletely described (Reaka-Kudla 1997). Most research and literature on coral reef organisms and their taxonomy has a strong bias towards the most conspicuous reef organisms, such as corals and fishes. The estimates of reef fish and coral diversity stand at about 4000 (Choat and Bellwood 1991; Bellwood et al. 2003) and about 800 species, respectively (Veron 2000). However, invertebrates other than corals account for the vast majority of animal species on coral reefs. Recent estimates indicate that there are at least 165,000 described invertebrate species associated with coral reefs (Stella et al. 2011). However, the true diversity of coral reef invertebrate species will not be known until there are many more systematic studies of groups. Given the ongoing global decline of coral reef ecosystems (Hughes et al. 2003), as well as the high dependency of many invertebrates on scleractinian corals (Stella et al. 2011), it is essential to have a more complete description of their diversity to understand the roles they play in coral reef ecosystems, and their contribution to reef resilience.

This chapter presents the marine non-cryptic (meaning obvious or clearly visible) macroinvertebrate diversity investigation carried out as part of the BIORAP survey conducted in the Vava'u Archipelago of Tonga (hereafter referred to as Vava'u) in February 2014. General information on the surveys and site descriptions are provided in detail elsewhere in this report. The broad objective of this work was to produce a comprehensive list of the non-cryptic macroinvertebrate species present (hereafter referred to as macroinvertebrates) and to assess the status (i.e. abundance) of three commercially valuable (targeted) groups of species: sea cucumbers, giant clams and trochus. This was achieved using standardised underwater visual census (UVC) methods conducted on scuba within safe recreational diving limits (to 35m). Visual census methods provide an effective way to monitor a broad range of species and collect large amounts of data within a relatively short period of time with limited post-processing. Based on the data and information collected, the main aim of this work was to provide reliable recommendations for the people and government of Vava'u to develop and implement effective management and conservation measures.

Despite having the second largest area of reef (9,952 ha) in Tonga (Anon. 2010), Vava'u has had relatively few coral reef studies and surveys (Zann 1994; Lovell and Palaki 2000; Chin et al. 2011). Of the surveys conducted in Vava'u most have focused primarily on commercially valuable species (e.g. sea cucumbers and giant clams; Chesher 1993; Okamoto 1984; Pakoa et al. 2013) or hard coral species (Scleractinia; UNEP/IUCN 1988; Holthus 1996; Chapter 7 of this report). Consequently, macroinvertebrate species diversity throughout much of the Vava'u Archipelago remains poorly documented. The earliest reports of coral reef surveys in Vava'u include those by Douglas (1969), Dawson (1971) and Chesher (1985); most of their work provides qualitative summaries (i.e. site descriptions, lists of potential threats) and short species inventory lists. Holthus (1996) conducted more extensive reef surveys around Vava'u documenting general reef health at 36 sites. However, these surveys focused primarily on quantifying the relative abundance of hard corals, soft corals and macroalgae species, and included only a few other reef-associated macroinvertebrate species (e.g. starfish, sea cucumbers, clams and molluscs). The most recent coral reef surveys (preceding the present work) were undertaken by a team of research scientists from the Khaled bin Sultan Living Oceans Foundation in September 2013, but results from these surveys have yet to be published.

The lack of scientific knowledge on macroinvertebrate species diversity in Vava'u prevents the development of specific actions that are urgently required to manage and conserve important reef resources and key habitats (i.e. ecosystems). This is critically important given that coral reef ecosystems in Vava'u have been confronted by multiple threats and disturbances over the last few decades, especially those located near population centres (e.g. Nieafu harbour) and in surrounding lagoons (Lovell and Palaki 2000; Chin et al. 2011).

As is the case for many South Pacific islands, coral reef ecosystems in Vava'u are being increasingly impacted through multiple disturbances (e.g. overfishing, coastal pollution and sedimentation) that are becoming more frequent and severe (Zann 1994; Lovell and Palaki 2000; Chin et al. 2011). Moreover, these disturbances are now being compounded by the more recent impacts of climate change (e.g. coral bleaching, severe tropical storms; Lovell and Palaki 2000; Chin et al. 2011; author, personal observation). Consequently, many coral reefs in Vava'u are increasingly threatened, and are now at risk of degrading with declines in reef health and diversity (Lovell and Palaki 2000; Chin et al. 2011). Most reports indicate substantial reductions in the abundance and diversity of many reef-associated species, particularly commercially valuable species (e.g. coral reef fishes, sea cucumbers and giant clams). This problem is being exacerbated by insufficient conservation and management measures that lack both proper monitoring and enforcement (Lovell and Palaki 2000; Chin et al. 2011). Given that the people of Vava'u are highly dependent on their coral reef resources (e.g. fishes and macroinvertebrate species) for their income and food security (Anon. 2010; Chin et al. 2011) it is critically important they ensure these resources are managed and conserved in an effective and sustainable manner for future generations.

8.3. Methods

Macroinvertebrate species richness, and abundances of commercially valuable species of sea cucumbers, giant clams and trochus, were assessed concurrently at 27 coral reefs sites over 14 days using underwater visual surveys. Survey methods employed closely followed methods utilised in previous rapid biodiversity surveys in New Caledonia (Tardy 2011) and Nauru (van Dijken, 2013, unpublished). The total survey time was approximately 27 hours of scuba diving per diver, with the maximum depth surveyed down to 35m. A list of all macroinvertebrate species observed, and the abundance of commercially valuable species, was compiled for each site. 'Macroinvertebrates' in this survey included all invertebrates in the following phyla: Annelida (i.e. marine worms), Arthropoda (i.e. crustaceans), Cnidaria (i.e. excluding scleractinian corals), Echinodermata (sea stars, urchins, sea cucumbers), Mollusca (i.e. gastropods, bivalves, cephalopods), Porifera (i.e. sponges) and subphylum Tunicata (ascidians). To our knowledge, this is the first comprehensive assessment of macroinvertebrate species on coral reefs in Vava'u, other than surveys focusing on hard corals (Holthus 1996; Chapter 7 of this report).

The scuba survey method allowed each diver to cover the full range of depths and habitats at each site during a single 60-minute dive. At each site a direct descent was made to the base of the reef, or beyond the deepest reef visible. Most of the dives then consisted of a slow meandering ascent along the reef up to the shallowest point looking for (or counting) macroinvertebrate species on the reef substrate. Survey effort (i.e. time) was divided equally amongst the various depth zones (e.g. 0–10, 11–20, 21–30) within each site. All habitats encountered were surveyed, including sandy areas, coral rubble patches, walls, overhangs, slopes and the shallow reef flat. Other important marine ecosystems that typically host macroinvertebrates, such as seagrass beds and mangroves, were not surveyed. Species were primarily identified insitu and their names recorded onto a slate with a printed underwater form. However, when identification could not be made definitely or needed further verification, photographs were taken. Photographs were subsequently analysed using reference materials and identification guides (Colin and Arneson 1997; Gosliner et al. 1996; Fabricius and Alderslade 2001; Humann and DeLoach 2010). Research databases, including the Global Biodiversity Information Facility (www. gbif. org) and World Register of Marine Species (www. marinespecies. org), were also used when species were not pictured or described in the identification guides or reference materials.

Following the completion of the identification process, all species were assigned to their respective taxonomic groupings using the following breakdown: phylum, class, order, family, genus and species. The total number of species was calculated for the entire survey, and subsequently for each site and six defined reef types (e.g. fringing reef, lagoonal patch reef, etc.). The taxonomic composition of each site and reef type was then assessed, and lists and tables of commonly occurring families and species across all sites and reef types were compiled.

Commercially valuable species (sea cucumbers, giant clams and trochus) were assessed independently for each site by Sione Matoto from the Tonga Ministry of Agriculture and Food, Forests and Fisheries. Similar to the methods above, the total number of individuals and species richness was calculated for the entire survey, and subsequently for each site and reef type. Sea cucumber species were also classified into four commercial value categories similar to those used in Pakoa et al. (2013).

8.3.1. DATA USED IN THIS REPORT

In this report, in order to develop the most comprehensive record of the macroinvertebrate biodiversity on coral reefs in Vava'u, some results from previous coral reef surveys in Vava'u (mainly Holthus 1996) were combined with the data recorded by the author. Site-specific details given in this report are based solely on diversity counts undertaken by the author. The method used in the present survey precluded the collection of quantitative data on the abundance of macroinvertebrate species, except for three commercially valuable groups of species: sea cucumbers, giant clams and trochus. Rapid biological assessments put an emphasis on recording as many species as possible, rather than quantitative records of species abundances.

The scientific names of many reef organisms, including macroinvertebrates, occasionally change as a result of new information or because it comes to light that the species was given a scientific name by an earlier author. Unfortunately, some macroinvertebrate species in Tonga have been described several times, each subsequent author either not being aware of the previous description (i.e. name) or thinking that their specimen represents a new species record. In cases where more than one scientific name exists for a single species (i.e. synonyms), the accepted species name on the World Register of Marine Species database (www. marinespecies. org) was used. Consequently, there are likely to be new species names used within the report which have previously not been reported. This does not automatically indicate a new species record for Vava'u or the Kingdom of Tonga, but rather an update or correction to a previously identified species. Note also that no samples were collected during the survey due to logistical problems with securing the collecting permits prior to the initial surveys. Thus, numerous species could not be identified beyond the family level.

8.4. Results

8.4.1. GENERAL CHARACTERISTICS AND COMPOSITION

A total of 249 macroinvertebrate species from 146 genera were identified in the survey (Figure 8.1). This included representatives from 101 families, 39 orders and 17 classes across seven phyla (Table 8.1; see Annex 8.1 for full species list). Species not identified to family level were excluded from the final analysis, species list and report. This consisted of approximately 72 species, many of which were sponges (24 species), ascidians (17), crustaceans (15) and bivalves (11).

Of the seven phyla, the phylum Mollusca accounted for the highest number of species recorded in the survey (38.6%; Figure 8.2). Echinodermata comprised the second highest number of species with 18.9%. Collectively these two phyla accounted for 57.5% of all species identified in the survey (Figure 8.2). In contrast, the phyla Annelida (class Polychaeta) and Chordata (class Ascidiacea) accounted for less than 1% and less than 4% of all species, respectively. The phyla Cnidaria, Porifera and Arthropoda (Crustacea) represented the remaining 39% of the species identified in the survey.

The class with the largest number of families, genera and species was Gastropoda (phylum Mollusca; Table 8.1). Gastropods accounted for 30% of all species identified in the survey. Moreover, one or more gastropod species was found on all 27 sites. Demospongiae and Malacostraca were the second and third most speciose classes with 28 and 24 species, respectively (10% and 9% of the total species identified). However, many sponges and crustaceans observed in the survey could not be identified beyond the class level. Both groups of organisms require specialised taxonomists to accurately identify them. By contrast, there were several families with only one or two species representatives identified within the survey. These included the classes Polychaeta (phylum Annelida), Maxillopoda (phylum Arthropoda: Crustacea), Cephalopoda (phylum Mollusca), Cirantipatharia (phylum Cnidaria), Calcarea and Homoscleromorpha (phylum Porifera).

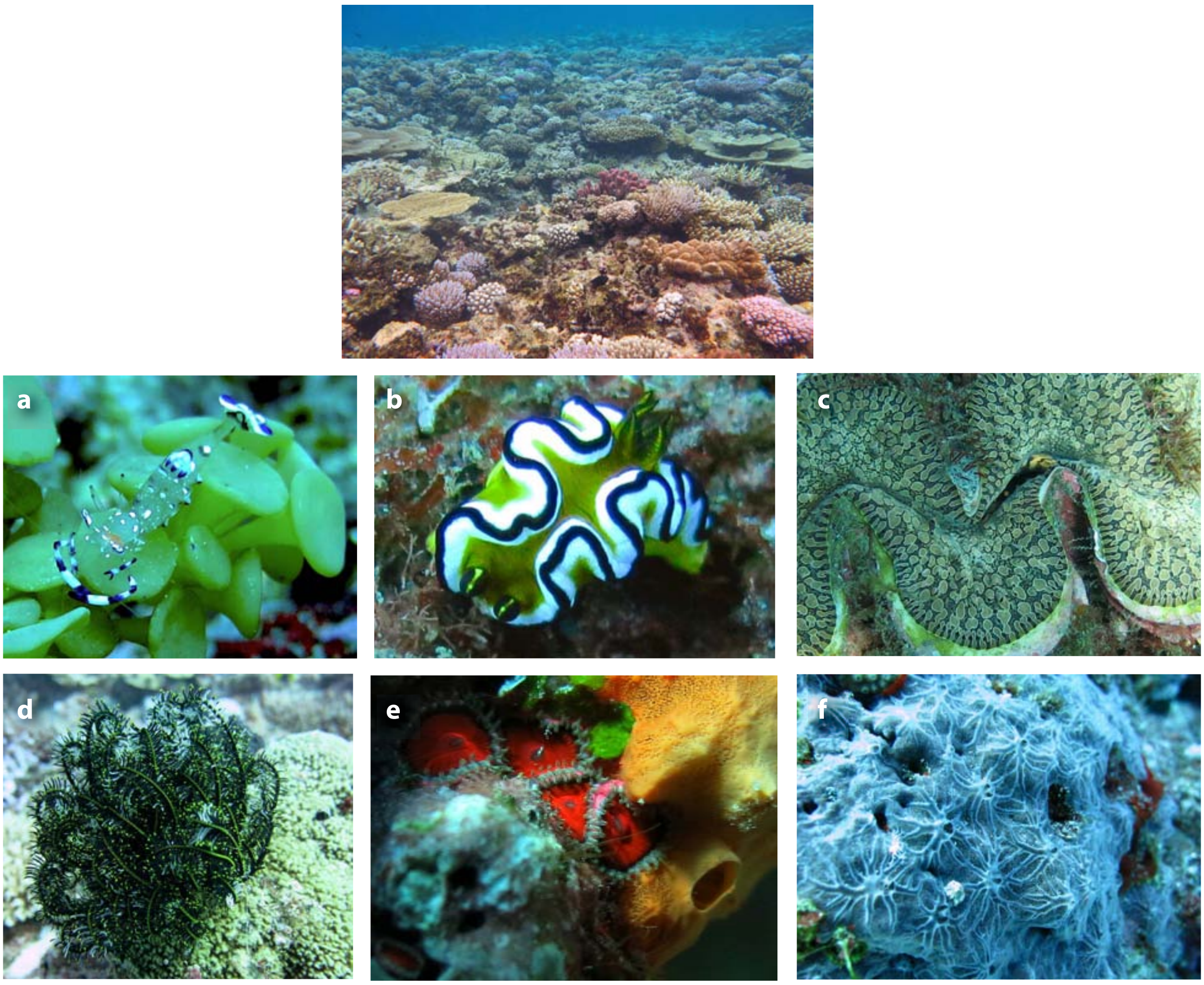

Figure 8.1. Examples of marine invertebrate species found on Vava'u reefs (top) during the 2014 BIORAP surveys: (a) *Periclimenes holthuisi*, (b) *Chromodoris* sp., (c) *Tridacna squamosa*, (d) *Comanthus briareus*, (e) unidentified *Zoanthus* sp., and (f) *Clathria* sp.

Table 8.1. Major phyla, classes and associated number of orders, families, genera and species identified during the 2014 BIORAP survey.

Phylum	Class (subclass)	Order	Family	Genera	Species	Total
Annelida						
	Polychaeta	1	2	2	2	2
Arthropoda (Crustacea)						
	Malacostraca	1	11	15	24	
	Maxillopoda	1	1	1	1	25
Chordata (Tunicata)						
	Ascidiacea	2	4	6	9*	9
Cnidaria						
	Anthozoa					
	(Cirantipatharia)	1	1	1	2	
	(Hexacorallia)	3	5	8	16	
	(Octocorallia)	1	9	15	15	
	Hydrozoa	2	3	4	6	39
Echinodermata						
	Asteroidea	1	4	6	7	
	Crinoidea	1	3	9	11	
	Echinoidea	2	4	7	10	
	Holothuroidea	1	2	5	14	
	Ophiuroidea	1	2	3	5	47
Mollusca						
	Bivalvia	5	8	13	19	
	Cephalopoda	2	2	2	2	
	Gastropoda	6	28	34	75	96
Porifera						
	Calcarea	1	1	1	2	
	Demospongiae	6	10	13	28*	
	Homoscleromorpha	1	1	1	1	31
Total	17	39	101	146	249*	

*Estimate.

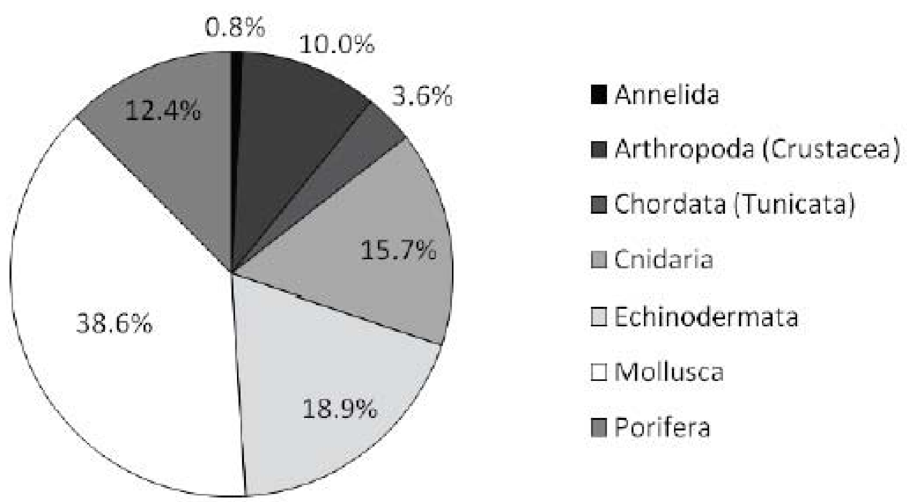

Figure 8.2. Distribution (%) of invertebrate species by phylum.

Site-specific macroinvertebrate diversity

Comparing macroinvertebrate diversity at the 27 sites (Figure 8.3), the median species richness was 28 species, with a mean species richness of 28.7 (± 0.95 SE) across the sites (Table 8.2). Species richness ranged from 15 to 38 species between sites (Table 8.2). Sites 22, 21 and 12 had the highest species richness, while sites 5, 10, 27 and 4 had the lowest species richness. Overall, there was a relatively weak pattern in species richness associated with the different sites around Vava'u. The majority of highly speciose sites were found within the central and southern islands of Vava'u (Figure 8.3; Table 8.2), with the exception of sites 6 and 7 on Toku Island (51 km north-northwest of Vava'u). Despite relatively similar species diversity across most sites, site 4 was distinct in holding substantially lower species richness. Site 4, located on the northern point of Fonualei Island (Figure 8.3), was situated on a shallow volcanic plateau (15–18 m) and noticeably different to all other reef types surveyed (extremely low complexity, large volcanic boulders).

During the survey there was a range of common families and species observed across a high number of sites (Figure 8.4a). Of the 101 families identified in the survey, five families were recorded at more than 50% of the sites (at least 14 of 27 sites). Alcyoniidae and Holothuriidae were the two most prevalent families, occurring at 85% of the sites (23 of 27 sites), while Comasteridae occurred at 74% of sites (20 of 27 sites). Other notable families with a high incidence among sites included: Oreasteridae (55%), Xeniidae (51%), Cardiidae, Muricidae, Stichodactylidae and Tegulidae (48% each), and Diogenidae (41%;).

Similarly, there were several species with a high incidence across survey sites (Figure 8.4b). The soft coral *Sarcophyton* sp. (family Alcyoniidae) was the most frequently observed species among sites (23 sites, 85% occurrence). Another soft coral, *Lobophyton* sp. (family Alcyoniidae), was the second most observed species among sites (22 sites, 81% occurrence). Other species with relatively high occurrence amongst sites included: *Sinularia* sp. (family Alcyoniidae) and *Tectus nilotucus* (family Tegulidae) found at13 sites (48% occurrence), *Holothuria fuscopunctata* (family Holothuriidae) at 12 sites (44%), and four other species, *Holothurian atra* and *Thelenota anax*, *Phanogenia gracilis*, and *Heteroxenia* sp. (41% each).

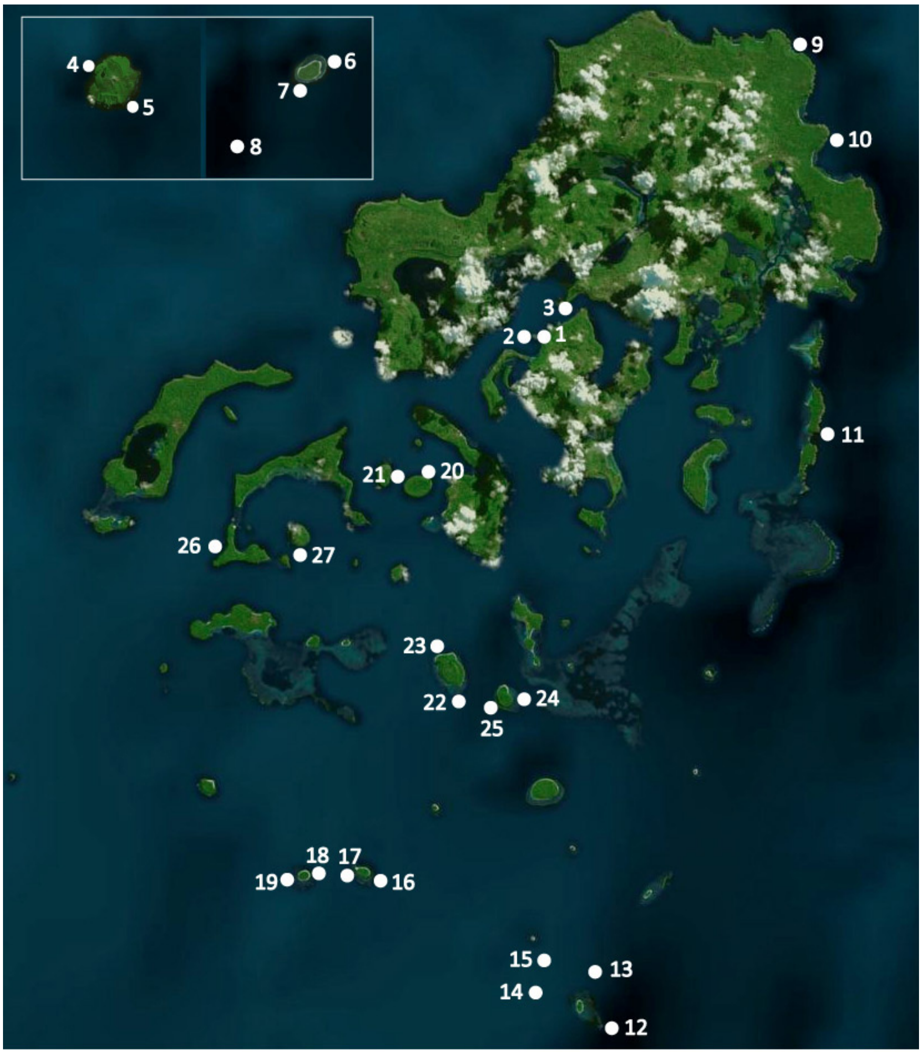

Figure 8.3. Map of Vava'u showing locations of sites surveyed.

Table 8.2. Total number of species observed (species richness) for each site, and site details.

Site No.	Site name	No. of species observed	Reef type
Site 22	'Euakafa Island, south	38	Fringing (moderately exposed)
Site 21	'Oto Island	37	Drop-off (wall)
Site 12	Maninita Island, inside	36	Fringing (moderately exposed)
Site 7	Toku Island, north	35	Fringing (moderately exposed)
Site 25	'Euaiki Island, west	34	Fringing (moderately exposed)
Site 20	A'a Island	33	Drop-off (wall)
Site 13	Maninita Island, outside	32	Fringing (exposed)
Site 23	'Euakafa Island, north	32	Fringing (moderately exposed)
Site 6	Toku Island, south	31	Fringing (moderately exposed)
Site 18	Fangasito Island, south	30	Fringing (moderately exposed)
Site 9	Mata'utuiliki, Vava'u lahi Island	29	Fringing (exposed)
Site 14	Taula Island, inside	29	Fringing (moderately exposed)
Site 26	Vaka'eitu Island	28	Fringing (exposed)
Site 17	Fonua'one'one Island, north	28	Fringing (moderately exposed)
Site 8	Toku Island, Joe's Spit	27	Exposed oceanic platform
Site 16	Fonua'one'one Island, south	27	Fringing (moderately exposed)
Site 19	FangasitoIsland, north	27	Fringing (moderately exposed)
Site 24	'Euaiki Island, east	27	Fringing (moderately exposed)
Site 11	'Umana Island	26	Fringing (exposed)
Site 1	Lotuma Island	26	Lagoon (sheltered)
Site 2	Lotuma Island Channel	26	Lagoon (sheltered)
Site 3	Mount Talau, Vava'u Lahi Island	25	Lagoon (sheltered)
Site 15	Taula Island, outside	25	Fringing (moderately exposed)
Site 10	'Onetale Bay, Vava'u lahi Island	24	Fringing (exposed)
Site 27	Langito'o Island	24	Fringing (moderately exposed)
Site 5	Fonualei Island, south	24	Fringing (volcanic reef)
Site 4	Fonualei Island, north	15	Fringing (volcanic reef)

Reef-type macroinvertebrate diversity

The total number of species identified for each reef type varied considerably from 37 to 157 species (Table 8.3). Moderately exposed fringing reefs had the highest number of species with 157, while the volcanic fringing reefs and lagoonal reefs had the lowest number of species with 37 and 41 species, respectively. Overall, the mean species richness was higher on reef drop-offs and moderately exposed fringing reefs compared to the lagoonal reefs and the volcanic fringing reefs.

Table 8.3. Total and mean species richness observed for each reef type. Exposed oceanic platform reef (site 8) was excluded (n = 1).

Reef type	No. of sites	Species richness (total no. of species)	Mean richness (± SE)
Fringing (moderately exposed)	14	157	30.2 (± 1.1 SE)
Fringing (exposed)	5	82	27.8 (± 1.2 SE)
Lagoonal (sheltered)	3	41	25.6 (± 0.3 SE)
Drop-off (reef wall)	2	53	35.0 (± 2.0 SE)
Fringing (volcanic reef)	2	37	19.5 (± 4.5 SE)

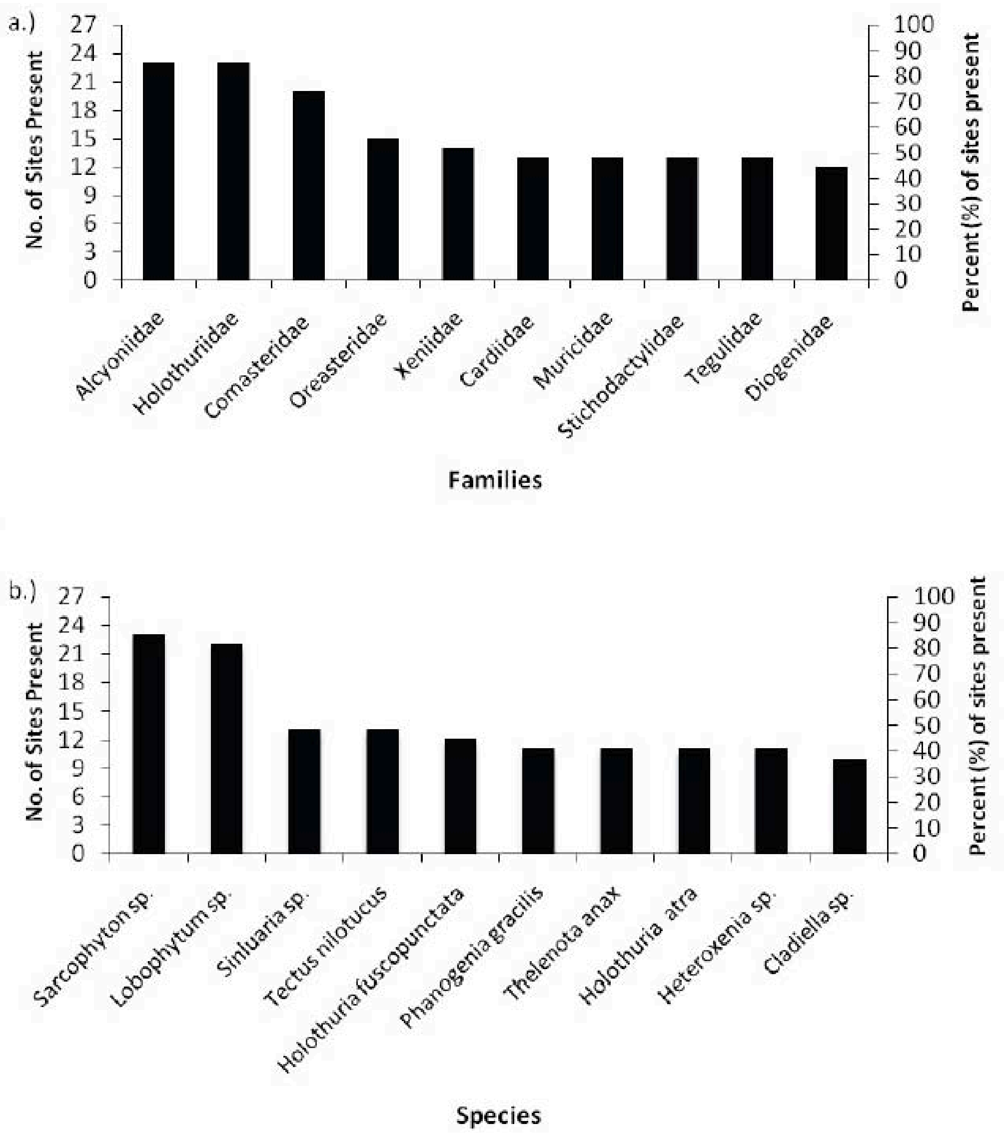

Figure 8.4. (a) The most common macroinvertebrate families and (b) the most common macroinvertebrate species across sites. Includes number of sites and percentage of sites at which they were recorded.

8.4.2. COMMERCIALLY VALUABLE SPECIES

Sea cucumbers

A total of 279 individual sea cucumbers were counted across all sites(Table 8.4). Of the 18 species of sea cucumber known to occur in Vava'u (Pakoa et al. 2013), 14 were recorded in the survey. Four species, *Bohadschia marmorata*, *Holothuria lessoni*, *Stichopus herrmanni* and *S. horrens*, were not observed. The most abundant species were *Holothuria atra* (34.4%), *H. fuscopunctata* (14.3%) and *Thelenota anax* (14.3%). Collectively these three species accounted for 63% of the total number of sea cucumbers counted. Moreover, these species were the most frequently recorded species among sites. *Holothuria fuscopunctata* was found at 12 sites (or 44% of sites), while both *H. atra* and *T. anax* were found at 11 sites (40.7% of sites). In contrast, *Actinopyga echinites*, *A. miliaris*, *Holothuria coluber* and *Thelenota ananas* were the least abundant species, each representing less than 3.5% of the total number of sea cucumbers, and the least common among sites. *Actinopyga echinites* was the most rare species with only two individuals from one site (site 20) which wasin relatively deep water (>30 m).

Among the 14 species of sea cucumbers documented in the survey, five species are considered of high commercial value, and one species very high commercial value (Table 8.4; Pakoa et al. 2013). The remaining eight species are regarded as medium (six species) or low commercial value (two species). Combined, commercially valuable species (high and very high value) accounted for 17.2% of the total individuals, whereas species of medium or low commercial value accounted for 82.8% of the total (Figure 8.5). Notably, low commercial value species, *Holothuria atra* and *H. fuscopunctata*, accounted for nearly half (49%) of all the sea cucumbers observed. Overall, the abundance of commercially valuable sea cucumbers (high and very high value) was disproportionately low, with a mean of 1.7 (± 0.11 SE) sea cucumbers per site.

Table 8.4. Sea cucumber species reported from Vava'u and observed in the 2014 BIORAP survey (+), including the total number of individuals, number of sites where it was present, and commercial value for each species (Pakoa et al. 2013).

Species	2014 BIORAP	Total no. of individuals (% of total)	No. of sites present	Commercial value
Actinopyga echinites	+	2(0.72%)	1	H
Actinopyga mauritiana	+	12 (4.30%)	2	H
Actinopyga miliaris	+	3(1.08%)	3	M
*Bohadschia argus**	+	14 (5.02%)	10	M
Bohadschia marmorata		–	–	M
*Bohadschia vitiensis**	+	10(3.58%)	6	M
*Holothuria atra**	+	96(34.4%)	11	L
Holothuria coluber	+	3(1.08%)	2	M
Holothuria edulis	+	25 (8.96%)	8	M
Holothuria fuscogilva	+	8(2.87%)	4	VH
Holothuria fuscopunctata	+	40 (14.3%)	12	L
*Holothuria lessoni**		–	–	VH
Holothuria whitmaei	+	16 (5.73%)	5	H
Stichopus chloronotus	+	7(2.51%)	3	H
*Stichopus herrmanni**		–	–	M
Stichopus horrens		–	–	M
Thelenota ananas	+	3(1.08%)	3	H
Thelenota anax	+	40 (14.3%)	11	M
Total	14	279		

* Locally consumed species.
VH = very high; H = high; M = medium; L = low.

Sea cucumber abundance and species richness varied considerably among sites and reef types (Table 8.5). The number of sea cucumbers per site ranged from 0 to 44 individuals. Sites 18, 17 and 19 had the highest number of sea cucumbers with 44, 27 and 25 individuals, respectively. Four sites had no sea cucumbers recorded. Species diversity, among sites where sea cucumbers were present, ranged from one to eight species. Site 21 was the most diverse site with eight species of sea cucumber, while five sites (2, 5, 6, 9 and 26) each had one sea cucumber species. Additionally, the abundance of high and very high commercial value species showed high spatial variation among sites. Sites located furthest from the capital city (Neiafu), which are generally more difficult to access, had the highest abundance of high or very high commercial value species. For example, site 5 (Fonualei Island, south) had the highest number of *Actinopyga mauritiana* (11 individuals), while site 6 (Toku Island, south) had eight *Holothuria whitmaei* individuals. By contrast, sites close to the capital (<3 km) had very low numbers of sea cucumbers, and only medium or low value species (e.g. sites 1, 2 and 3). Remarkably, more than half the survey sites (15) had no high or very high commercially valuable species observed.

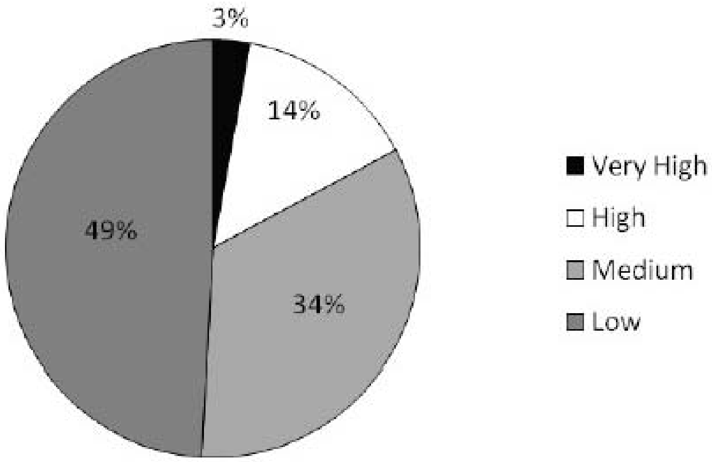

Figure 8.5. Percent (%) of sea cucumbers recorded for each commercial value category.

Table 8.5. Number of sea cucumbers per site, species per site, and commercial value of species per site.

Site	Individuals per site	Species per site	Value (no. of species)
1	3	2	M (1); L (1)
2	1	1	L (1)
3	11	3	M (2); L (1)
4	0	–	–
5	11	1	H (1)
6	8	1	H (1)
7	4	2	H (2)
8	0	–	–
9	3	1	H (1)
10	0	–	–
11	0	–	–
12	8	6	VH (1); H (2); M (2); L (1)
13	14	4	VH (1); H (1); M (1); L (1)
14	14	4	M (2); L (2)
15	8	3	M (2); L (1)
16	10	3	M (2); L (1)
17	27	6	VH (1); H (1); M (2); L (2)
18	44	4	M (2); L (2)
19	25	2	VH (1); L (1)

Site	Individuals per site	Species per site	Value (no. of species)
20	7	4	H (1); M (2); L (1)
21	13	8	H (1); M (5); L (2)
22	12	5	M (4); L (1)
23	22	7	H (1); M (4); L (2)
24	9	5	M (3); L (2)
25	21	4	M (3); L (1)
26	1	1	M (1)
27	3	3	H (1); M (2)

VH = very high; H = high; M = medium; L = low.

The highest numbers of sea cucumbers recorded were on the moderately exposed fringing reefs sites with 215 individuals, while the lowest number of sea cucumbers was on the volcanic fringing reefs with 11 individuals (Table 8.6). The number of sea cucumbers ranged from 15.3 (± 3.01 SE) on moderately exposed fringing reefs to 3.6 (± 2.65 SE) on exposed fringing reefs. Species diversity (richness) also varied among reef types. The reef drop-off was the most diverse, with a maximum of eight sea cucumber species recorded, while the volcanic fringing reefs had one species of sea cucumber. Commercially valuable sea cucumbers (high and very high value) were found on all reef types except within sheltered lagoon reefs and on the exposed oceanic platform.

Table 8.6. Total number of individual sea cucumbers recorded by reef type.

Reef type	Number of sites per reef type	Total no. of individuals	Mean no. of individuals (± SE)
Fringing (moderately exposed)	14	215	15.3 (± 3.01 SE)
Fringing (exposed)	5	18	3.6 (± 2.65 SE)
Lagoonal (sheltered)	3	15	5.0 (± 3.06 SE)
Drop-off (reef wall)	2	20	–
Fringing (volcanic reef)	2	11	–
Exposed oceanic platform	1	–	–

Giant clams

A total of 92 giant clams were counted in the survey (Table 8.7). Four species were identified: *Tridacna maxima, T. squamosa, T. derasa* and *T. crocea*; the latter was previously undocumented in Tonga. The most abundant species was *Tridacna maxima* with 78 individuals, followed by *T. squamosa* (ten individuals), *T. crocea* (four) and *T. derasa* (three). *Tridacna maxima* accounted for 82% of the individuals counted, and was the most common species among sites, occurring at 13 of the 27 sites (48% of sites). In contrast, *T. derasa* was the least common species, occurring at only two sites (7% of sites). The abundance of giant clams and species diversity varied greatly among sites and reef types. The number of giant clams per site ranged from zero to 21 individuals (see Table 8.8). The highest number of giant clams was found at sites 8, 6 and 7, which had 21, 18 and 16 individuals, respectively (Figure 8.3; see Table 8.8). Nearly half the sites (13 sites) had no giant clams. Collectively, sites 6, 7 and 8 accounted for nearly 60% of all giant clams recorded in the survey. Notably, these three sites are located around Toku Island, 51 km north-northwest of Vava'u Lahi. Giant clam diversity within sites ranged from one to three species. Sites 8, 10 and 14 had three clam species, while the remaining 10 sites had one or two species of clams each. The highest number of clams was recorded on the moderately exposed fringing reefs with 52 individuals, while no clams were recorded on the sheltered lagoon reefs or fringing volcanic reefs (see Table 8.8).

Table 8.7. Giant clam species recorded during the BIORAP survey, including total number of individuals and number of sites where it was present.

Species	Total no. of individuals (% total)	Sites present (% total)
Tridacna maxima	75 (82%)	12 (44%)
Tridacna squamosa	10 (11%)	6 (22%)
Tridacna derasa	3 (3%)	2 (7%)
*Tridacna crocea**	4 (4%)	3 (11%)
Total	92	

*New species record for Kingdom of Tonga.

Table 8.8 Number of individual giant clams observed per site and species richness per site.

Site	Site name	Individuals site per site	Number of species per site
1	Lotuma Island	0	–
2	Lotuma Island channel	0	–
3	Mount Talau, Vava'u Lahi	0	–
4	Fonualei Island, north	0	–
5	Fonualei Island, south	0	-
6	Toku Island, south	18	1
7	Toku Island, north	16	2
8	Toku Island, Joe's Spit	21	3
9	Mata'utuiliki, Vava'u lahi	8	2
10	'Onetale Bay, Vava'u lahi	4	3
11	'Umana Island	0	–
12	Maninita Island, inside	0	–
13	Maninita Island, outside	4	1
14	Taula Island, inside	5	3
15	Taula Island, outside	2	2
16	Fonua'one'one Island, south	6	2
17	Fonua'one'one Island, north	0	–
18	Fangasito Island, south	0	–
19	Fangasito Island, north	3	1
20	A'a Island	2	1
21	'Oto Island	0	–
22	'Euakafa Island, south	0	–
23	'Euakafa Island, north	0	–
24	'Euaiki Island, east	2	2
25	'Euaiki Island, west	0	–
26	Vaka'eitu Island	1	1
27	Langito'o Island	0	–

Trochus

A total of 59 trochus (*Tectus nilotocus* formerly *Trochus nilotocus*) was counted across all 27 sites. The number of trochus per site ranged from zero to 16 individuals (see Table8.9). Sites 12 and 23 had the highest number of trochus with 16 and 15 individuals, respectively. Fourteen sites had no trochus, while the remaining 11 sites had between one and five individuals (see Table 8.9). Trochus were observed on four reef types: reef drop-offs, moderately exposed and exposed fringing reefs, and on the oceanic platform (see Table 8.9), while no trochus were recorded on the sheltered lagoon reefs or fringing volcanic reefs. The majority (80–85%) of trochus observed were adults or sub-adults (>10 cm basal diameter).

Table 8.9. Number of individual trochus observed per site.

Site	Site name	Individuals per site
1	Lotuma Island	0
2	Lotuma Island channel	0
3	Mount Talau, Vava'u Lahi	0
4	Fonualei Island, north	0
5	Fonualei Island, south	0
6	Toku Island, south	0
7	Toku Island, north	0
8	Toku Island, Joe's Spit	2
9	Mata'utuiliki, Vava'u lahi	5
10	'Onetale Bay, Vava'u lahi	3
11	'Umana Island	5
12	Maninita Island, inside	16
13	Maninita Island, outside	2
14	Taula Island, inside	2
15	Taula Island, outside	0
16	Fonua'one'one Island, south	2
17	Fonua'one'one Island, north	1
18	Fangasito Island, south	0
19	Fangasito Island, north	0
20	A'a Island	0
21	'Oto Island	3
22	'Euakafa Island, south	2
23	'Euakafa Island, north	15
24	'Euaiki Island, east	1
25	'Euaiki Island, west	0
26	Vaka'eitu Island	0
27	Langito'o Island	0

8.5. Discussion

The survey findings indicate a relatively diverse suite of macroinvertebrates on the coral reefs of Vava'u (Annex 8.1). Many of the dominant invertebrate families and species identified across the 27 survey sites are found on coral reefs throughout the wider region (e.g. in Fiji, American Samoa and Samoa) and in other parts of the Indo-Pacific (Gosliner et al. 1996; Colin and Arneson 1997; Fabricius and Alderslade 2001). Overall, the molluscs (e.g. gastropods, bivalves and cephalopods) accounted for the highest number of species recorded in the survey. This not surprising given that the phylum Mollusca contains the second highest number of described living species (c. 100,000) of which roughly half are marine species. However the arthropods, which comprise the largest phylum of living organisms on Earth (roughly one million species), were underrepresented throughout the survey representing only about 10% of the total number of species. Further, the abundance of both the polychaete and ascidian species was also considerably low. One possible explanation for the low number of polychaetes is because they are often difficult to detect, as many species are cryptic, burrowing in sediments and corals or living in well camouflaged tubes that they construct. Many of the ascidians observed in the survey were not identified to the order/family level (c. 17 species), and were therefore not included in the final species counts. Ascidians are one of the least documented groups of macroinvertebrates in the tropical Pacific, primarily because they have only recently (i.e. late 19th century) been recognised as an individual group (Shenkar and Swalla 2011).

The data indicate that many of the species identified in the survey represent new species records for Tonga. However, this requires further confirmation because updated species lists for Tonga are difficult to obtain, and many of the published national reports (e.g. the National Biodiversity Strategy and Action Plan, Tonga Biodiversity Stocktaking) provide very limited species information or lists. It is also important to recognise that the survey represents only a 'snapshot' of the total macroinvertebrate richness around Vava'u. Given the short duration of the survey (12 days) it was not possible to inventory all invertebrate species around Vava'u, nor have all species within each site or habitat been recorded. Species richness should increase dramatically with additional surveys. Further, attempts should be made to include additional habitats not surveyed (e.g. seagrass beds, mangroves, detritus reef flats), and non-targeted species, including cryptic and nocturnal species. Most importantly, the survey represents the first comprehensive assessment of macroinvertebrates in Vava'u, and should be used as a 'baseline' for future survey work in Vava'u and throughout the islands of Tonga.

Species richness among sites exhibited spatially variability; however, there were no clear invertebrate 'hotspots'. Instead, results revealed that sites with higher species richness were interspersed among sites with lower species richness. Site-specific differences in species richness are not overly surprising given that coral reefs are inherently variable ecosystems. Coral reefs are strongly influenced by biotic and abiotic processes that operate over different spatial and temporal scales. At local scales, the structure and development of individual reefs including their associated fauna (e.g. fishes, invertebrates) are subject to diverse and often interacting environmental variables (e.g. temperature, light, salinity and hydrodynamic factors), as well as intra- and interspecific biological interactions (e.g. competition, predation and disease). Collectively, these processes are important in controlling ecosystem dynamics, including species diversity (richness) and distributions patterns. Natural and anthropogenic disturbances also play important roles in determining the structure and dynamics of coral reef communities, and are considered integral components of ecosystem theory.

Of the six reef types examined, mean species richness was relatively higher on the moderately exposed fringing reefs and drop-offs compared to the lagoon and volcanic reefs. However, comparing species richness among reef types requires cautious interpretation. Given that the number of species identified for each reef type is proportional to the sampling effort, the low replication among certain reef types (e.g. lagoon reefs) and temporal variability (e.g. sites surveyed at different times) preclude an accurate assessment of the overall species richness amongst reef types. Nonetheless, differences among reef type characteristics allow for some inferences to be made as to why mean species richness likely varies. For example, reef drop-offs/walls (sites 20 and 21) had sheer vertical slopes with high habitat complexity. Similarly, moderately exposed fringing reefs had higher mean percentage cover of scleractinian corals with many branching *Acropora* species. Higher habitat complexity has recently been shown to house a higher number of reef-associated macroinvertebrate communities while aloss of habitat complexity has been associated with losses in many macroinvertebrate groups, especially predation-prone mobile taxa, including crustaceans and crinoids (Fabricius et al. 2014). By contrast, lagoonal reef types (sites 1, 2 and 3) had relatively low complexity and lower overall species diversity. These reefs were also situated close to the main city centre Neiafu and the Port of Refuge (<3 km). Anthropogenic refuse, anchor damage and discarded fishing gear were strikingly more noticeable on lagoon reefs compared to other reef types, indicating anthropogenic disturbance which may affect species richness.

Findings from the survey also revealed considerable spatial heterogeneity in the abundance of commercially valuable species (sea cucumbers, giant clams and trochus) at the selected sites in Vava'u. In general, sites located furthest from the city of Neiafu (e.g. the islands of Fonualei and Toku) had the highest abundance of highly valued sea cucumbers and giant clams, whereas two nearshore sites had the highest abundance of trochus. The results highlight that the abundances of both commercially valuable sea cucumbers and giant clam species are extremely low given the amount of effort and reef area surveyed. At the majority of sites, highly valued sea cucumbers and giant clams were a rare occurrence. Overfishing of commercially valuable sea cucumbers throughout Vava'u is well documented (Pakoa et al. 2013). Results from this survey are similar to those reported from sea cucumber surveys conducted in 2010 (Pakoa et al., 2013), but also provide further evidence that the composition of sea cucumbers has shifted from high- to low-value species as a result of persistent fishing pressure and overexploitation. Furthermore, the results from this survey also suggest that giant clams are being overexploited. Nearly 60% of the giant clams were found on sites that were more than 50 km from Neiafu. Collectively, these results emphasise the need for improved management and conservation to limit the harvesting of both sea cucumbers and giant clams to allow their stocks to recover.

Similarly, the abundance of trochus on the survey sites in Vava'u was extremely low relative to the number of diving hours and mean area surveyed at each site (c. 350 m^2). The densities of trochus were unevenly distributed across sites showing no clear distribution patterns. Similar to both the sea cucumber and giant clam abundances, sites further away from the town of Neiafu tended to host higher number of trochus, suggesting that nearshore sites (e.g. sheltered lagoon reefs) are likely overexploited. An alternative explanation for the low number of trochus is that their preferred habitat was not sufficiently sampled during the survey. In many regions of the Pacific, adult trochus are often found living in shallow high-energy zones (i.e. areas where waves break), while juveniles are generally more cryptic, hiding in crevices and amongst rubble, on back reefs and rocky substrates (Sims 1988; Pakoa et al. 2010, Tardy 2011). In order to determine the status of trochus in Vava'u, dedicated assessments similar to those conducted in Tongatapu Lagoon (Pakoa et al. 2010) are required to quantify adult and juvenile populations.

During the surveys one species of giant clam new to Tonga, *Tridacna crocea*, was observed. Previous records indicate that *T. crocea* does not occur naturally within Tongan waters, however giant clam restocking programmes in the late 1980s attempted to introduce the species (Friedman and Teitelbaum 2008). Similarly, in the neighbouring islands of Fiji, *T. crocea* is listed as not naturally occurring but was introduced, and reportedly exported in significant quantities between 1997 and 2000. Given the relatively short geographical distance between Vava'u and the eastern outer islands of Fiji (c. 500 km) it is possible that *T. crocea* larvae could have been transported from Fiji through a broad range of mesoscale processes (e.g. boundary currents). Alternatively, the few *T. crocea* recorded in Vava'u could be remnant survivors from the unsuccessful introduction programme in the late 1980s. Regardless of how *T. crocea* arrived in Vava'u, it is important that these species are correctly identified and appropriately monitored in future coral reef or fisheries surveys.

8.6. Conservation recommendations

One of the main challenges in producing this report was to ensure that the recommendations reflect both the complex marine diversity and rapidly changing marine landscape of Vava'u, while providing significant added value for the people and the government. Based on the current state of knowledge from this survey, some general recommendations are made.

- Develop comprehensive invertebrate species lists that are consistently updated.
- Continue to conduct taxonomic surveys of macroinvertebrate species to provide a comprehensive inventory of Vava'u biodiversity.
- Commission marine invertebrate taxonomists and specialists to assist with describing and documenting new species.
- Ensure adequate representation of all the major habitats when conducting future taxonomic surveys.
- Develop conservation legislation and establish marine protected areas (MPAs) to include areas that have highly diverse sites of macroinvertebrate species.
- Immediately reduce harvesting pressure of all sea cucumbers and giant clam species, and monitor regularly.
- Impose a permanent or temporary moratorium on all commercially valuable sea cucumbers.
- Carry out a comprehensive assessment of giant clam and trochus species around Vava'u.
- Develop awareness and education programmes on the importance of coral reefs and their associated flora and fauna, including marine macroinvertebrates.

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CHAPTER 9 CORAL REEF FISH OF VAVA'U

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9.1. Summary

A rapid assessment of coral reef fish was carried out around the Vava'u archipelago at 25 sites during 25 hours of underwater visual observations while scuba diving. Reef fish over 5cm in length were recorded.

Data were collected primarily on exposed, moderately exposed and sheltered fringe reefs. Each island, where possible, had two dives carried out, one leeward and one windward. All data were recorded from depths between 30and 3m. Other critical habitats such as pelagic zones, mangrove forests and seagrass beds were not included in this study.

A total of 406 species of reef fish was recorded during the survey including one range extension for *Caseio lunaris*. No new species of fish were recorded and no collections of fish were made.

Reef fish fauna is dominated by Pomacentridae (57 species), Labridae (52 species), Chaetodontidae (31 species), Acanthuridae (31 species), Scaridae (22 species) and Serranidae (24 species).

Low species numbers of piscivores and carnivores, including sharks, were recorded throughout the survey.

9.2. Introduction

The objective of this study was to produce a comprehensive list of the reef fish of the Vava'u archipelago (hereafter referred to as Vava'u) through a rapid assessment of selected marine sites some of which had not been previously surveyed. The coral reefs surveyed were predominantely fringing reefs with only Lotuma Island and Mount Talau showing characteristics similar to lagoons and A'a and Oto with limestone walls. All surveys were conducted on SCUBA to depths of 30m.

Coral reef ecosystems are essential to subsistence and commercial fishing in Vava'u as well as to the economic and sustainable development of the tourism industry. The coral reef's ability to respond to climatic changes and other impacts is dependent on the health or state of all its components (e.g. corals, fish, algae, etc.). A healthier reef will be more resilient and better able to adjust to stressors such as those related to fishing activities, coastal development and tourism. The richness and abundance of fish species on a coral reef is one of many important factors that make up the health and resilience of a reef.

Coral reef surveys conducted in Vava'u prior to this rapid assessment have mainly concentrated on scleractinia corals and commercially targeted macro invertebrates.

Previous coral reef surveys by Holthus (1996) were conducted in the waters of Vava'u including Maninita Island and the outer southern islands, but were mainly confined to the sheltered waters around the harbours. The study of Holthus (1996) was conducted to investigate the impacts of coral harvesting in the Vava'u group and the possible effects on reef fish communities and reef health. The results showed that coral harvesting in Vava'u is not sustainable and the coral reefs are under stress due to anthropogenic and natural impacts.

A further coral reef survey of Ha'apai, Vava'u and the Niua's was conducted in Spetember 2013 by the Khaled bin Sultan Living Oceans Foundation (Bruckner A. W, 2014). The results also showed that certain reef areas with in Vava'u are being impacted on by fishing and economic development including coastal development and the increase in vessel traffic.

The marine aquarium trade has not yet affected Vava'u, though fish and live rock are collected in the main island of Tongatapu (located south in the Tongatapu Group) under licences from the Ministry of Agriculture, Fisheries, Forests and Foods.

There are currently no large scale no-take marine reserves in Vava'u that would contribute to building the health and resilience of the coral reef ecosystems. At present within the Vava'u archipelago there are two special managed areas (SMAs) at Ovaka and Taunga, as defined under the Fisheries Act 2002. Each area has a limited no-take zone and an aquaculture programme and is managed by the community. These SMAs were not assessed during this BIORAP. Ovaka was surveyed by the Khaled bin Sultan Living Oceans Foundation, Bruckner, AW,(2014). Fish catch data collected by the community from the SMA are held by the Ministry of Agriculture, Fisheries, Forests and Foods.

Improving on conservation methods, awareness and marine managed areas is vital to the future of Vava'u marine diversity.

The study by Randall et al. (2003) describing the reef and epipelagic fishes of Tonga was used as a reference for this rapid assessment of the coral reef ecosystems of Vava'u.

9.3. Sites visited and methods

9.3.1. SITES

Survey sites for the BIORAP were chosen in cooperation with the Ministry of Lands, Environment, Climate Change and Natural Resources with the goal being to record and report on the biodiversity and habitats of marine and terrestrial ecosystems within the Vava'u archipelago in line with the National Biodiversity Action Plan. The reef sites chosen for this survey are shown in Figure 9.1. The sites selected were predominantly fringing reefs, which are commonly associated with limestone islands such as those of Vava'u. Only the islands of Fonualei, A'a and 'Oto are comprised of different reef structure and habitat. Fonualei is a volcanic island while the islands of A'a and 'Oto are limestone drop-offs. Fringing reefs were characterised by the extent of the exposure to swell, which predominantly comes from a south to southeast direction.

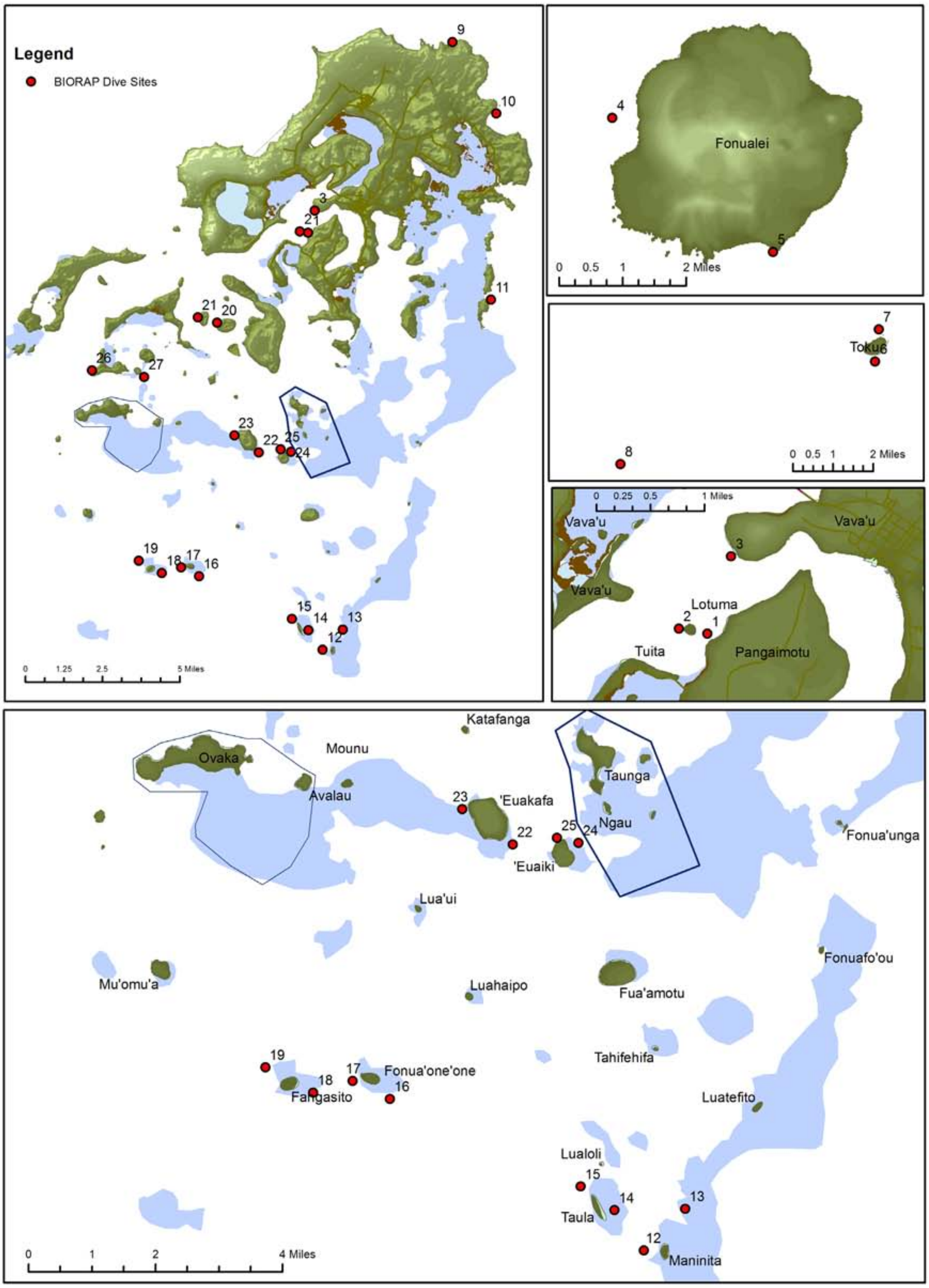

Figure 9.1. The reef fish survey sites.

9.3.2. METHODS

The rapid assessment of reef fish was carried out for a period of 15 days in February and included 27 sites on 18 islands. Limestone islands with coral reefs both leeward and windward had one reef site surveyed on each side of the island where possible with one dive conducted on Mount Talau, A'a Island and Oto Island.

The surveys involved identifying reef fish species and monitoring reef fish abundance for coral reef health and resilience. The methodology was replicated from previous BIORAP assessments in other countries (e.g. Allen 2002; Kerr 2013; Feary 2013).

The species were divided into commercially valuable species and other reef fish species. Commercially valuable and targeted fish species are covered in Chapter 10, however all reef fish species identified during this rapid assessment were collated together for total reef fish diversity.

The collection of data on species and abundance of coral reef fish was done while scuba diving. At each site the diver descended to 30m and then slowly ascended to the top of the reef area, the majority of time being spent between 15m and 3m where the largest numbers of coral reef fish are found. Each dive was 60 minutes in duration and a variety of coral reef habitats including crevices, reef slopes and sand areas were included in the surveys.

Reef fish species were recorded on underwater paper and each species was given a score for abundance. The scoring for abundance was replicated from a BIORAP survey of the North Western lagoon, Grande Terre, New Caledonia (Kerr 2013) as follows: 1 = a single individual, 2 = 2–10 individuals, 3 = 11–50 individuals, and 4 = over 50 individuals.

Those species known as indicators of biogeographic location, including endemics, rare and vulnerable species, were noted. Only the names of fish species for which identification was certain were recorded. Photographs were taken for referencing to Fishbase. org (Froese, R. and Pauly, D, 2014).

Coral Fish Diversity Index

The Coral Fish Diversity Index(CFDI) method developed by Allen (1998) was used to assess and compare the overall reef fish diversity in the waters of the Vava'u archipelago. The CFDI is used to predict the total number of reef fish species expected to be found within the survey area.

The method involves an inventory of six key families found within reef habitats: Chaetodontidae (butterfly fish), Pomacanthidae (angelfish), Pomacentridae (damselfish), Labridae (wrasse), Scaridae (parrotfish) and Acanthuridae (surgeonfish). These species are chosen due to the range of sizes of the fish species and the placement in the trophic level through diet affiliations. The number of species identified in each of these families was totalled from the BIORAP surveys to find the CFDI (no other survey counts were included in this analysis).

The technique applies a regression formula based on anaylisis of actual survey data from a wide range of sites within the area.

The CFDI enables researchers to more accurately compare fish community structure and diversity through shorter survey times of three to four weeks. For this assessment we used the formula for relatively restricted areas (sea areas less than 2000 km^2). The formula was:

Total expected number of reef fish species = 3.39 x (CFDI) – 20.595

The results were then compared to other CFDI surveys conducted in the Pacific region for comparison and are shown in Table 9.3.

Reef classification

Coral reefs were classified by exposure to swell and wave energy, which can impact the diversity and topography of the reefs (Table 9.1). All reefs in Vava'u except Fonualei, A'a and 'Oto have fringing reef characteristics.

Table 9.1. Coral reef classifications for the survey sites.

Type	Description	Site No.	Site name
Exposed reef	Reefs exposed to considerable wave energy and swell; mainly the outer reef areas to the north	9	Holonga
		10	Keitahi
		11	Umana
		13	Maninita outside reef
		26	Vakeitu
Volcanic reef	Volcanic rocks	4	Fonualei north
		5	Fonualei southpoint
Other	Exposed oceanic pinnacle	8	Toku Island Joe's Spit
Moderately exposed reefs	Fringing reefs surrounding sandy islands generally in the southern part of the archipelago	6	Toku Island south
		7	Toku Island north
		12	Maninita inside
		14	Taula inside
		15	Taula outside
		16	Fonua'one'onesouth
		17	Fonua'one'onenorth
		18	Fangasito south
		19	Fangasito north
		22	'Euakafa north
		23	'Euakafa south
		24	'Euaiki east
		25	'Euaiki west
		27	Lto'o
Limestone coast drop-off	Steep limestone walls, in middle of archipelago	20	A'a
		21	Ota
Sheltered reef	Sites in inner part of the archipelago, gentle slopes	1	Lotuma Island
		2	Lotuma Islandchannel
		3	Mt Talau

Results

9.4.1. OVERVIEW OF THE REEF FISH FAUNA

A total of 406 species belonging to 156 genera and 52 families was observed during this rapid assessment, with the highest number of species recorded from two families, Pomacentridae (damselfish) and Labridae (wrasses). Annexe 9.1 lists the reef associated species recorded during this rapid assessment, and Annex 9.2 details the family structure of the species recorded.

Table 9.2. Number of reef fish species by site identified during the survey. Entries in bold indicate sites with the highest number of species.

Site	No. of species	Site	No. of species
1	120	15	128
2	101	16	136
3	102	17	90
4	70	**18**	**142**
5	100	19	118
6	98	**20**	**148**
7	126	21	129
8	**200**	**22**	**151**
9	116	**23**	**163**
10	107	24	128
11	126	25	123
12	117	26	86*
13	**150**	27	72*
14	**146**		

*Sites 26 and 27 were not fully surveyed for reef fish diversity, however these reefs were estimated to have lower diversity than the average value.

The total number of reef fish species observed for each site is given in Table 9.2. Species richness totals ranged from a minimum of 70 to the highest of 200 species at site 8, with an average of 144.88 species per site. Species abundance was also noted for each site with the trend of the highest abundance recorded at the sites with the highest species diversity.

The highest diversity and abundance of reef fish species was recorded at site 8, Joe's Spit, which is situated southwest of Toku Island. This site showed habitat complexity with large changes in topography and stronger currents preferred by larger fish species and especially piscivores such as *Lutjanus kasmira* and *Lutjanus gibbus*. The species count of 200 at this site is similar to the higher levels of diversity recorded on some reefs located in the 'coral triangle' areas of the Indo-Pacific (Allen 2002, 2006).

9.4.2. CORAL FISH DIVERSITY INDEX

The CFDI value was derived byadding the number of species recorded for the six dominant families: Pomacentridae (57), Labridae (52), Acanthuridae (31), Chaetodontidae (31), Scaridae (22) and Pomacanthidae (8). This resulted in a CFDI value of 201.

When the formula was applied to these results, the estimated number of reef fish species that could be expected in this area was found to be 661. The total number of reef-associated fish species recorded during this survey was 406, which corresponds to 61.4% of reef fish species that estimated by the CFDI that could be expected within this area.

Table 9.3 provides CFDI values, estimated total numbers of reef fishes predicted by the CFDI, and the known number of reef fish for a range of countries spanning the South Pacific east to west.

The location of the Vava'u islands places this group outside the Indo-Pacific region that is recognised as having the highest diversity of coral reef fishes (i.e. Indonesia, Papua New Guinea and Solomon Islands). Tonga is noted for a lower diversity of fish species in comparison to Fiji, which has a total of 1,337 species, though slightly higher than that of Samoa (940) and the Cook Islands (603). Tonga is also noted as having a lower than average number of species with a wide geographical range (Kulbicki et al. 2002).

Table 9.3. Coral Fish Diversity Index (CFDI), estimated total numbers of reef fishes predicted by the CFDI, and the known number of reef fish for a range of countriesacross the South Pacific region.

Locality	CFDI	No. reef fishes	Estim. Reef fishes
Milne Bay, Papua New Guinea	337	1109	1313
Maumere Bay, Flores Indonesia	333	1111	1107
Raja AmpatiIslands, Indonesia	326	972	1084
Togean and banggai islands, Indonesia	308	819	1023
Komodo islands, Indonesia	280	722	928
Calamaines islands, Philipines	268	736	888
Madang, Papua Bew Guinea	257	787	850
Mont Panié, New Caledonia	255	597	844
Kimbe Bay, Papua New Guinea	254	687	840
Manado, Sulawesi, Indonesia	249	624	823
Northwest Lagoon, New Caledonia	234	527	773
Capricorn Group, Great Barrier Reef	232	803	765
Ashmore/Cartier Reefs, Timor Sea	225	669	742
Kashiwa-Jima islands, Japan	224	768	738
Scott/Seringapatam Reefs, West Australia	220	593	725
Samoa islands, Polynesia	211	852	694
Chersterfield islands, Coral Sea	210	699	691
Sangalakki Islands, Kalimantan, Indonesia	201	461	660
Vava'u archipelago, Kingdom of Tonga	201	406	661
Bodgaya islands, Sabah, Malaysia	197	516	647
Pulua Weh, Sumatra, Indonesia	196	533	644
Izu islands, Japan	190	464	623
Christmas island, Indian Ocean	185	560	606
Sipidan island, Sabah, Malaysia	184	492	603
Rowley Shoals, West Australia	176	505	576
Northwest Madagascar	176	463	576
Cocos-Keeling Attoll, Indian Ocean	167	528	545
North-West Cape, West Australia	164	527	535
Tunku Abdul Rahman Is. Sabah, Malaysia	139	357	450
Lord Howe island, Australia	139	395	450
Monte Bello islands, West Australia	119	447	382
Bintan island, Indonesia	97	304	308
Kimberley Coast, West Australia	89	367	281
Cassini island, West Asutralia	78	249	243
Johnston island, Central Pacific	78	227	243
Midway Atoll, Pacific, USA	77	250	240
Rapa, Polynesia	77	209	240
Norfolk Island, Australia	72	220	223

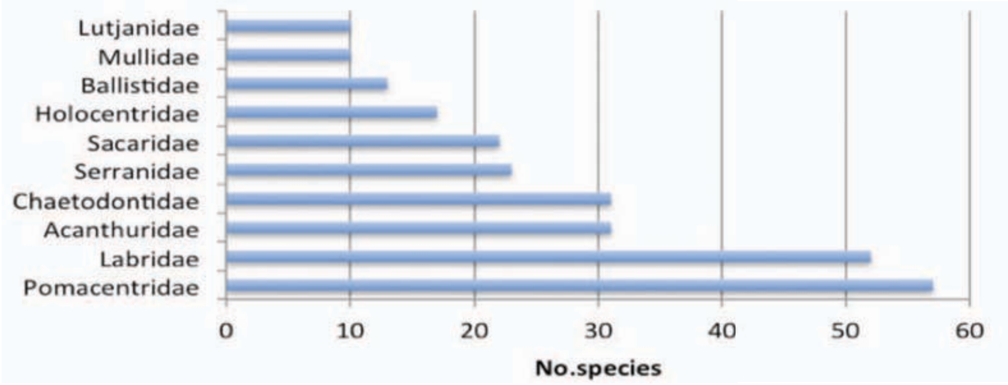

Figure 9.2. Top ten families for species diversity identified during the rapid assessment.

9.4.3. REEF FISH FAUNA COMPOSITION BY FAMILY

The coral reefs of Vava'u are dominated by the families Labridae and Pomacentridae, with lower diversity of Pomacanthidae, Serranidae and other higher trophic fish families that create a balanced ecosystem for coral reef health and resilience (Figure 9.2). Several sites showed an increased balance in functional groups, which indicates healthier reef systems and improved reef functions.

The Moorish idol, *Zanclus cornutus*, was a dominant species recorded at every site during the rapid assessment, though it has a single species within the genus.

The angelfish or Pomacanthidae family was recorded in low abundance and occurrence over sites with the exception of the two-spined angelfish, *Centropyge bispinosa*. This species was recorded at 95% of sites with an abundance ranging from two to ten individuals at 56% of the sites and an abundance of greater than ten individuals for44% of sites surveyed. *Pomacanthus imperator* or emperor angelfish was recorded at only 18% of sites with only two individuals recorded at each of the five sites.

The damselfish or Pomacentridae family was recorded at every site with the dominant species *Chromis iomelas* recorded at 92% of the sites. The abundance observed for this family was lower than ten individuals at 82% of sites, between 11 and 50 individuals at 11%of the sites, and greater than 50 individuals at 3% sites of the sites (i.e. sites 12 and 13, Maninita inside and outer reef). *Pomacentrus vaiuli* was recorded at 100% of sites and had an average abundance of between two and 20 individuals per site. Damselfish from the genus *Stegastes*, which included three species, was recorded on a total of 12 sites or 44% of the sites surveyed.

Members of the wrasse family (Labridae) were recorded at 100% of sites, with *Thalassoma lutescens* or sunset wrasse recorded at all sites. Sites with the lowest diversity of wrasse species included Toku Island site 6 with only nine species recorded. The abundance of wrasse species noted during the rapid assessment was predominantly between ten and 15 individuals with the exception of site 5 where the species *Macropharyngodon meleagris* or leopard wrasse had over 50 individuals.

Members of the butterflyfish or Chaetodontidae family were recorded at each site with *Chaetodon pelewnsis* at 100% of sites, *Chaetodon citrinellus* at 96% of sites, *Chaetodon ephippium* at 88% of sites and *Forcipiger flavissimus* at 85% of sites. The abundance for each species was less than ten individuals at most sites except for four sites where *Forcipiger flavissimus* was observed in a greater abundance of 14 individuals. A few sites had species of fish not recorded at other sites during the rapid assessment (Table 9.4).

Table 9.4. Reef fish species recorded at a single site.

Family	Species	Site no.	Abundance (no. of individuals)
Acanthuridae	*Acanthurus Achilles*	16	1
Ballistidae	*Sufflamen fraenatum*	7	2
Blennidae	*Meiacanthus procne*	1	2
Bothidae	*Bothus pantherinus*	14	1
Carangidae	*Caranx sexfasciatus*	8	1
	Gnathanodon speciousus	22	1
	Trachinotus blochii	4	1
Carcharhinidae	*Carcharhinus melanopterus*	16	1
Chaetodontidae	*Chaetodon semeion*	13	1
	Heniochus acuminatus	24	1
	Heniochus singularis	20	1
Diodontidae	*Diodon holocanthus*	7	1
Echeneidae	*Echeneis naucrates*	8	2
Gerreidae	*Gerres oyena*	3	1
Gobiidae	*Koumansetta rainfordi*	24	1
Holocentridae	*Neoniphon argenteus*	22	2
	Sargocentron punctatissimum	7	1
	Sargocentron violaceum	23	1
Labridae	*Anampses meliagrides*	16	1
	Haliochoeres melanurus	4	1
	Haliochoeres prosopeion	1	1
	Pseudojuloides cersinus	19	1
Lethrinidae	*Gymnocrainius* sp.	14	1
	Gymnocranius euanus	26	1
	Gymocranius microdon	8	1
Microdesmidae	*Gunnelichthys monostigma*	15	1
	Ptereleotris sp.	16	1
	Ptereleotris zebra	18	4
Monocanthidae	*Pervagor aspricaudus*	1	1
	Pervagor janthinosoma	1	1
Mullidae	*Liza vaigiensis*	20	10
Muraenidae	*Gymnothorax flavimarginatus*	11	1
	Gymnothorax javanicus	14	1
Ophichthidae	*Leiuranus semicinctus*	25	1
Pempheridae	*Parapriacanthus schwenkii*	14	>50
Plotosidae	*Plotosus lineatus*	26	10
Pomacentridae	*Abudefduf sordidus*	20	1
	Abudufduf vaigiensis	17	4
Serranidae	*Pseudanthias cooperi*	4	1
Sphyraenidae	*Sphyraena obtusata*	3	1
Tetradontidae	*Canthigaster janthinoptera*	12	1

9.4.3 REEF FISH FAUNA DIETARY COMPOSITION

Functional groups are species that are placed together due to diet preferences rather than nomenclature. By monitoring functional groups i. e piscivores, herbivores, corallivores and carnivores, it creates an insight into the predator prey relationships as well as to the overall health of the reef ecosystems. If one functional group is dominating or is not apparent in sufficient numbers and diversity this can impact on the ecosystem health and the economic benefits that can be gained through fishing and tourism.

The overall functional groups were examined for the fish species recorded during the rapid assessment (Figure 9.4). Habitat complexity was limited on many of the fringing reef areas with the exception of Maninita, 'Euakafa and Joe's Spit. Habitat complexity which is created through an improved range of different coral species offers varying topographical changes for larger fish species such as snappers and groupers as well as improved habitat for cryptic marine life such as moray eels. If reefs have little diversity in coral reef species, the reef has low habitat complexity and topography and often is dominated by smaller reef fish species such as damselfish and wrasse.

Figure 9.3. Reef scene at 'Euaiki (photo by Karen Stone).

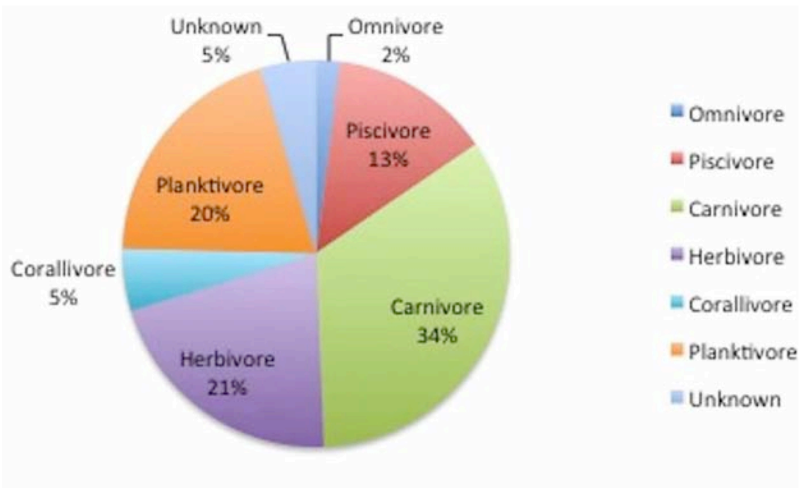

Figure 9.4. Reef fish functional groups as characterised by the main diet of the species. In this figure the corallivore diet group consists of only obligate corallivore species where more than 80% of the diet is comprised of live coral.

The Pomacentridae and Labridae families dominated the planktivore and carnivore diet groups respectively, and also had a higher abundance at sites where they were recorded. More complex carnivore species belonging to the family Muarenidae (moray eels) were recorded with a low diversity (three species) and very low occurrence. Moray eels are a cryptic species hiding in crevices and under rocks which can make them difficult to find and record.

Piscivore diet groups including the Carcharinidae, Serranide and Lethrinidae families were also observed to have low diversity and low abundance. One exception was *Plectopromus laevis*, observed at two sites, 9 and 23, where an abundance score of 11–20 individuals was recorded, though many were of immature phase.

Caesionidae (fusilliers), Holocentridae (soldierfish), Pomacentridae (damselfish) and Acanthuridae (surgeonfish) belong to the omnivore diet group. *Sargocentron spineferum* from the Holocentridae family was recorded at81% of sites with an abundance rating of two to ten individuals per site. *Pterocaesio tile* from the Caesionidae family was recorded on 52% of sites with an average abundance of 11–50 individuals with the exception of site 23, 'Euakafa South, where an abundance of over 50 individuals was recorded.

Herbivore species include the families Scaridae (parrotfish), Acanthuridae (surgeonfish), Pomacentridae (damselfish), Siganidae (rabbitfish), Kyphosidae (chubs) and Pomacanthidae (angelfish).

Naso unicornis was recorded at site 25, 'Euaiki north with an abundance rating of over 50 individuals and an estimated size of less than 20cm in length. 'Euaiki north had large amounts of algae on the coral reef (Figure 9.3) which will be relevant to the juvenile and immature fish sizes recorded. *Naso hexacanthus* was recorded with an average abundance of two to ten individuals on ten sites while an abundance of over 50 individuals was observed at site 23. Damselfish from the genus *Stegastes* were recorded at 12 sites or 44% of the total sites surveyed. These sites (e.g. Lotuma site 2 and 'Euaiki sites 25 and 26) were predominantly characterised by lower coral cover and weakened reef structure dominated by algae.

Corallivore fish species feed primarily on live coral tissue and are a diverse functional group related to coral cover and topographic complexity. Corallivores are split into two groups: obligate corallivores whose diet consists of more than 80% live coral and facultative corallivores whose diet consists of less than 80% live coral(Cole et al. 2008). Figure 9.5 and Table 9.5 show the corallivore species recorded during the survey.

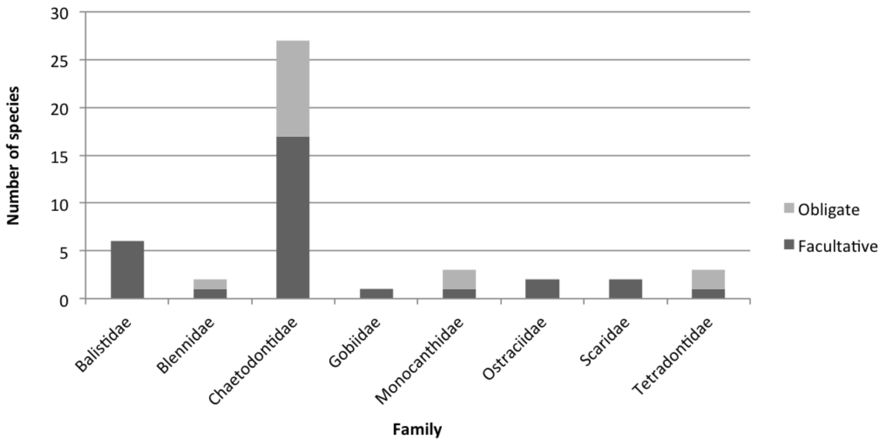

Figure 9.5. Obligate and facultative corallivore species (grouped into families) recorded during the reef fish surveys.

Table 9.5. Obligate and facultative corallivore species recordedduring the reef fish surveys.

Family	Species	Diet	No. of individuals observed
Balistidae	*Balistapus undulatus*	F	21
	Balisoides viridecens	F	4
	Rhinecanthus aculeatus	F	5
	Pseudobalistes flavimarginatus	F	5
	Suffalmen fraenatum	F	1
Blennidae	*Exallias brevis*	O	4
	Escenius bicolor	F	1
Chaetodontidae	*Chaetodon auriga*	F	23
	Chaetodon baronessa	O	4
	Chaetodon benetti	O	4
	Chaetodon citinellus+	F	26
	Chaetodon ephippium+	F	24
	Chaetodon flavirostris	F	4
	Chaetodon kleinii+	F	7
	Chaetodon lineolatus	F	2
	Chaetodon lunula	F	12
	Chaetodon lunulatus	O	19
	Chaetodon melannotus+	O	6
	Chaetodon mertensii	F	19
	Chaetodon ornatissimus	O	4
	Chaetodon pelewensis+	F	27
	Chaetodon plebeius	O	8
	Chaetodon quadrimaculatus+	F	2
	Chaetodon raflessi	F	11
	Chaetodon reticulatus	O	21
	Chaetodon trifascialus	O	12
	Chaetodon ulietensis	F	19
	Chaetodon vagabundus+	F	22
	Chaetodon unimaculatus+	O	14
	Forcipiger flavissimus	F	23
	Heniochus acuminatus	F	1
	Heniochus chrysostomas+	F	19
	Heniochus singularis	O	1
	Heniochus varius	F	9
Gobiidae	*Gobiodon cirtinus*	O	1
Monocanthidae	*Aluterus scriptus*	F	2
	*Cantherhines dumerilii**	O	3
	Oxymonocanthus longirostris	O	3
Ostraciidae	*Ostracion cubicus*	F	3
Scaridae	*Cetoscarus bicolor**	F	10
	*Chlorus microrhines**	F	16
Tetradontidae	*Arothron hispidus**	F	1
	*Arothron meleagris**	O	1
	*Arothron nigropunctatus**	O	7

O = obligate corallivore, F =facultativecorallivore (Cole et al. 2008).
*Fish species that ingestskeletal material, + fish species that feed on soft corals.

Chaetodon pelewensis was recorded from every site however the occurrence was low with only five or six individuals recorded at the majority of sites, except sites 14, 15, 16 and 17 where 15–18 individuals were recorded. These sites had the highest coral cover as indicated in Figure 9.6 below. *Chaetodon citrinellus* was recorded at26 sites with a higher abundance of 10–11 individuals per site. *Heniochus singularis* had low abundance and occurrence being sighted only at site 20 (i.e. A'a, a limestone drop-off habitat).

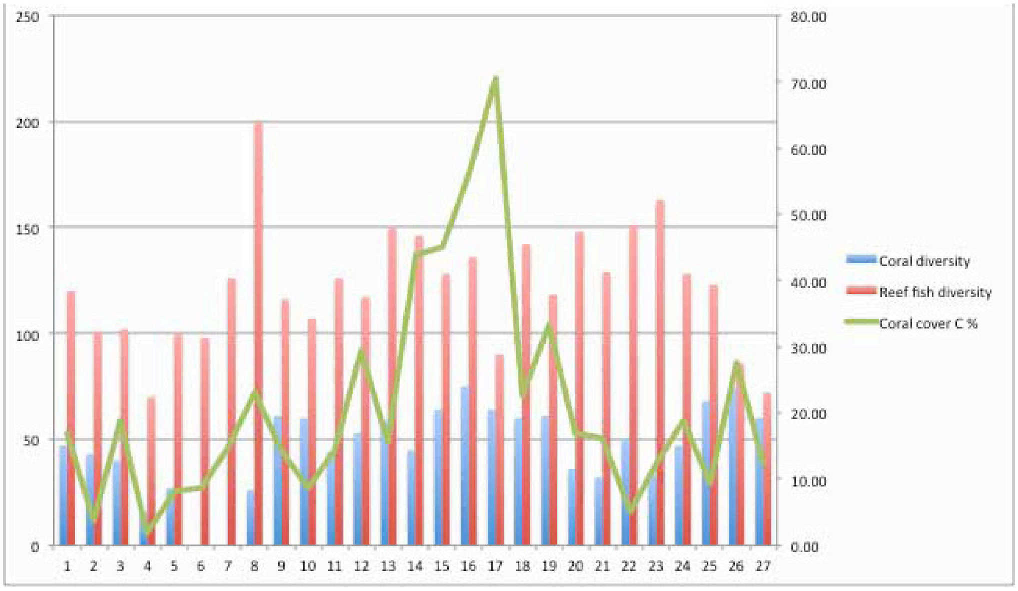

Figure 9.6. Coral species diversity, coral cover and reef fish diversity at the sites surveyed in the rapid assessment.

Fonualei (sites 4 and 5) is a volcanic island with very low coral cover where the number of corallivorous and herbivorous Scarridae species was low due to the lack of habitat for food and shelter.

Sites with greatest coral cover, i.e. sites 12, 14, 15, 16 and 19, had a mean number of reef fish species of 144.88 species per site. Sites with the highest coral diversity, which offers greater habitat range, topography changes and shelter, included sites 15, 16, 17, 18, 19 and 26. These sites also were observed to have an above average fish diversity.

Coral reef areas with higher coral diversity, coral cover and reef fish diversity such as Maninita (sites 12 and 13), Taula (sites 14 and 15) and 'Euakafa (sites 22 and 23) are important areas for reef fish diversity and coral reef resilience. These sites displayed a more balanced and functional coral reef habitat, which increases coral reef resilience. Other coral reef areas, which displayed lower coral cover and diversity such as A'a and 'Oto (sites 20 and 21), had lower numbers of coral-dependent species such as corallivores and higher number of planktivore and omnivore species.

Species of concern

The International Union of Conservation of Nature (IUCN) produces a Red List that categorises species of concern for their location (IUCN 2013). These species are under threat from anthropogenic and climate change stressors. Table 9.6 presents the IUCN Red List species of concern for Tonga not observed during this survey, and Figure 9.7 shows those that were recorded.

Table 9.6. IUCN Red List species not observed during rapid assessment surveys. Only the last species listed, ***Siganus niger***, is endemic.

Family	Species	IUCN Listing
Serranidae	*Epinephelus malabaricus*	Near threatened (NT)
Serranidae	*Epinephelus socialis*	Near threatened (NT)
Serranidae	*Plectopromus aerolatus*	Vulnerable (V)
Scarridae	*Bolbometopon muricatum*	Vulnerable (V)
Siganidae	*Siganus niger*	Vulnerable (V)

Although there were no observations of *Bolbometopon muricatum* or *Epinehelus malabaricus* during the rapid assessment surveys, the author has observed these at other times within the Vava'u Archipelago, but in low abundance and low occurrence. *Bolbometopon muricatum* is targeted by fishermen and has been recorded in the markets.

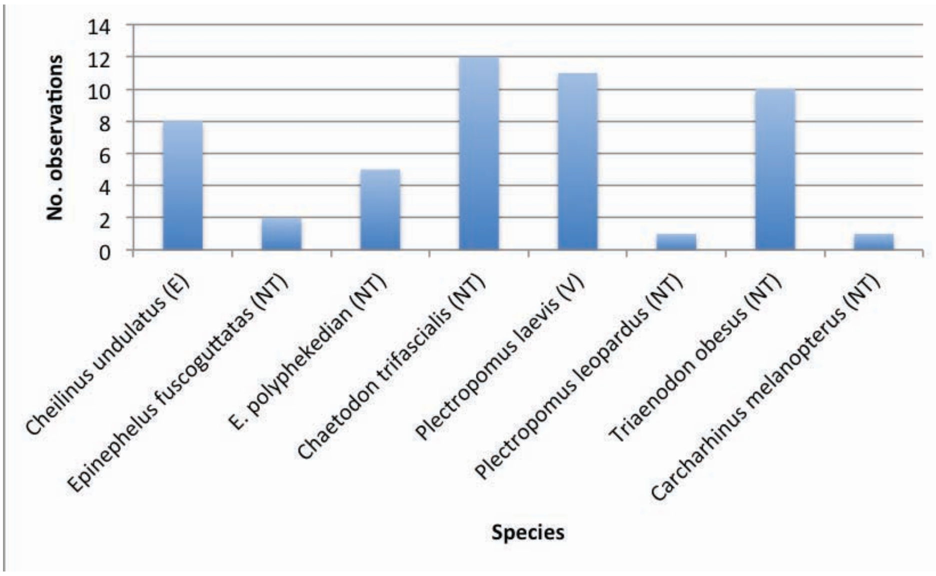

Figure 9.7. Graph showing recordings of IUCN Red List species of concern. E = species currently listed as endangered, NT = species currently listed as near threatened and V = species currently listed as vulnerable.

Figure 9.8. Blacktip reef shark, *Carcharhinus melanopterus*(photo by Karen Stone).

Though the above species were sighted during the rapid assessment, occurrence and abundance was low especially for important apex predators such as *Triaenodon obesus, Carcharhinus amblyrhyncos* and *Carcharhinus melanopterus (Figure 9. 8)*. In the 27 sites surveyed only 11 sites were recorded with shark species.

The carnivorous species *Plectropomus leopardus* was only recorded a single time at site 13, Maninita outside. *Chaetodon trifascialis*, an obligate corallivore, was of low abundance with only two individuals recorded on each of 12 sites.

9.5. Discussion

The coral reefs of the Vava'u archipelago are under increasing pressure from anthropogenic impacts especially from fishing and climate change (e.g. increased ocean temperatures and damage from cyclones). Coral reef ecosystems are vital to the economic development of the islands and to provide protection against climate change for the Vava'u archipelago.

In a report by Kramer (2008), Tonga's coral reefs was identified as "extremely vulnerable due to overfishing, destructive fishing practices, coastal development, onshore pollution and dredging, alongside impacts from cyclones and Crown of Thorns outbreaks".

Anthropogenic activities that are affecting coral reef fish and coral reef ecosystems include pollution from run-off areas and low lying coastal developments, and fishing. These activities weaken the coral reef ecosystems and their resilience. Healthier coral reefs with greater coral cover and coral diversity offer a wider range of habitats and a better balance of functional fish groups, including predator–prey relationships (Komyakova et al 2013). Healthy predator–prey relationships between piscivores and predatory carnivores reduce the potential for families such as pomacentrids and smaller labrid species to dominate.

The low abundance or absence of important predatory species including piscivores and carnivores from the lutjanid, serranid and lethrinidfamilies indicates that overfishing of these group sis occurring. Smaller fish families are dominating the reefs. These smaller fish, such as pomacentrids, imbalance the reef by encouraging more algal growth and reduce the predator-prey relationships and resilience of the coral reef ecosystem for other higher trophic groups.

Two families, Pomacentridae and Labridae, dominated the coral reef fish diversity. Though the Labridae family is a very diverse group of feeders, the Pomacentridae are primarily herbivores and zooplankton feeders with a few species of invertivores. Pomacentrids encourage algae growth on corals in certain areas, while feeding off algae in other areas. This can damage coral health when the algae overgrows and smothers the corals. Typical fish capable of this effect are species of *Stegastes* that are highly territorial; these species are able to control areas of reef due to a lack of piscivore species thatincludes the cryptic species of moray eels.

There were no observations during this survey of large excavator fish species such as *Bolbometopon muricatum*. Excavator herbivores including the Scaridae family help coral reef resilience by scraping close to the surface of the coral and removing epilithic algae (Green & Bellwood 2009). Large excavator fish remove dead coral, exposing the hard skeleton below and creating improved areas for coralline algae and coral recruitment.

Grazers and detritivores, such as species of *Centropyge* from the Pomacanthidae family and many species of acanthurids, when in abundance will consume large amounts of algae from the reefs. These important functions of herbivorous fish help maintain coral reef health. If algae become dominant due to overfishing of functional herbivores, the coral reef is not able to regenerate and loses resilience.

Browser species such as *Naso unicornis* and *Naso tonganus* help maintain the important balance of algae and coral. Browsers remove the algae from the coral without scraping or excavating the coral; this reduces the shading of corals that restricts the coral's ability to photosynthesise.

Scaridae and Labridae species, such as the large *Cheilinus undulates*, are diurnal species and during the night they lie within the reef to sleep, making them easy prey for night time spearfishing. Overharvesting of these species can occur rapidly. Species of both of these families are economically valuable and threatened by fishing. Given their critical ecological functions, viable populations of these species have to be in place for the reef to remain healthy and resilient.

Lutjanus bohar was the most commonly seen lutjanid during the rapid assessment. This may be due to the species being a known carrier of ciguatera in certain reef ecosystems and thereby not a favourite species for harvest and consumption. Other species *Lutjanus kismira* and *Lutjanus gibbus* were found in large abundance only at sites 4 and 5, Fonualei and site 8, Joe's Spit, where reef fishing pressure appears to be reduced due to distance from the main island. These sites had lower abundance of the pomacentrid species. Sites 4, 5, 6, 7 and 8 also have reduced anthropogenic impacts such as pollution due to their distance from the main island 'Uta Vava'u.

Sites 12 and 13 on Maninita Island and sites 22 and 23 on 'Euakafa Island also showed good predator–prey relationships with a lower abundance of pomacentrid species and higher abundance of omnivore and carnivore functional groups. These sites had a lower dominance of smaller fish, indicating better resilience. This also enhances adjacent areas by spillover effect of fish to other nearby coral reefs.

'Euaiki Island (sites 24 and 25) showed lower resilience to anthropogenic impacts. Site 25 had a higher abundance of *Stegastes*spp. and large areas of algae dominated reefs. Corallivore species were in lower abundance.

Elasmobranch species were at low numbers with sightings at only eleven of the 27 sites. The most common shark species recorded was *Triaenodon obesus* with 11 sightings of which only site 8 had more than one individual. Only two individual sightings of *Carcharhinus amblyrhynchos* and one individual sighting of *Carcharhinus melanopterus* on Fonua'one'one were recorded during the survey.

For conservation planning, important areas to consider would be coral reefs areas that show the highest coral cover and diversity and abundance of reef fish species. These reefs are considered as having a higher resilience to climatic and anthropogenic impacts. Corallivore species are known indicators of healthy reefs. They remain in the reef while food is abundant, but as the reef ecosystem declines they move to healthier reefs and other species such as pomacentrids start to dominate the reefs, impacting on the ability on the reef to regenerate.

Coral reefs and reef fish are under threat from human induced pressures. Overfishing is prevalent in small developing nations such as Tonga, where current legislation and recommendations are often ignored over economic benefits related to marine life. As coral reefs are relied upon so heavily for food and income, it is vital that community consultations are undertaken to improve stakeholder relationships before moving forward with legislation and policy decisions.

Important coral reef ecosystems identified within the Vava'u archipelago from the reef fish survey are:

- Maninita and Taula islands are located towards the south east of the Vava'u Island group, Maninita and Taula scored higher on species richness than other sites. Incorporating a larger management zone around both islands and outer reef would be beneficial and create improved recovery and resilience to climatic and fishing activities. The long outer reef to the East of Maninita showed increased habitat complexity and larger diversity and abundance of reef fish species.
- 'Euakafa Island and 'Euaiki island were both identified as important habitat and diversity sites for marine fishes. These islands are being impacted by coastal developments on the islands and could benefit from marine management to protect the biodiversity.
- Lotuma Island and Mt Talau are unique as these two sites were the only sites surveyed with characteristics similar to lagoon areas. Both sites showed a fragility to anthropogenic impacts, however both sites are important to observe and cosider management plans for due to their locality.
- Fonualei and Toku islands are potential spawning grounds, however these islands may be negatively affected by giving them a conservation status and therefore attracting attention to their fishing potential. These areas should be included in current management systems such as the GEF Biodiversity Program for the Megapode on Fonualei. Other spawning grounds need to be identified and investigated through further studies and included under marine management plans.

Increased habitat complexity offers increased shelter for reef fish in holes and crevices, and protection from predators. Moreover, high habitat complexity creates areas shaded from the direct sunlight which provides improved habitat for cryptic fishes such as moray eels and larger predatory species of groupers and snappers. The above named coral reefs are important due to locality, topography and diversity.

The aquarium trade is of growing concern to Vava'u, although it could be managed in a sustainable way that would assist the islands economically. The main fish families targeted by the aquarium trade (i.e. Pomacentridae, Pomcanthidae, Ballistidae, Scorpaenidae, Tetrodontidae, Acanthuridae, Labridae and Chaetodontidae) are also vitally important for coral reef health and resilience. By removing these species, especially the Pomacanthidae and corallivore species, reef health will further degrade.

The methods commonly used by the aquarium trade maybe harmful to the health of people as well as the reef. For example, the aquarium trade often uses cyanide poisoning to capture fish.

A possible alternative is to use aquaculture and develop a small scale artisanal trade of ornamental reef species. Larvae of fish species are captured in nets or trapped using lights and then placed in culture tanks to grow and develop. This method can be used to engage communities in a small-scale aquarium fish trade without placing further stress on natural coral reef ecosystems.

Vava'u currently has a strong tourism industry based on humpback whales which migrate to Tonga between the months of June and October. The whale watching industry brought in approximately US $1,893,052 to Tonga in 2006 (IFAW 2008). This tourism is dependent on healthy coral reef ecosystems and reef fish diversity and abundance. With stronger marine conservation efforts, tourism could increase and develop as a year round industry, creating many alternative livelihood options for Tongans. Healthy reef systems attract in a wide range of tourists, as demonstrated in countries such as Palau that have strong marine protection and enhancement programmes.

9.6. Conservation recommendations

Reef fishing is extensive throughout the Vava'u islands. Licences are required from the Ministry of Agriculture, Fisheries, Forests and Foods (MAFFF) under the Fisheries Act 2002 unless the fishing is "subsistence fishing or any local fishing vessel or non-motorised canoe used only for subsistence fishing" (Section IV, 21(2)).

The legislation concerning marine areas including coral reef ecosystems is divided among two ministries within the Government of Tonga – MAFFF and the Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR, since restructured and renamed the Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC)). These ministries have different mandates and laws pertaining to marine areas (Table 9.7).

Table 9.7. Legislation of the Kingdom of Tonga relatingto protected areas and marine species protection.

Legislation	Year	Applications
Fisheries Act	2002	Provides for the conservation, management and sustainable utilisation and development of fisheries resources in the kingdom and other matters incidental thereto
Fisheries Management (Conservation) Regulations	2008	Species management, licence requirements and permit forms, size limits
Aquaculture Management	2003	Management and development of aquaculture
Parks and Reserves Act	1976	Provides for the establishment of a parks and reserves authority and for the establishment and preservation of parks and reserves
Environment Impact Assessment Act and Regulations	2003 (Act), 2010 (Regulations)	Provides for the application of environmental impact assessment to the planning of development projects

MAFFF legislation allows for species protection and the development of special managed areas (SMAs) as well as legislation restricting destructive fishing practices with the use of poisons and explosives. The legislation also regulates the size and use of nets, recording of data of fisheries catches, and implementing quotas as needed.

MEC implements corporate plans to support the Government's national priorities and is ratified to the Convention of Biodiversity (CBD) (May 1998). Tonga's National Biodiversity Strategy and Action Plan (NBSAP) includes the following goals:

1. Marine ecosystems – priority ecosystems and habitats including coral reefs, slope fisheries areas, priority spawning and feeding sites are productive, healthy and sustainably managed.
2. Species conservation – Tonga's priority species are protected and thriving in their natural habitats and diversity of endemic, native and non-native species compromising Tonga's natural heritage is well documented, effectively conserved, and managed sustainably.

MEC is also responsible for environmental impact assessments under Tongan law.

One of the ongoing areas of concern is that with two ministries there is potential for different laws and programs to be cited at the discretion of their own ministers. There is often a cross over as to which Ministry can have the most effective programs, legislation and enforcement.

Vava'u needs sustainable economic development and improved resilience to climatic change and anthropogenic effects. There is a general feeling of waiting for government to act on the protection of the natural resources without individuals and communities being able to sustain resources themselves. Vava'u needs to move forward on marine protected and marine managed areas for the conservation of coral reefs.

Current legislation does not encompass marine protected areas, and an amendment to current legislation or new legislation to strengthen the policy on marine protected areas will be of paramount importance for the coral reef ecosystems. The conservation recommendations below can be undertaken with current legislation and mandates as well as recommendations that would need to be included in amendments and new legislations.

To improve the immediate and long-term health and functions of Vava'u's coral reef ecosystems the following conservation actions are recommended.

Reduce anthropogenic effects including the removal of mangroves, run-off and pollution including sewage from coastal developments areas, which degrade coral reef health and impact on coral reef fish abundance, including important functional fish groups such as corallivore species. This can incorporate the Environmental Impact Assessment legislation (2003), to monitor and mitigate impacts from coastal and large developments.

Impose seasonal closures of spawning grounds to protect lutjanids such as *Lutjanus gibbus* and *Lutjanus kasmira* and serranids to improve on the abundance and occurrence of these species in the surrounding reef areas. It is recommended that the important spawning grounds are closed for a minimum of 5 years to aid in repopulating the coral reef ecosystems and enhancing predator–prey relationships.

Design and implement marine managed areas and give research and data support to Special Managed Areas, promoting improved habitat choice for no-take areas. In the special managed areas of Ovaka and Taunga, the current no-take zones are in shallow areas, which have limited coral diversity and fish habitat. It is recommended that the no-take areas be calculated towards improving on fish biodiversity and looking at healthy coral reef areas within the special managed areas to improve on the resilience of the reef ecosystems.

Establish community networks for monitoring and mitigating the effects of climate change and anthropogenic impacts on coral reef systems and to engage the communities to help improve the resilience of the reefs for their sustainable livelihoods. Implement and maintain community discussions on coral reef ecosystems, benefits of marine managed areas, design of marine managed areas and implementation and enforcement of policy.

Introduce species protection for *Cheilinus undulates* and *Bolbometopon muricatum* including a moratorium of night spearfishing. These species are important species for coral reef health and ecotourism development.

Develop alternative livelihood options to reduce economic pressure faced by communities. These could include support for aquaculture programmes to supply the aquarium trade, and ecotourism.

Develop environmental guidelines for tourism operators and visiting yachts on use of coral reef ecosystems, to reduce anchoring and illegal fishing, and to improve on coral reef awareness within the tourism sector.

Review current fishing practices and legislation including netting and spearfishing of fish species such as herbivores and piscivores that are important for resilience of coral reef ecosystems.

Protect and monitor herbivorous species that control algal growth on reefs. Information on catches would be useful to record the species and size of fish caught.

Carry out monitoring and mapping of climate change impacts on coral reef ecosystems.

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CHAPTER 10 TARGETED FISH OF VAVA'U

MAËL IMIRIZALDU

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10.1. Summary

A rapid assessment of targeted fish was conducted in the archipelago of Vava'u in the Kingdom of Tonga.

Targeted species are those that are found near coral reefs and targeted for commercial, recreational or subsistence fishing.

A total of 226 species (of which one was not previously recorded) belonging to 75 genera and 34 families were identified over 27 study sites.

The targeted fish population of Vava'u appears to have a species composition quite common and representative of coral reefs ecosystems.

Fish communities were highly dominated by the families of surgeonfishes (Acanthuridae) and parrotfishes (Scaridae). Snappers (Lutjanidae) and goatfishes (Mullidae) were poorly represented. Groupers (Serranidae), snappers (Lutjanidae) and emperors (Lethrinidae) were underrepresented.

The structure of fish communities was unbalanced with a high rate of herbivores species and a very low rate of predators such as large carnivore species and piscivore species.

For at least six species, no mature individual were observed. This means that all the individuals that were observed didn't yet reach the size were they can reproduce.

Strong signs of overfishing were observed. There is an important need for management measures to ensure sustainable stock exploitation which will contribute to food security overtime.

The reef areas along the sites of Joe's Spit (Toku Island), Fangasito Island, Maninita Island and 'Euakafa Island were identified as priority conservation sites.

10.2. Introduction

This chapter presents the status of targeted and commercial fish species diversity as investigated at 27 reefs sites located off islands in the Vava'u group in Tonga during the BIORAP survey in February 2014. The objective of this work was to produce a rapid assessment of the composition and structure of the fish species that are of interest for sale and consumption (i.e. targeted). The main aim of this study is to provide recommendations for the Tongan government and the Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC) to develop and implement efficient management measures. This assessment was achieved through a standardised underwater visual census, a method frequently used in studies of this type and known to be efficient.

The people of Vava'u and Tonga have a long history of fishing which overtime contributes to a special relationship with their marine environment and its resources. Several articles describe the evolution of this relationship from the Lapita time (around 2,700 years ago) until the end of the 19th century (e.g. Bataille-BenguiguieDensmore 2010). This early knowledge is added toby detailed articles and reports describing more contemporary practices of fishing (Lui and Bell 1994; Hunt 1997; Kronen 2002; Kronen and Samasoni 2006). Despite a complete list of documents talking about fisheries in Tonga – Vava'u, the first complete checklist of the shore and epipelagic fishes of Tonga was compiled by Randall et al. in 2003 and included 1162 species. The first surveys of fish resources were conducted by the Tongan Ministry of Fisheries (Lui and Bell, 1994) for the whole Kingdom of Tonga and focused on fish landings. The first complete checklist of the shore and epipelagic fishes of Tonga was compiled by Randall et al. in 2003 and included 1,162 species. The first underwater survey focusing on the archipelago of Vava'u was conducted by the Secretariat of the Pacific Community (SPC) in 2004 (Kulbicki, 2004) under the DemEcoFish project and included a socioeconomic assessment. This study was the first to provide reliable information on the Vava'u fisheries dynamic and its potential impacts on the reef fish species community structure from an ecosystem perspective. As useful as these studies were, providing guidance for resources management, none of them provided a complete survey of the reef fish species community structure.

Since the early 1990s, concern has been expressed about fishing pressure and its impact on fish stocks. Observations suggested that emperors, groupers and snappers were being depleted while herbivore species such as parrotfish and surgeonfish were dominating the fish communities. A shift in fish landings reported by the Ministry of Fisheries as well as lower density and reduced sizes reported by SPC (Friedman et al. 2009) indicated a moderate to high overfishing status. The results of this BIORAP survey confirm these conclusions and highlight that overfishing has increased over the last ten years. Several usually common groups of fishes are underrepresented, the structure of the overall fish population is unbalanced, and many species are small and under the minimum maturity size.

As the use of marine resources is not only a matter of the conserving the environment but also a matter of food security for the people of Vava'u, it is becoming necessary and urgent to engage strong management strategies and ensure sustainable resource use overtime.

10.3. Sites and methods

The BIORAP was conducted in Vava'u over 15 days from 13 to 28 February 2014. Sampling was done at 27 reef sites in 18 locations around Vava'u's main group of islands (Table 10.1) as well as more remote sites at Toku and Fonualei islands. Sites included various reef types such as patchy lagoonal reef, outer reef slope, reef slope, fringing reef and volcanic rock plateau.

Table 10.1. Sites by island/location.

Islands/Locality	Sites	Islands/Locality	Sites
Lotuma Island	Site 1 Lotuma Island	Taula Island	Site14 Taula Island inside
	Site 2 Lotuma chanel		Site15 Taula Island outside
Mt Talau	Site 3 Mount Talau, Vava'u Lahi	Fonua'one'one Island	Site16 Fenua'one'one Island south
Fonualei Island	Site 4 Fonualei north		Site17 Fenua'one'one Island north
	Site 5 Fonualei south	Fangasito Islan	Site18 Fangasito Island north
Toku Island	Site 6 Toku Island south		Site19 Fangasito Island south
	Site 7 Toku Island north	A'a Island	Site20 A'a Island
	Site 8 Toku, Joe's Spit	'Oto Island	Site21 'Oto Island
Mata'utuiliki, Vava'u Lahi	Site 9 Mata'utuiliki, Vava'u Lahi	'Euakafa Island	Site22 'Euakafa Island south
Onetale Bay, Vava'u Lahi	Site 10 Onetale Bay, Vava'u Lahi		Site23 'Euakafa Island north
'Umana Island	Site 11 'Umana	'Euaiki Island	Site24 'Euaiki Island east
Maninita Island	Site 12 Maninita Island inside		Site25 'Euaiki Island west
	Site 13 Maninita Island outside	Vaka'eitu Island	Site26 Vaka'eitu
		Langito'o Island	Site27 Langito'o Island

As previously defined, targeted species are those that are found near coral reefs and targeted for commercial, recreational or subsistence fishing. These species will differ depending on the type of fishing practiced and the geographical area, and it is therefore difficult to define a list of 'targeted' species. For this BIORAP survey, the list of species was developed through: (a) a review of reef fish identification books with local fisheries' officers; (b) discussion with K. Stone who was surveying coral reef fish for the BIORAP (Chapter 9); and (c) review of the lists published by Randall et al. (2003).

To better fit with the BIORAP objectives (biodiversity inventory, rapid assessment of stocks, use of resources by local communities, and identification of key conservation areas), a quick survey was made with the fisheries' officers. Using identification books (Allen et al. 2005), the aim was to identify among the targeted species, the ones that are preferentially caught and are subjected to higher fishing pressure. These species are called 'highly targeted species' in this document. The native Tongan/Vava'uan names for the species are given when known. Some names may differ from previous studies as some of the names are specific to the archipelago of Vava'u.

The underwater survey method used for this survey is reported in Samoilys and Carlos (2000) and was used in previous BIORAPs (Grace 2009; Imirizaldu 2011, 2013). This method is frequently used in studies of this type and allows for comparison of results from one study to another.

Because the species of interest are used to being pursued, they may flee or avoid the diver (Kulbicki, 1998). To minimise this risk the targeted fish team members entered the water before the rest of the team (i.e. those carrying out other marine surveys). The 50 m tape was quickly unwound and then the diver left the site for a few minutes before returning. Surveying took place along a belt transect with a length of 50m and a width of 10m; an area of 500m² was thus sampled. Only individuals in front of the diver and already present in the area were counted, while individuals arriving from behind the diver were not included to avoid counting the same fish twice. However, some exceptions were made for uncommon and easily recognisable species. This distinction is sometimes difficult to assess and the count may be a slight overestimate. The fish were counted individually and their size estimated (to the nearest 1cm for fish ≤ 10cm; to the nearest 2cm for fish ≤ 30cm; to the nearest 5cm for fish ≤ 60cm; and to the nearest 10cm for fish ≥ 60cm). When a group of over 50 individuals was seen, an estimate of the number was made (in increments of 10 to 50 individuals) and an average size estimated. For each transect, counting time, depth and visibility were systematically recorded (Table 10.2).

Table 10.2. Transect parameters.

	Counting time (min)	Depth (m)	Visibility (m)
Average	38.7	10.9	13.1
Minimum	20	4	7
Maximum	50	15	18

A single count was performed at each site. However, to obtain a more accurate representation of the communities present at each site, a random five minute swim was also carried out at the beginning and end of each count in both deep and shallow water to record species that had not been observed on the transect but were present in the sampling area. Most of the time, only the species name was noted as data from this could not be compared with data obtained during the counting. However when a fish with a notable size was observed, the fork length was recorded for maximum length comparisons.

Using the data collected, species richness was defined and indices of abundance, density and biomass were calculated. Species richness is defined by the number of taxa identified during counts. Abundance is the number of individuals recorded for a sampling site. Density corresponds to abundance related to a specific surface area, and is here expressed as number of fish per square metre (fish/m²), converted from the original number of fish for 500m². Biomass represents the overall quantity of fish on a site and is estimated from the number of fish and their individual weight. Biomass is also related to a specific surface area. Individual weight is determined from the length of the fish according to the following equation (Letourneur et al. 1998):

$$W = aLb$$

where W is the weight, L the estimated fork length in cm and the coefficients *a* and *b* are species specific and defined by Letourneur et al. (1998). The biomass is expressed in tonnes per square kilometre (t/km²), converted from the original expression in grammes per 500m².

As the survey was conducted in shallow waters on the reef, some families/species were difficult to observe when counting. These include pelagic fish such as planktivore species or larger predators such as barracudas or mackerels that stay in the water column. Also, cryptic species that hide in caves or holes such as moray eels or soldierfish and squirrelfish were hardly seen. This may have resulted in an underestimation of the real species richness, biomass and density of these families and species. Fleeing behaviour at sites where fishing pressure was high may also have reduced the number of fish observed and the overall species richness recorded.

Table 10.3. Classification of targeted fish families by diet.

Diet	Family	Common name
Carnivore	Carangidae	Jacks
	Carcharhinidae	Sharks
	Gerreidae	Silver biddy
	Holocentridae	Soldierfish, squirrelfish
	Labridae	Wrasses
	Lethrinidae	Emperors
	Lutjanidae	Snappers
	Mullidae	Goatfish
	Nemipteridae	Breams
	Serranidae	Groupers, allies
	Chaetodontidae	Butterflyfish
	Fistulariidae	Cornetfish
	Priacanthidae	Big eyes
	Muraenidae	Morays
	Haemulidae	Grunts, sweetlips
	Myliobatidae	Eagle rays
	Dasyatidae	Stingrays
Herbivore	Acanthuridae	Surgeonfish
	Kyphosidae	Chubs
	Scaridae	Parrotfish
	Siganidae	Rabbitfish
Omnivore	Acanthuridae	Surgeonfish
	Balistidae	Triggerfish
	Carangidae	Jacks
	Kyphosidae	Chubs
	Chaetodontidae	Butterflyfish
	Tetraodontidae	Puffers
	Monacanthidae	Filefish
	Ephippidae	Spadefish
	Mugilidae	Mullets
	Scorpaenidae	Lionfish
Piscivore	Carangidae	Jacks
	Carcharhinidae	Sharks
	Lutjanidae	Snappers
	Scombridae	Tunas, mackerels
	Serranidae	Groupers, allies
	Sphyraenidae	Barracudas
	Aulostomidae	Trumpetfish
	Muraenidae	Morays
Spongivore	Zanclidae	Moorish idol
Corallivore	Chaetodontidae	Butterflyfish
	Tetraodontidae	Puffers
Planktivore	Acanthuridae	Surgeonfish
	Balistidae	Triggerfish
	Caesionidae	Fusiliers
	Holocentridae	Soldierfish, squirrelfish
	Lutjanidae	Snappers
	Chaetodontidae	Butterflyfish
	Pempheridae	Sweepers

To better understand the fish community structure from an ecosystem perspective and identify the existing balance on the selected reef sites surveyed in the Vava'u Island group, part of the analysis focuses on diet groups. Seven diets groups were defined (Table 10.3) (Randall 2005; Lieske and Myers 2005).

Since observations of low occurrence could be due to either rarity or low detectability, the main focus of this report is the 15 most frequently observed families (Table 10.4) for which this survey method provides efficient assessment. This approach is supported by previous assessments conducted in the Pacific region by SPREP and SPC.

In the following results, data from a previous survey conducted by the SPC (Kulbicki 2004) are given for information only – because the sites, sampling effort and survey methodology differed, no real comparisons can be made. The standard deviation (SD) is systematically calculated for the indices of density and biomass. As the mean biomass and mean density are calculated over the 27 sites surveyed, a large SD value indicates wide variability in the quantity of fish found from one site to another.

10.4. Results

10.4.1. GENERAL CHARACTERISTICS

Species richness and composition

A total of 225 targeted species belonging to 76 genera and 34 families were identified during the survey with 9,590 individuals observed. A mean of 12 families, 22 genera, 40 species and 355 fish were observed and recorded at each site. The review conducted with the fisheries officers showed that of these species, 21 (or 10%) were highly targeted species and potentially subject to higher fishing pressure. A complete list of fish species identified during the BIORAP, including targeted and commercial species is presented in Chapter 9 . The random swim of 10 minutes performed before and after each counting event allowed a large number of species not observed on transects to be recorded. This led to a noteworthy increase in the total species richness (Table 10.4).

The composition by family for the archipelago of Vava'u is similar to other study sites in the region with the 15 most dominant families on coral reefs present (Table 10.4) (SPC 2004). The families of butterflyfishes (Chaetodontidae; 29 species), surgeonfishes (Acanthuridae; 27 species) and parrotfishes (Scaridae; 22 species) were the most diverse with 83.3%, 86.1% and 75.8%, respectively, of the species previously reported in Vava'u observed during this survey. Conversely, less than the half of all the species of groupers (Serranidae), snappers (Lutjanidae) and jacks (Carangidae) known to occur in these waters were observed with only 45.9%, 41.6% and 26.6%, respectively, of the previously reported species being spotted.

Much of the total species richness (87%) is composed of species observed at less than 14 of the 27 sites surveyed, with 60% observed at a maximum of six sites. Only 4% of the total richness, corresponding to seven species, was observed at more than 20 sites. These species belong to the families of surgeonfishes (Acanthuridae; three species), butterflyfishes (Chaetodontidae; one species), moorish idol (Zanclidae; one species), parrotfishes (Scaridae; one species) and goatfishes (Mullidae; one species). A total of 21 highly targeted species was recorded during this survey corresponding to 10% of the total richness. Among these species, only three species (14.3% of the highly targeted species) were observed at more than 14 sites and two of these (9.5%) were recorded at more than 20 sites: *Ctenochaetus striatus* (Acanthuridae, striped bristletooth, Pone Uli(Vava'uan name): 24 sites) and *Naso lituratus* (Acanthuridae, orangespine unicornfish, Ume Lei: 25 sites).

In contrast, 12 highly targeted species (23.3%) were recorded only at a maximum of six sites (excluding species that are hardly seen during underwater surveys such as moray eels): *Cephalopholis miniata* (Serranidae, coral hind, Ngatala PulePule: one site), *Naso Brachycentron* (Acanthuridae, humpback unicornfish, Ngatala Ume Atu: one site), *Parupeneus indicus* (Mullidae, indian goatfish, Tukuleia: one site), *Pterocaesio digramma* (Caesionidae, twostripe fusilier, Huli: one site), *Caranx lugubris* (Carangidae, black jack, Tapauli: two sites), *Lethrinus harak* (Lethrinidae, thumbprint emperor, Tanu: three sites), *Mulloidichthys vanicolensis* (Mullidae, yellowfin goatfish, Vete: three sites), *Lethrinus olivaceus* (Lethrinidae, yongface emperor, Ngutukao: four sites), *Lethrinus obsoletus* (Lethrinidae, orangestripe emperor, Tanu: five sites), *Lutjanus kasmira* (Lutjanidae, bluestriped snapper, Fate: five sites), *Mulloidichthys flavolineatus* (Mullidae, yellowstripe goatfish, Memea: six sites) and *Siganus argenteus* (Siganidae, forktail rabbitfish, Maava: six sites).

Only one species listed as Endangered on the IUCN Red List was observed: the humphead wrasse (Labridae, C*heilinus undulatus*, Lalafi (juvenile)/Tangafa (adult)). A total of 11 individuals were sighted on eight sites with sizes ranging from 39cm to 100cm (maturity length = 64cm). A species listed as Vulnerable was also observed: the blacksaddle coral grouper (Serranidae, *Plectropomus laevis*, Ngatalu). Eight individuals were sighted on eight sites with sizes ranging from 31cm to 53cm (maturity length = 60cm). Also, eight species listed as Near Threatened were recorded during this survey: of these, three were sharks, with the white-tip shark (Carcharhinidae, *Triaenodon obesus*) being the most frequently sighted with 12 individuals recorded on ten sites. The black-tip (Carcharhinidae, *Carcharhinus melanopterus*) and the grey reef sharks (Carcharhinidae, *Carcharhinus amblyrhynchos*) were rare with only one individual and two individuals observed respectively. Three species of groupers observed during this survey are also listed as Near Threatened: *Plectropomus leopardus* (Serranidae, coral trout, Ngatalu Kuli), *Epinephelus polyphekadion* (Serranidae, camouflage grouper, Ngatala) and *Epinephelus fuscoguttatus* (Serranidae, brown-marbled grouper, Ngatala). Each of these was recorded only once. None of these grouper species were recorded as a highly targeted species.

Table 10.4. Number of genera, species and individuals identified for each of the targeted families (ranked by decreasing number of species). A distinction is made between genera and species recorded only on transects (transect counts) and the number of records including those recorded during the random swim (total). Families in bold correspond to the 20 dominant families in the region (the Pomacanthidae do not appear as the family was not included in the survey).

Families	No. of genera (transect counts)	No. of genera (total)	No. of species (transect counts)	No. of species (total) / No. of reef-related species previously recorded (Randall, 2003)	No. of individuals (transect counts)
Chaetodontidae	4	4	25	30 / 36	705
Acanthuridae	5	5	19	31 / 36	3,192
Scaridae	4	5	18	22 /29	1,481
Serranidae	2	4	8	17 / 37	301
Holocentridae	3	3	9	17 / 27	330
Labridae	6	6	12	12 / –	183
Mullidae	3	3	9	11 / 15	323
Balistidae	5	7	6	12 / 18	496
Lutjanidae	3	4	7	10 / 24	969
Carangidae	0	5	0	8 / 30	15
Lethrinidae	3	4	4	8 / 15	135
Caesionidae	1	2	5	7 / 6	1,063
Siganidae	1	1	3	5 / 7	103
Carcharhinidae	0	2	0	3 / 6	3
Tetraodontidae	1	1	3	3 / –	7
Kyphosidae	0	1	1	4 / 4	2
Nemipteridae	1	1	1	2 / 4	76
Sphyraenidae	0	1	1	3 / 6	52
Haemulidae	1	1	1	2 / 3	1
Muraenidae	0	1	0	3 / –	2
Scombridae	0	1	0	1 / 4	1
Monacanthidae	1	1	1	1 / –	1
Fistulariidae	1	1	1	1 / 1	2
Zanclidae	1	1	1	1 / 1	111
Dasyatidae	0	1	0	1 / 1	Out of transect
Gerreidae	0	1	0	1 / 4	Out of transect
Scorpaenidae	0	1	0	1 / –	Out of transect
Aulostomidae	1	1	1	1 / 1	17
Atherinidae	0	1	0	1 / –	Out of transect
Pempheridae	0	1	0	1 / 2	Out of transect
Mugilidae	0	1	0	2 / 5	Out of transect
Priacanthidae	1	1	1	1 / 3	18
Ephippidae	0	1	0	1 / 1	1
Myliobatidae	0	1	0	1 / 1	Out of transect
TOTAL	48	75	138	225	9,590

Overall quantitative results

The means for biomass and density recorded over the entire mission are given in Tables 10.5 and 10.6 for all families found. The contribution of highly targeted species in relation to the complete community is also shown. The percentage of each family for total biomass and density is shown graphically in Figures 10.1 and 10.2. A mean biomass of 175.06 t/km^2 (± 251.43) (SPC survey (Kulbicki 2004): total mean biomass = 98.14 t/km^2) and a mean density of 0.71 fish/m^2 (± 0.4) (SPC survey (Kulbicki 2004):total mean density= 1.18 fish/m^2) were found per site with highly targeted species contributing 12.8% of this biomass and 19% of the density.

Table 10.5. Mean biomass of targeted families (ranked by decreasing mean biomass). Values found during the SPC assessment in 2004 (Kulbicki 2004) are presented for comparison. The contribution of highly targeted species (HTS) is expressed as a percentage.

Family	Mean biomass recorded in 2004 (t/km^2)	Mean biomass recorded in 2014 (t/km^2)	Contribution of HTS to mean biomass (%)	Rank
Acanthuridae	15.99	48.71 (± 79.50)	20.94%	1
Scaridae	27.84	38.02 (± 28.77)	0%	2
Lutjanidae	4.28	29.75 (± 87.87)	31.40%	3
Caesionidae	0.17	12.6 (± 39.64)	4.25%	4
Sphyraenidae	–	10.7 (± 54.25)	0%	5
Labridae	10.7	8.54 (± 21.45)	0%	6
Serranidae	7.16	4.62 (± 6.93)	0%	7
Lethrinidae	3.89	4.46 (± 7.14)	24.87%	8
Balistidae	2.07	3.4 (± 4.73)	0%	9
Holocentridae	2.58	3.12 (± 6.85)	19.90%	10
Mullidae	5.14	2.14 (± 2.59)	15.57%	11
Carcharhinidae	–	1.95	0%	12
Carangidae	2.29	1.93 (± 5.48)	0%	13
Chaetodontidae	5.25	1.27 (± 0.88)	0%	14
Siganidae	1.31	1.05 (± 1.56)	23.29%	15
Scombridae	0.07	0.76	0%	16
Zanclidae	1.38	0.43 (± 0.21)	0%	17
Nemipteridae	0.67	0.4 (± 0.6)	0%	18
Priacanthidae	–	0.37 (± 1.16)	0%	19
Haemulidae	0.77	0.29	0%	20
Tetraodontidae	0.05	0.18 (± 0.5)	0%	21
Kyphosidae	0.49	0.17	0%	22
Aulostomidae	0.75	0.07 (± 0.12)	0%	23
Ephippidae	0.02	0.06	0%	24
Muraenidae	–	0.04 (± 0.12)	0%	25
Monacanthidae	–	0.01	0%	26
Fistulariidae	0.06	0.001	0%	27
Total fish fauna	98.14	175.06 (± 251.43)	12.79%	–

Table 10.6. Mean density of targeted families (ranked by decreasing mean density). Values found during the SPC assessment in 2004 (Kulbicki 2004) are presented for comparison. The contribution of highly targeted species (HTS) is expressed as a percentage.

Family	Mean density recorded in 2004 (fish/m²)	Mean density recorded in 2014 (fish/m²)	Contribution of HTS to mean density (%)	Rank
Acanthuridae	0.26	0.236 (± 0.11)	34.84%	1
Scaridae	0.21	0.11 (± 0.08)	0%	2
Caesionidae	0.029	0.079 (± 0.13)	3.76%	3
Lutjanidae	0.048	0.072 (± 0.19)	52.94%	4
Chaetodontidae	0.13	0.052 (± 0.02)	0%	5
Balistidae	0.019	0.037 (± 0.09)	0%	6
Holocentridae	0.043	0.024 (± 0.05)	9.39%	7
Mullidae	0.06	0.023 (± 0.02)	23.97%	8
Serranidae	0.039	0.022 (± 0.05)	0%	9
Labridae	0.043	0.014 (± 0.01)	0%	10
Lethrinidae	0.041	0.01 (± 0.016)	10.37%	11
Zanclidae	0.014	0.008 (± 0.004)	0%	12
Siganidae	0.028	0.008 (± 0.007)	34.95%	13
Nemipteridae	0.014	0.006 (± 0.008)	0%	14
Sphyraenidae		0.004 (± 0.02)	0%	15
Priacanthidae		0.001 (± 0.003)	0%	16
Aulostomidae	0.002	0.001 (± 0.001)	0%	17
Carangidae	0.013	0.001 (± 0.002)	0%	18
Tetraodontidae	0.002	0.001 (± 0.0003)	0%	19
Carcharhinidae		0.0002	0%	20
Muraenidae		0.0001	0%	21
Kyphosidae	0.0006	0.0001	0%	21
Fistulariidae	0.001	0.0001	0%	21
Ephippidae	0.0008	0.0001	0%	24
Haemulidae	0.0004	0.0001	0%	24
Monacanthidae		0.0001	0%	24
Scombridae	0.001	0.0001	0%	24
Total fish fauna	1.18	0.71 (± 0.42)	19.01%	–

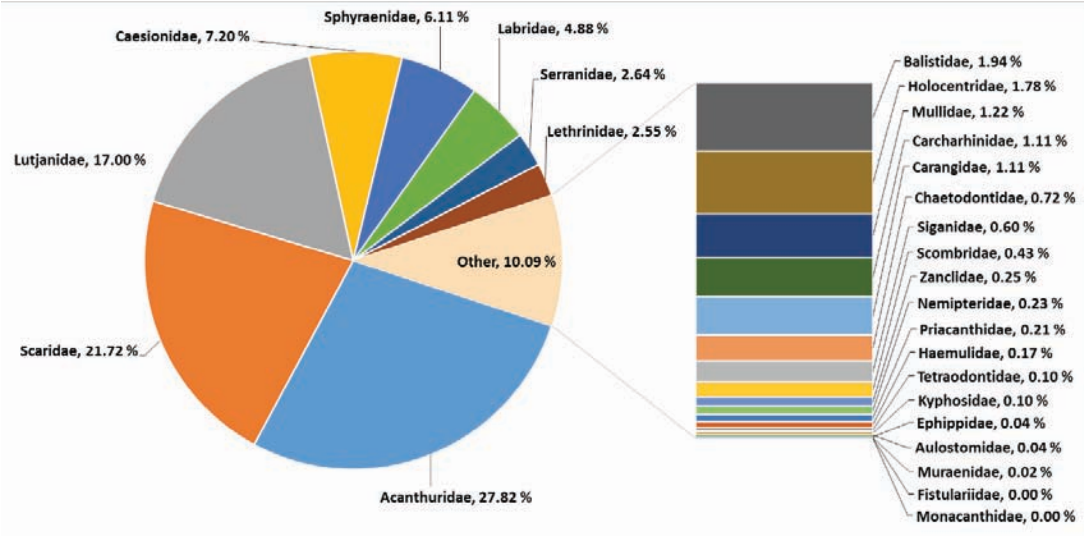

Figure 10.1. Contribution (%) of targeted families to the total biomass.

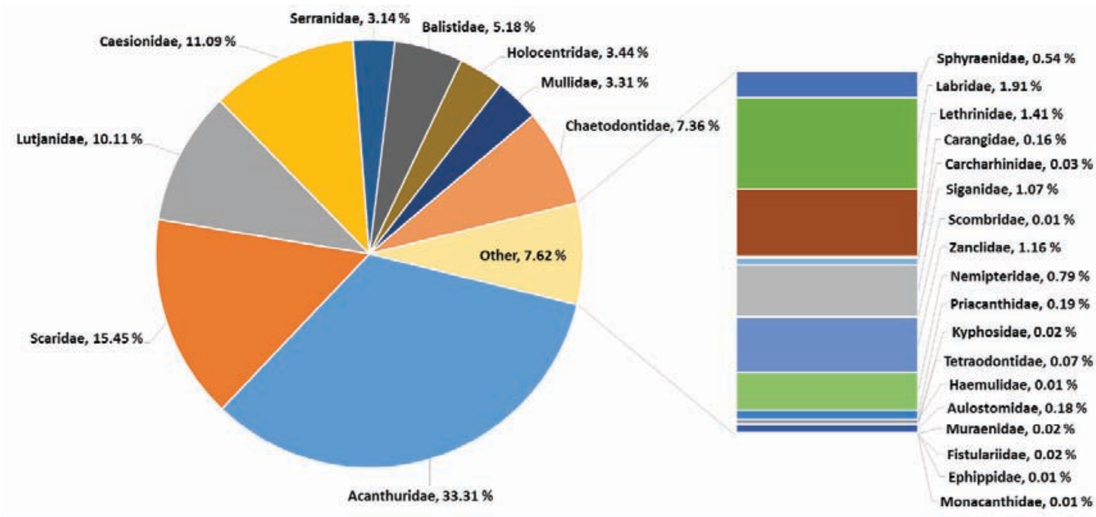

Figure 10.2. Contribution (%) of targeted families to the total density.

10.4.2. TWO FAMILIES DOMINATING THE REEFS (ACANTHURIDAE AND SCARIDAE)

The family Acanthuridae includes surgeonfishes and unicornfishes and represents a set of species with varying diets (herbivores, omnivores, planktivores), found over a wide range of habitats where some species are relatively common and abundant. They were the most frequent fish observed on the reefs (100% of the sites surveyed) and they dominated the fish community, representing over 33.3% of the total mean biomass (48.7 ± 79.50 t/km^2) and 23.3% of the total mean density (0.23 ± 0.11 fish/m^2) with a predominance of genera *Acanthurus*, *Ctenochaetus*and *Naso* noted (Table 10.7). A total of 31 species out of the 36 reef-related species previously recorded for Tonga (Randall et al. 2003) was observed during this survey. Within this family, two small-sized herbivores species were present in particularly high densities: *Ctenochaetus striatus* (highly targeted species; striated surgeonfish, Pone Uli) observed at 88% of the sitessurveyed and *Acanthurus nigrofuscus* (highly targeted species; brown surgeonfish, Pone) observed at 85% of the sites surveyed. These were followed by *Zebrasoma scopas* (two tone tang), while the species *Naso lituratus* (highly targeted species; orangespine unicornfish, Ume Lei), *Naso hexacanthus* (sleek unicornfish, Ume Atu) and *Naso Caesius* (gray unicornfish, Ume Atu), observed respectively at 92%, 20% and 22% of the sites surveyed, were the most abundant unicornfishes.

Table 10.7. Mean biomasses and mean densities of the main Acanthuridae species. Values found during the SPC assessment in 2004(Kulbicki 2004) are presented for comparison.

Species	Mean density recorded in 2004 (fish/m²)	Mean density recorded in 2014 (fish/m²)	Mean biomass recorded in 2004 (t/km²)	Mean biomass recorded in 2014 (t/km²)
Ctenochaetus striatus (HTS)	0.134	0.050 (± 0.045)	5.18	4.61 (± 4.35)
Acanthurus nigrofuscus	0.005	0.047 (± 0.045)	0.32	1.75 (± 4.53)
Zebrasoma scopas	0.062	0.019 (± 0.015)	1.41	0.37 (± 0.4)
Naso lituratus (HTS)	0.018	0.013 (± 0.014)	2.91	2.65 (± 3.7)
Naso hexacanthus	0.007	0.011 (±0.022)	0.67	4.75 (± 12.09)
Naso caesius	–	0.010 (± 0.024)	–	5.39 (± 17.55)
Acanthurus triostegus (HTS)	0.026	0.008 (± 0.026)	0.62	0.29 (± 0.77)
Naso brevirostris(HTS)	0.008	0.005 (± 0.02)	0.92	0.87 (± 2.67)
Naso unicornis (HTS)	0.005	0.003 (± 0.004)	1.24	1.32 (± 3.45)
Acanthurus lineatus (HTS)	0.012	0.003 (± 0.007)	1.67	0.46 (± 1.09)

– no data or value available. HTS = highly targeted species.

The Scaridae family includes the parrotfishes and is one of the main herbivore families of coral reefs (Randall 2005) with species found from fringing reefs out to the outer reef slope. While some species are solitary, others form groups, sometimes of large size. A total of 22 species out of the 29 reef-related species previously recorded for Tonga (Randall et al. 2003) was observed during this survey (Table 10.8). Fish were observed at 96% of the sites surveyed, individually or forming small (up to five individuals) to medium-sized (up to 70 individuals) groups. The overall mean density recorded was 0.11 ± 0.08 fish/m² (15.45% of the total mean density) and the biomass was 38.02 ± 28.77 t/km² (21.72% of the total mean biomass). The genera *Scarus and Chlorurus* were dominant with a predominance in density of the species *Scarus schlegeli* (yellowbar parrotfish, Hohomo (male)/Pose (female)), *Chlorurus sordidus* (bullethead parrotfish, Hohomo) and *Scarus psittacus* (palenose parrotfish, Hohomo) with 63%, 81% and 41% respectively observed at the sites surveyed. According to a study on parrotfish over the whole of Tonga including Vava'u (Clua and Legendre 2008), these three species together with *Scarus rubroviolaceus, Hipposcarus longiceps* and *Scarus ghobban* belong to a group of parrotfishes that show a lower than average sensitivity to fishing pressure. This might make them more abundant than other species in places where fishing pressure is high. Observations in this survey are consistent with the results obtained by Clua and Legendre (2008).

A significative proportion of the Scaridae family was constituted by small sizes juveniles for whom species identification was not possible (noted *Scarus* sp. in Table 10.8). The large-size species *Chlorurus microrhinos* (steephead parrotfish, Sika Toki) was observed at 59% of the sites surveyed but with densities 2.5 times smaller than *s. psittacus* previously mentioned. Together with *Scarus longipinnis*, *Chlorurus bleekeri*, *Cetoscarus bicolor* and *Scarus altipinnis*, these species belong to a group of parrotfishes showing a higher than average sensitivity to fishing pressure which means they are expected to be more abundant in places where fishing pressure is low.

Table 10.8. Mean biomasses and mean densities of the main Scaridae species. Values found during the SPC assessment in 2004 (Kulbicki 2004) are presented for comparison.

Species	Mean density recorded in 2004 (fish/m²)	Mean density recorded in 2014 (fish/m²)	Mean biomass recorded in 2004 (t/km²)	Mean biomass recorded in 2014 (t/km²)
Scarus schlegeli	0.053	0.020 (± 0.018)	5.90	7.31 (± 10.02)
Chlorurus sordidus	0.094	0.019 (± 0.016)	7.22	4.99 (± 4.8)
Scarus psittacus	0.009	0.015 (± 0.027)	1.62	5.11 (± 10.16)
Scarus sp.	–	0.013 (± 0.013)	–	1.01 (± 1.16)
Chlorurus microrhinos	0.019	0.006 (± 0.010)	3.80	3.13 (± 5.28)
Scarus longipinnis	0.005	0.004 (± 0.007)	0.70	1.25 (± 2.37)
Chlorurus bleekeri	0.013	0.004 (± 0.006)	2.61	2.05 (± 3.07)
Scarus rubroviolaceus	0.001	0.002 (± 0.004)	0.12	2.11 (± 3.18)
Hipposcarus longiceps	0.006	0.002 (± 0.007)	0.43	2.19 (± 8.96)
Scarus ghobban	0.013	0.001 (± 0.002)	1.132	0.30 (± 0.72)
Cetoscarus bicolor	0.006	0.001 (± 0.002)	0.503	0.56 (± 0.58)
Scarus altipinnis	0.003	0.0004 (± 0.0007)	1.180	0.55 (± 1.07)

– no data or value available.

10.4.3. LESS ABUNDANT FAMILIES (CHAETODONTIDAE, MULLIDAE, CAESIONIDAE, LUTJANIDAE, SERRANIDAE AND HOLOCENTRIDAE)

The Chaetodontidae (butterflyfishes) comprises a large number of species commonly found on reefs that are typically diurnal and belong to different diet groups (corallivore, omnivore and planktivore). Although not really targeted by fishermen, they do usually constitute good indicators of reef health. A total of 30 of the 36 reef-related species previously recorded for Tonga (Randall et al. 2003) were observed during this survey. They were found at100% of the sites surveyed and in high density representing 7.36% of the total mean density (0.05 ± 0.02 fish/m²). Because of their small size, they represented only 0.72% of the total mean biomass (1.27 ± 0.88 t/km²).

Fish of the Mullidae family (goatfishes) are usually found scouring the sand for worms, crustaceans, brittlestars and small fish. Certain species feed during the day, others at night, and a few both. During the day, the night-time feeders often form aggregations in open water or near the protection of the reef. A total of 11 of the 15 reef-related species previously recorded from Tonga (Randall et al. 2003) were observed during this survey. Goatfishes were observed at 100% of the sites surveyed. The family represented 3.31% of the total mean density (0.023 ± 0.02 t/km²) and 1.22% of the total mean biomass (2.14 ± 2.59 fish/m²) with a predominance of the genera *Parupeneus*. The highest density and biomass by far were recorded for the species *Parupeneus multifasciatus* (multibar goatfish, Tukuleia) which was observed at 92.6% of the sites surveyed and which was three time more abundant than the following highly targeted species *Mulloidichthys vanicolensis* (yellowfin goatfish, Vete) which was observed as a group of 50 individuals on only one site. The three species *Parupeneus cyclostomus* (goldsaddle goatfish, Tukuleia), *Parupeneus barberinus* (dot-dash goatfish, Tukuleia) and the highly targeted species *Mulloidichthys flavolineatus* (yellowstripe goatfish, Memea) were more frequently seen and were present at 48.1%, 44.4% and 22.2% of the sites, respectively. As only small schools (from two to 15 individuals) were observed, their total mean densities and biomasses remain small. The other species of goatfishes presented low to very low densities and they were observed at less than 20% of the sites, for example, the highly targeted species *Parupeneus indicus* (indian goatfish, Tukuleia) for which only six individuals were observed during the survey at only one site ('Euakafa Island).

Table 10.9. Mean biomasses and mean densities of the main Mullidae species. Values found during the SPC assessment in 2004(Kulbicki 2004) are presented for comparison.

Species	Mean density recorded in 2004 (fish/m²)	Mean density recorded in 2014 (fish/m²)	Mean biomass recorded in 2004 (t/km²)	Mean biomass recorded in 2014 (t/km²)
Parupeneus multifasciatus	0.029	0.009 (± 0.007)	1.83	0.71 (± 0.92)
Mulloidichthys vanicolensis	0.003	0.003	0.02	0.121
Parupeneus cyclostomus	0.004	0.002 (± 0.004)	0.35	0.20 (± 0.31)
Parupeneus barberinus	0.008	0.002 (± 0.003)	1.35	0.39 (± 0.98)
Mulloidichthys flavolineatus (HTS)	0.011	0.002 (± 0.003)	0.50	0.16 (± 0.18)
Parupeneus indicus (HTS)	0.00004	0.0004	0.002	0.051

HTS = highly targeted species.

The Caesionidae (fusiliers) is a small family of fish that are close relatives of snappers. They typically congregate in large, fast-swimming zooplankton-feeding aggregations in mid-water along outer reef slopes. Such schools often consist of mixed species. All six of the reef-related species previously recorded for Tonga (Randall et al. 2003) were observed during this survey. In addition, *Caesio lunaris* was recorded for the first time in Tonga and its geographical range is now extended.

Figure 10.3. *Caesio lunaris* (photo by Karen Stone).

Fusiliers were observed at 44.4% of the sites surveyed. Because they form large schools, they represented the third biggest density and fourth biggest biomass recorded with 11.09% of the total mean density (0.079 ± 0.13 fish/m²) and 7.2% of the total mean biomass (12.6 ± 39.64t/km²). The highest density and biomass by far were recorded for the species *Caesio caerulaurea* (scissortail fusilier, Huli) which was observed at 25.9% of the sites in schools of up to 250 individuals. These schools are quite small compared to the schools of thousands of individuals that can be seen on other reefs in the region. Counting all species together, schools observed ranged from 20–40 individuals to 120–250 individuals. The second most abundant species recorded was *Pterocaesio tile* (neon fusilier, Huli) which was present at 29.6% of the sites with the biggest school observed consisting of 120 individuals. The other species were much less abundant, observed at only one or two sites in schools not bigger than 40 individuals. This included the highly targeted species *Pterocaesio digramma* (twostripe fusilier, Huli).

Table 10.10. Mean biomasses and mean densities of the main Caesionidae species. Values found during the SPC assessment in 2004(Kulbicki 2004) are presented for comparison.

Species	Mean density recorded in 2004 (fish/m²)	Mean density recorded in 2014 (fish/m²)	Mean biomass recorded in 2004 (t/km²)	Mean biomass recorded in 2014 (t/km²)
Caesio caerulaurea	0.008	0.05 (± 0.09)	0.05	3.93 (± 7.98)
Pterocaesio tile	0.034	0.02 (± 0.04)	0.16	0.82 (± 1.52)
Pterocaesio trilineata	–	0.002 (± 0.005)	–	7.09 (± 36.53)
Caesio lunaris	–	0.003 (± 0.014)	–	0.21 (± 0.92)
Pterocaesio digramma (HTS)	–	0.003	–	0.53

– no data or value available. HTS = highly targeted species.

The Lutjanidae family (snappers) comprises species that mostly feed on crustaceans and fish but can also be planktivores (genus *Macolor*, Tukukumoana). Generally living or feeding on or next to the substrate bottom, they can be found down to depths of about 450 m. A total of ten species of the 24 reef-related species previously recorded for Tonga (Randall et al. 2003) was observed during this survey. Snappers were observed at 85% of the sites and represented the fourth biggest density and third biggest biomass recorded during this survey with 29.75 ± 87.87t/km² (17% of the total mean biomass) and 0.072 ± 0.19 fish/m² (10% of the total mean density), respectively. However, these high values are mainly due to large schools (up to 250 individuals) of the two species *Lutjanus kasmira*(highly targeted species, bluestriped snapper, Fate) and *Lutjanus gibbus* (humpback snapper, Fate) observed at two sites: Fonualei and Joe's Spit. These aggregations were suspected to be for spawning purposes as specific colours patterns and behaviours were observed for some individuals and density was particularly high. Without these two sites, biomass and density of snappers drop down to 3.48% of the total mean biomass and 1.48% of the total mean density. Even without considering these aggregation sites, the two species mentioned together with the species *Lutjanus bohar* (twinspot snapper, Fangamea) presented the highest densities of snappers for the Vava'u group of islands. Present at 55% of the sites surveyed, the species *Lutjanus bohar* was the most frequent while *Lutjanus kasmira* and *Lutjanus gibbus* were observed on only 18.5% and 37% of the sites respectively. Other highly targeted species such as *Aprion virescens* (jobfish, Utu) and *Lutjanus fulvus* (blacktail snapper, Fate) were observed at only a few sites and generally individually or in small groups (up to 12 individuals).

Table 10.11. Mean biomasses and mean densities of the main Lutjanidae species. Values found during the SPC assessment in 2004 (Kulbicki 2004) are presented for comparison.

Species	Mean density recorded in 2004 (fish/m²)	Mean density recorded in 2014 (fish/m²)	Mean biomass recorded in 2004 (t/km²)	Mean biomass recorded in 2014 (t/km²)
Lutjanus kasmira (HTS)	0.042	0.035 (± 0.094)	0.05	7.69 (± 23.62)
Lutjanus gibbus	0.005	0.023 (± 0.06)	1.09	10.40 (± 35.32)
Lutjanus bohar	0.003	0.004 (± 0.006)	0.90	6.04 (± 15)
Macolor macularis	–	0.003 (± 0.009)	–	1.65 (± 5.7)
Lutjanus fulvus(HTS)	0.008	0.002 (± 0.004)	1.02	0.35 (± 0.419)
Aphareus furca	0.003	0.002 (± 0.003)	1.59	0.65 (± 1.24)
Macolor niger	0.005	0.001	0.64	1.48
Aprion virescens(HTS)	0.000	0.001 (± 0.002)	0.41	1.30 (± 2.17)
Lutjanus monostigma	0.002	0.0004 (± 0.001)	0.28	0.19 (± 0.256)

– no data or value available. HTS = highly targeted species.

The Serranidae family (groupers) is a set of bottom-dwelling predator species that feed on crustaceans and fish, and are highly commercial food fish. A total of 17 of the 37 reef-related species previously recorded for Tonga (Randall et al. 2003) was observed during this survey. Groupers were observed at 96.8% of the sites but only a few individuals were spotted at each site. The family represented 2.64% of the total mean biomass (4.62 ± 6.93 t/km^2) and 3.14% of the total mean density (0.022 ± 0.05 fish/m^2) with a predominance of the genera *Cephalopholis* and *Epinephelus*. The highest densities and biomasses were recorded for the two species *Cephalopholis urodeta* (darkfin hind, Ngatala Kuda) and *Epinephelus fasciatus* (blacktip grouper, Ngatala) observed at 63% and only 11% of the sites, respectively. The blacktip grouper was observed only at the two remote sites of Fonualei north and Joe's Spit. Fish were suspected to be forming spawning aggregations as density was particularly high (up to 41–120 individuals spotted) and individuals were displaying special colours patterns and showing mating behaviours. Without these two sites, biomass and density of groupers drop to 1.1% of the total mean biomass and 0.82% of the total mean density which is very low. Only solitary individuals of the Vulnerable species *Plectropomus laevis* (blacksaddle coral grouper, Ngatala Kuli) were observed at 29% of the sites surveyed while the Near Threatened species *Plectropomus leopardus* (coral trout, Ngatala Kuli), *Epinephelus polyphekadion* (camouflage grouper) and *Epinephelus fuscoguttatus* (brown-marbled grouper) were only spotted once. According to the discussion and review with the fisheries' officers, no species is particularly more targeted than any other within this family.

Table 10.12. Mean biomasses and mean densities of the main Serranidae species. Values found during the SPC assessment in 2004 (Kulbicki 2004) are presented for comparison.

Species (IUCN status)	Mean density recorded in 2004 (fish/m^2)	Mean density recorded in 2014 (fish/m^2)	Mean biomass recorded in 2004 (t/km^2)	Mean biomass recorded in 2014 (t/km^2)
Epinephelus fasciatus	0.004	0.012 (± 0.03)	0.196	1.85 (± 2.58)
Cephalopholis urodeta	0.011	0.007 (± 0.005)	0.800	0.68 (± 0.75)
Variola louti	0.005	0.001 (± 0.001)	3.900	0.65 (± 0.74)
Cephalopholis argus	0.008	0.0009 (± 0.001)	1.385	0.53 (± 0.56)
Epinephelus merra	0.022	0.0003 (± 0.0007)	0.826	0.058 (± 0.11)
Plectropomus laevis (VU)	0.001	0.0003	1.234	0.43 (± 0.79)
Epinephelus fuscoguttatus (NT)	–	0.00007	–	0.13
Plectropomus leopardus (NT)	0.002	0.00007	0.887	0.06
Epinephelus polyphekadion (NT)	0.001	0.00007	0.254	0.08

– no data or value available. IUCN status whererelevantis given in brackets next to the species names: NT = Near Threatened, VU = Vulnerable.

The Holocentridae family which includes the squirrelfish and soldierfish is a group of mostly nocturnal fish. Usually cryptic during the day, they hide in crevices or beneath ledges of reefs. It is thus difficult to record all the squirrelfish and soldierfish that are on transects. Soldierfish feed mainly on large zooplankton whereas squirrelfish feed on benthic invertebrates and small fishes. A total of 17 of the 27 reef-related species previously recorded for Tonga (Randall et al. 2003) were observed during this survey. The family was observed at 74.1% of the sites and contributed 3.44% of the total mean density (0.024 ± 0.05 fish/m^2) and 1.78% of the total mean biomass (3.12 ± 6.85 t/km^2) but these numbers might be slightly underestimated. A predominance in density of fish genera *Sargocentron* and *Myripristis* was noted. The highest densities and biomasses were recorded for the two carnivore species *Sargocentron caudimaculatum* (silverspot squirrelfish, Telekihi) and *Neoniphon sammara* (spotfin squirrelfish, Telekihi), observed at 37% and 22% of the sites respectively. These were followed by the three species *Myripristis kuntee* (shoulderbar Soldierfish, Malau), *Myripristis berndti* (big-scale soldierfish, Malau) and *Sargocentron spiniferum* (highly targeted species; sabre squirrelfish, Taa), observed at 29.6%, 33.3% and 51.9% of the sites respectively. Although as noted this species can be difficult to spot during transect counts, particularly high densities were observed on big bommies or coral patches with higher structural complexity like the ones observed at Fangasito and 'Euaiki.

Table 10.13. Mean biomasses and mean densities of the main Holocentridae species. The values found during the SPC assessment in 2004 (Kulbicki 2004) are presented for comparison.

Species	Mean densities recorded in 2004 (fish/m^2)	Mean densities recorded in 2014 (fish/m^2)	Mean biomass recorded in 2004 (t/km^2)	Mean biomass recorded in 2014 (t/km^2)
Sargocentron caudimaculatum	0.001	0.007 (± 0.025)	0.15	0.41 (± 1.18)
Neoniphon sammara	0.018	0.005 (± 0.006)	0.54	0.32 (± 0.40)
Myripristis kuntee	0.005	0.003 (± 0.007)	0.38	0.39 (± 0.92)
Myripristis berndti	–	0.002 (± 0.005)	–	0.75 (± 1.85)
Sargocentron spiniferum (HTS)	0.010	0.002 (± 0.003)	1.77	0.62 (± 1.58)

– no data or value available. HTS = highly targeted species.

10.4.4. TWO FAMILIES RARELY SEEN (LETHRINIDAE AND SIGANIDAE)

The Lethrinidae (emperors) is a family of bottom-feeding, carnivorous coastal fish, ranging primarily on or near reefs. They typically feed primarily at night on benthic invertebrates, fish or hard-shelled invertebrates. They can be solitary or schooling and do not appear to be territorial. A total of eight of the 15 reef-related species previously recorded for Tonga (Randall et al. 2003) was observed during this survey. The family was observed at77.8% of the sites and contributed 1.41% of the total mean density (0.01 ± 0.01 fish/m^2) and 2.55% of the total mean biomass (4.46 ± 7.14 t/km^2), with a large predominance of the species *Monotaxis grandoculis* (big-eye bream, Mumea) that were always found in groups at 74.1% of the sites surveyed. This was followed by the species *Gnathodentex aureolineatus* (striped large-eye bream) that was observed at 14.8% of the sites. *Lethrinus* species were found in very low densities as only a few individuals (from one to four) were spotted atless than 20% of the sites surveyed. It is probable that more fish might be present in deeper water or in other habitats such as seagrass beds.

Table 10.14. Mean biomasses and mean densities of the main Lethrinidae species. Values found during the SPC assessment in 2004(Kulbicki 2004) are presented for comparison.

Species	Mean density recorded in 2004 (fish/m^2)	Mean density recorded in 2014 (fish/m^2)	Mean biomass recorded in 2004 (t/km^2)	Mean biomass recorded in 2014 (t/km^2)
Monotaxis grandoculis	0.037	0.005 (± 0.006)	2.81	2.84 (± 6.13)
Gnathodentex aureolineatus	0.007	0.003 (± 0.01)	0.13	0.47 (± 2.12)
Lethrinus obsoletus (HTS)	0.006	0.0005 (± 0.0007)	0.82	0.11 (± 0.24)
Lethrinus olivaceus (HTS)	0.001	0.0005 (± 0.0003)	0.27	0.99 (± 2.28)

HTS = highly targeted species.

The Siganidae family (rabbitfishes) is another dominant group of herbivores observed in Vava'u. They are diurnal herbivores that feed on benthic algae in large schools or small groups. A total of five of the seven reef-related species previously recorded for Tonga (Randall et al. 2003) was observed during this survey. The family was observed at 59.3% of the sites surveyed and contributed only 1.07% of the total mean density (0.008 ± 0.007 fish/m^2) and 0.6% of the total mean biomass (1.05 ± 1.56 t/km^2). Large schools of these fish can usually be seen on the reefs, however during this survey only small (two to five individuals) to medium (up to 20 individuals) sized schools were observed. The species *Siganus doliatus* (goldspotted rabbitfish, Pongpongo) was the most abundant, present at 33.3% of the sites surveyed, followed by the species *Siganus argenteus* (highly targeted species; forktail rabbitfish, Maava) at 22.2% of the sites.

Table 10.15. Mean biomasses and mean densities of the main Siganidae species. Values found during the SPC assessment in 2004(Kulbicki 2004) are presented for comparison.

Species	Mean density recorded in 2004 (fish/m²)	Mean density recorded in 2014 (fish/m²)	Mean biomass recorded in 2004 (t/km²)	Mean biomass recorded in 2014 (t/km²)
Siganus argenteus (HTS)	0.017	0.002 (± 0.006)	0.61	0.24 (± 0.55)
Siganus doliatus	0.019	0.003 (± 0.003)	0.58	0.22 (± 0.11)
Siganus punctatus	0.002	0.0009 (± 0.001)	0.39	0.50 (± 0.81)

HTS = highly targeted species.

10.4.5. THE APEX PREDATORS

Apex predators are large piscivore species which have a slow growth rate, are at the top of the food web and have a very few predators. Very few of them were observed during the survey. No large groupers, only one jobfish and one Spanish mackerel and a few solitary barracudas besides a school of 50 individuals spotted on Joe's Spit were observed. Regarding the sharks, as mentioned above, only about 15 individuals were observed and these were mainly white-tip sharks.

The Carangidae family, which includes jacks, pompano and runners, are fast swimming predators usually patrolling above the reef and in the open sea. Some root in sand for invertebrates and fishes. They were the most common apex predators seen on Vava'u's reefs but they were not found to be really abundant. A total of eight of the 30 reef-related species previously recorded for Tonga (Randall et al. 2003) was observed during this survey. The family was observed at 44.4% of the sites surveyed and contributed only 0.16% of the total mean density (0.008 ± 0.007 fish/m²) and 1.1% of the total mean biomass (1.93 ± 5.48 t/km²). The genera *Caranx* was dominant and was almost the only one observed on transects. The species *Caranx melampygus* (bluefin trevally, Lupo) was the most abundant and was observed at 33.3% of the sites. The two species *Elagatis bippinulata* (rainbow runner, Utu mea) and *Caranx ignobilis* (giant trevally, Tafaula) were observed only once each. The five other species of jacks including the highly targeted species *Caranx lugubris* (black trevally, Tafauli) were observed only once or twice each and always out of transects.

Table10.16. Mean biomasses and mean densities of the main Carangidae species. Values found during the SPC assessment in 2004 (Kulbicki 2004) are presented for comparison.

Species	Mean densityrecorded in 2004 (fish/m²)	Mean densityrecorded in 2014 (fish/m²)	Mean biomass recorded in 2004 (t/km²)	Mean biomass recorded in 2014(t/km²)
Caranx melampygus	0.005	0.0008 (± 0.001)	2.16	0.56 (± 0.76)
Caranx ignobilis	–	0.0001	–	1.15
Elagatis bippinulata	–	0.0002	–	0.21

– no data or value available.

Size analysis

The existing information in reference databases onmaturity size is very limited, despite the fact that this parameter is critical with regards to conservation strategies. Data on maturity length for a limited number of species were provided by the fish specialist M. Kulbicki. This information was available only for 74 of the 175 species (42.3%) for which the size was recorded during this survey.

Using this information, a size analysis was performed on species for which at least 10 individuals were recorded. Results revealed that 20 species presented, on average, sizes smaller than or equal to the minumum maturity length (MML). These species belonged to the following families: Lutjanidae (one species), Serranidae (one species), Carangidae (one species), Aulostomidae (one species), Acanthuridae (three species), Scaridae (two species), Labridae (two species), Mullidae (two species), Siganidae (one species), Holocentridae (two species) and Chaetodontidae (four species). It is important to note that the difference between the MML and the average size recorded is sometimes small (1–3cm) and corresponds to the acceptable limits of size estimation as described in the methodology. In this case, the average size may have been slightly underestimated and may in reality be equal to or slightly higher than the MML. The fishes observed remain small though. Of the 20 species, five had a maximum size smaller than the MML. This means that none of the individuals observed of the following species were able to reproduce: *Naso hexacanthus* (Acanthuridae, sleek unicornfish, Ume Atu), *Scarus ghobban* (Scaridae, blue-barred parrotfish, Olomea), *Epibulus insidiator* (Labridae, sling-jaw wrasse), *Mulloidichthys vanicolensis* (Mullidae, yellowfin goatfish, Vete) and *Myripristis murdjan* (Holocentridae, pinecone soldierfish, Malau). Figure 10.4 highlights these results (Chaetodontidae were removed from the graphic).

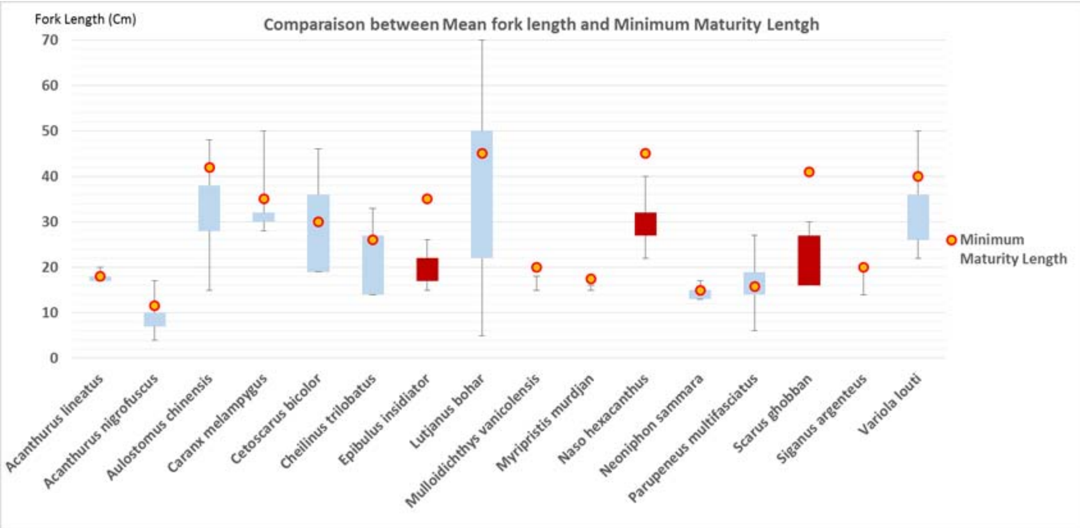

Figure 10.4. Sizeclasses distributions for the species with mean fork length less than or equal to the minimum maturity length (MML). The spots represent the MMLs. The boxes represent the range of sizes recorded. The boxes in red highlight the species for which no individuals bigger than the MML were recorded during the survey. The upper bar represent the biggest individual recorded, and the lower bar represents the smallest individual recorded.

In addition to these main observations, it was also noted that for the parrotfish *Chlorurus microrhinos*, all the individuals spotted were smaller than the supposed common 'male size', i.e. 49cm(Myers 1999). Complex mechanisms such as genetic loss as well as more intrinsically biological factors can influence size, but these observations are nonetheless cause for concern and indicate possible issues that may affects future generations.

Small sizes were also observed in a wider range of species but where fewer than ten individuals were observed. However, it should also be noted that some species use different habitat types at different life stage, which may have contributed to observations of only small fish. Further investigations should be undertaken to confirm the trends observed and draw more precise conclusions.

Trophic structure analysis

To better understand the balance in fish communities from an ecosystem perspective, and to provide the basis for conservation recommendations, the following presents the distribution of the main trophic groups in the fish population (Figure 10.5).

Herbivores (surgeonfish, parrotfish, rabbitfish and chubs) feed on algae turf, macroalgae and cyanobacteria. They are by far the most abundant group found on Vava'u's reefs. They represent 39.2% of the total mean biomass with 68.7 t/km^2 and 41.1% of the total mean density with 0.3 fish/m^2. The planktivores (surgeonfish, triggerfish, fusiliers, soldierfish, squirrelfish, snappers, butterflyfish and sweepers) feed on plankton in the water column. They are the second most important group observed during this survey, representing 22.6% of the total mean density with 0.16 fish/m^2 and 18.1% of the total mean biomass with 31.7 t/km^2. Carnivores (small trevallies, soldierfish, squirrelfish, emperors, small snappers, goatfish, small groupers and others) are predators that feed on crustaceans, shells and small fish. Their mean density is slightly lower than the planktivores, representing 21.7% of the total mean density with 0.15 fish/m^2, but as some larger sized species are in this group, their mean biomass is bigger and represents 27.5% of the total mean biomass with 48.19 t/km^2. The piscivores include larger predators (trevallies, large snappers, large groupers, sharks and others) that feed exclusively on other species of fish. This group is particularly sensitive to fishing pressure as fishers usually target larger fish which have higher value in the markets. As shown in Chapter 9, this group represents only 2.3% of the total mean density with 0.017 fish/m^2 and9.3% of the total mean biomass with 16.28 t/km^2 (sharks included). As an observation, when the two spawning aggregation sites are removed from the analysis, total mean density for carnivores drops to only 14.8% of the total while that for herbivores rises to 48% and for the other group it is not much affected. This further highlights the great dominance of herbivory on Vava'u's reefs. As a comparison, the sites of Joe's Spit and Fangasito, which are considered the most balanced reefs in this survey, have total mean densities for piscivores species of 7.14% and 4% respectively and total mean biomasses of carnivores species of 60.15% and 24%.

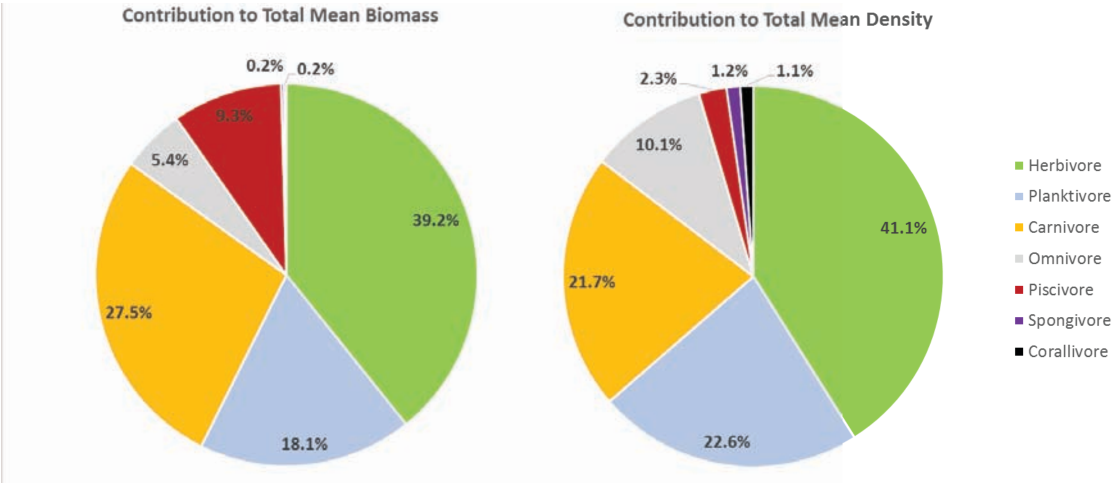

Figure10.5. Contribution (%) of diet groups to the total mean density and biomass.

10.4.6. COMPARATIVE STUDY OF LOCATIONS

Tables 10.17 and 10.18 provide a ranking of the 18 locations and 27 sites surveyed based on the species richness, biomass and density. Table 10.17 presents the species richness for each site to highlight the variability that can exist at a single location. Biomasses and densities are presented as a mean for each location (i.e. one or two sites) in Table 10.18. As conservation will likely focus on locations, this seems more relevant. As the sampling effort is different at the different locations (i.e. either one or two sites), comparison might be slightly biased but we assume this information is accurate enough for conservation recommendations. The Caesionidae were excluded from this analysis because of high numbers in certain areas (with a limited consumption interest), which skews comparison between sites. The Carcharhinidae family was also excluded as their large size can skew the comparison of biomass between sites.

From a fisheries conservation perspective, indices such as species richness, density and biomass are essential but not sufficient to make informed decisions and ensure the sustainability of fisheries. Other factors related to the life history and ecological traits of the species also need to be taken into account. For example, while spawning aggregation sites are essential for reproduction which ensure stock recovery, the sizes of fish also matter, not only as an indicator of maturity but also in terms of productivity as bigger fish will produce more gametes. Therefore the comparison between locations below consider the following:

- Average ranking of biomass/density (for targeted and highly targeted species): the average between the rank of total mean biomass and the rank of total mean density for a site;
- Average ranking of biomass/density (for piscivore and carnivore species);
- Maximum species richness (for targeted and highly targeted species): for locations with two sites, the one with the greatest species richness was used;
- Average fork length (for targeted and highly targeted species): the average sizes of the fish belonging to the 15 main families found on a location;
- Potential spawning aggregation ground: based on underwater observations during this survey;
- Presence of Emblematic (Popular, easily recognised) and Endangered or Vulnerable species (IUCN Redlist).

Four main groups of sites can be identified and compared for guidance regarding conservation priorities: (1) distant and remote sites; (2) associated sites; (3) the exposed east coast and (4) the threatened centre.

Table 10.17. Ranking of the 27 sites for species richness in descending order.

Island/location	Site	Species richness
Toku Island	Site 8 Joe's Spit	83
'Euakafa Island	Site 23 'Euakafa Island north	82
Maninita Island	Site 13 Maninita Island outside	68
Fangasito	Site 18 Fangasito Island south	66
Toku	Site 7 Toku Island north	63
'Euaiki Island	Site 25 'Euaiki Island west	59
'Onetale Bay, Vava'u Lahi	Site 10 Onetale Bay	58
'Euakafa Island	Site 22 'Euakafa Island south	58
Maninita Island	Site 12 Maninita Island inside	54
Fonualei Island	Site 5 Fonualei Island south	54
Fenua'one'one Island	Site 16 Fenua'one'one Island south	54
Vaka'eitu Island	Site 26 Vaka'eitu Island	54
'Euaiki Island	Site 24 'Euaiki Island east	54
'Oto Island	Site 21 'Oto Island	53
Mata'utuiliki Island	Site 9 Mata'utuiliki Island	53
Taula Island	Site 15 Taula Island outside	53
Lotuma Island	Site 1 Lotuma Island	51
Umana Island	Site 11 Umana Island	50
Taula Island	Site 14 Taula Island inside	49
A'a Island	Site 20 A'a Island	47
Mount Talau, Vava'u Lahi	Site 3 Mount Talau	43
Lotuma Island	Site 2 Lotuma Island channel	43
Langito'o Island	Site 27 Langito'o Island	42
Fangasito Island	Site 19 Fangasito Island north	41
Fenua'one'one Island	Site 17 Fenua'one'one Island north	37
Toku Island	Site 6 Toku Island south	36
Fonualei Island	Site 4 Fonualei Island north	28

Table 10.18. Ranking of the 18 locations for density and biomass in descending order.

Site	Total mean density (fish/m²)	Site	Total mean biomass (t/km²)
Toku Island, Joe's spit	1.822	Toku Island, Joe's spit	1,315.35
'Euaiki Island	0.797	'Euaiki Island	242.69
'Euakafa Island	0.764	Maninita Island	212.14
Fangasito Island	0.717	Fonualei	207.12
Toku Island	0.705	'Euakafa Island	158.92
Fonualei Island	0.703	Mata'utuiliki	136.00
Umana Island	0.612	Fangasito Island	106.00
Maninita	0.61	Langito'o	97.17
Onetale bay	0.61	Toku Island	89.85
Mata'utuiliki	0.584	Umana Island	86.97
Taula Island	0.54	A'a Island	82.70
'Oto Island	0.514	Taula Island	78.19
Langito'o Island	0.478	Onetale bay	68.97
A'a Island	0.46	Vaka'eitu Island	68.93
Lotuma Island	0.431	'Oto	66.02
Fonua'one'one Island	0.362	Mount Talau	52.04
Vaka'eitu Island	0.352	Lotuma Island	43.38
Mount Talau	0.346	Fonua'one'one Island	41.58

Distant and remote sites

The reefs located on Joe's Spit (Toku Island), Fangasito, Maninita and 'Euakafa stand out as the sites with the most diverse, abundant and best balanced communities of fish. These four sites have the four greatest species richness (out of five) including the two highest species richness of highly targeted species. The greatest numbers of emblematic and IUCN red-listed species were also observed at these sites. Regarding the composition of fish communities, these sites presented the three greatest proportions (out of five) of piscivores and carnivores indicating well balanced communities. Also, the fish observed were bigger with the average fork lengths measured for both targeted and highly targeted species being the three largest records (out of five). All these sites are either remote from the main group of islands (Joe's Spit) or in the south of the main group of islands, distant from villages (Fangasitoand Maninitaislands) except 'Euakafa Island which is located within two nautical miles from the nearest village (Taunga).

Within this group of sites, one stands out as the healthiest and richest site: Joe's Spit, an isolated and remote reef located near to Toku Island. For almost all the indices calculated (excluding maximum richness of highly targeted species and the rank biomass/density for piscivores), the reef presents the highest values with by far the biggest quantity of fish (even when excluding the species aggregated for spawning purpose from the analysis). In addition the site represents a potential spawning aggregation ground for the species *Lutjanus kasmira* (highly targeted species, bluestriped snapper, Fate), *Lutjanus gibbus* (humpback snapper, Fate) and *Epinephelus fasciatus* (blacktip grouper, Ngatala), and probably for many more species. The highest proportion of emblematic and IUCN red-listed species was observed here together with the island of Maninita, including apex predators such as the greyreef and white-tip sharks, groupers such as the blacksaddle coral grouper and the coral trout and the emblematic humphread wrasse.

The three islands of Fangasito, Maninita and 'Euakafa reach the same score for this ranking comparison exercise but slightly differ in their profiles.

Fangasito and Maninitaare located in the southern part of the main group of islands in Vava'u. Under direct oceanic influences, both are located close to other islets (Fonua'one'one and Taula) but Maninita Island is surrounded by a greater reef network. Even if the two sites do not present the same outstanding quantity of fish as found at Joe's Spit, they still have high densities and biomasses with the fourth and fifth greatest value for biomass/density for Fangasito and Maninita respectively. A good diversity of species was also recorded on both sites even considering the highly targeted species for which Fangasito was the second richest site. It is important to note that this diversity was found on the outer reef sites (site 13 and site 18). The fish communities observed on both locations were quite balanced regarding the trophic groups, in particular with the fourth and fifth best proportions of piscivore species. Both sites present a good proportion of emblematic and IUCN listed species including apex predators such as the white-tip shark, groupers such as the blacksaddle coral grouper, the coral trout or the camouflage grouper and the emblematic humphread wrasse. The distance separating these sites from the nearest villages (eight to ten miles from Ovaka or Taunga) may contribute to reduced the fishing pressure. Indeed, the averages sizes of targeted species were the third largest on Maninita Island while the sizes of highly targeted species were the fourth and the fifth largest respectively on Fangasito Island and Maninita Island.

Of the sites in this group, 'Euakafa Island is the nearest to villages with Taunga being two nautical miles and Ovaka eight to ten miles. Surrounded by a network of islets (the closest being 'Euaiki) right next to a large reef patch (including Ovaka, Langakali, Ovalau and Mounu), this site presented the third best ranking of biomass and density of fish with a great diversity of fish for both targeted and highly targeted species. This was the second richest site of this survey and had the greatest number of highly targeted species. Although probably subjected to fishing pressure, as fish sizes recorded were not of the biggest, and similarly the quantity of highly targeted species and the proportion of piscivore species, the site remains in quite good condition with a good proportion of carnivore species (ranking fourth) and the presence of emblematic and IUCN listed species.

Associated sites

This group includes a set of sites in good condition (apart from 'Euaiki Island) but without much remarquable features regarding the diversity, quantity of fish and balance within communities. Each one of these sites can however be coupled to one of the sites described previously as they are geographically closed-by. This can have interesting implication for marine protected area (MPA) network and conservation planning at the seascape scale.

Fonualei and Toku islands are remote from the main group of islands in the same area as Joe's Spit. Fonualei Island is a volcanic site with very little coral cover and very specific habitats of black sand, rocks and rubble which may reduce the number of species and quantity of fish that are found there. Indeed, the density and biomass values found at the site and presented in Table 10.18 were in great part due to the aggregation of three species for spawning purpose (*Epinephelus fasciatus*, *Lutjanus kasmira*and *Lutjanus gibbus*), making this site interesting in terms of conservation as, along with Joe's Spit, these are the only potential spawning grounds observed during this survey. However, without these three species, the site has a low quantity of fish. As it is distant from the main island of Vava'u, the fishing pressure may be reduced. Indeed fish of both targeted and highly targeted species had the second largest sizes recorded during this survey, and the quantity of highly targeted species was the second highestafter Joe's Spit. Emblematic and IUCN red-listed species were also observed at this site.

Together with Fonualei Island and Joe's Spit, Toku Island could be considered as part of a network of remote sites for conservation purposes. With very bad reef conditions and very low coral coverage leading to bare habitats with low food supply, the quantity of fish found on the site was reduced and unbalanced compared to the sites described above. Indeed, the lowest proportion of carnivore species of the whole survey was recorded here. The quantity of highly targeted species was particularly low (fifth lowest) although they had the third biggest sizes on average. The density recorded on the site was the fifth highest of the survey (see Table 10.18), but almost entirely constituted of juveniles. Overall diversity of species was the fifth highest. Emblematic and IUCN red-listed species were also observed on this site.

Located right next to 'Euakafa Island which was one of the most interesting sites surveyed, 'Euaiki Island is notable only for its quantity of fish which was the second highest ratio of biomass/density after Joe's Spit. Emblematic and IUCN red-listed species were also observed on this site. Apart from this, the location does not hold much interest.

Located next to Maninita Island which was also one of the most interesting locations surveyed, Taula Island doe snot present any particularly good attributes despite the presence of emblematic and IUCN listed species. The site presented the third smallest sizes of highly targeted species recorded during this survey.

As for Taula Island, Fonua'one'one Island is located right next to one of the most interesting sites surveyed (Fangasito Island) but doesnot share the same characteristics at all. On the contrary, all the species (including the highly targeted species) presented the fifth lowest biomass/density ranking for as well as the fifth smallest sizes average. Despite a high proportion of piscivore species, probably due to its seaward location, the site has characteristics indicative of an out-of-balance or poor community of fish.

The exposed east coast

The eastern sites of Umana, Mata'utuiliki and Onetale Bay are localised along the cliffs of Vava'u's main island and Umana Island and are exposed to waves and strong hydrodynamic energy most of the year. With these conditions, these sites are characterised by a low diversity of species with the lowest diversities of highly targeted species recorded at Umana Island and Mata'utuiliki. However, these locations were also characterised by the third (Mata'utuiliki and Umana) and fourth (Onetale bay) highest quantities of highly targeted species, which may be explained by the difficult access for fishers to these sites most of the time (because of distance and sea conditions). Aside from these common characteristics, the three sites presented quite different profiles.

Despite a low species richness, the site of Umana Island presents quite good characteristics with the fifth best proportion of piscivore species and the fourth highest average sizes.

Mata'utuiliki is the northern most location surveyed in the main island of Vava'u and hasno villages nearby. This site is probably the most exposed to strong hydrodynamic conditions which may contribute to the low values found at the site for the various indices. Indeed, the site had the fourth worst proportion of carnivore species probably due to very low coral coverage and highly bare habitats with low food supply, as seen for Toku Island.

Of these three locations, Onetale Bay was the one with the worst characteristics, with the second lowest proportion of piscivore species and more importantly, very small-sized fish with overall size average the fourth smallest and second smallest for targeted and highly targeted species respectively.

The threatened centre

Located in the central part of the Vava'u main group of islands and within two nautical miles of up to three villages, the reefs located at'Oto island, Mount Talau, Langito'o Island, A'a Island, Lotuma Island and Vaka'eitu Island stand out as the sites with the least diverse, least abundant and the most unbalanced communities of fish. Indeed, together these six locations present the four lowest species richness values (out of five) and the four lowest quantities of fish (out of five), including the three lowest quantities of highly targeted species. A'a Island had the lowest species richness of highly targeted species. Regarding the compositions of fish communities, these sites present the four and the three lowest proportions (out of five) of piscivore and carnivore species indicating unbalanced communities. The fish observed on 'Oto Island, Mount Talau and Lotuma Island were smaller with the average fork lengths measured for targeted species the three smallest (out of five). One exception is A'a Island where the average fish size was the fifth biggest. Vaka'eitu Island stands out as the worst site of the whole survey. The site is located in the south of the group of islands and presented a very healthy reef with high coral coverage and no signs of significant fishing activities (lines or anchorages). However, almost no fish were found on the reef apart from parrotfishes, surgeonfishes and butterflyfishes. Although this is concerning, it is difficult to explain.

A combination of factors may explain the poor results from this group of sites, including but not limited to higher fishing pressure due to the sites' proximity to villages; poor environmental conditions due to watershed influences, waste water and rubbish; and reduced hydrodynamic activity to help renew water quality.

10.5. Discussion

Vava'u is located in the northern part of Tonga and has a network of over 50 islands and reefs which are mainly subject to oceanic influences, with coastal influences (wastewater, sewage and runoff) limited to the main island, its neighbouring islands and the few inhabited islands. As also shown in other chapters of this BIORAP, the reefs of Vava'u were found to be generally healthy with few visual signs of apparent fishing activities (lines, anchorages, and only a few fishing boats observed during the survey). Vava'u appears to have rich fish communities, with findings indicating that most of the dominant fish families generally found in the Pacific are present in Vava'u. A great diversity of species was recorded and spawning aggregations observed.

However, several factors appear to be affecting fish composition in Vava'u. The coexistence of multiple species within a trophic level can be a result of, for example, competition for space and food, predation, resource availability, and environmental conditions (Tilman 1977; Emery et al. 2001; Gross et al. 2001; del-Val and Crawley 2005). In nearshore marine communities, patterns of species coexistence are temporally and spatially dynamic, with fluctuations often occurring following ecosystem-level changes such as natural disturbances like storms (Fourqurean and Rutten 2004) and anthropogenic impacts like overfishing of top predators(Jackson et al. 2001) and coastal nutrient enrichment (Cardoso et al. 2004). As it will be further discussed, overfishing actually seems to be the main factor impacting the fish communities of Vava'u.

10.5.1. FEW SPECIES AVAILABLE FOR FISHING

Previous studies are extremely limited and it is therefore impossible to identify any trends in the quantity of fish for the archipelago overtime. However, there are indications that we should be concerned for the fish community of Vava'u. A large number of fish species were found on half or less than half of the sites surveyed. Only the most abundant species were observed on almost all the sites surveyed, comprising only seven species.

As a comparison, in 1994 the inshore fisheries statistics program of the Ministry of Agriculture & Food, Forests and Fisheries (MAFFF) listed the major reef fish species foundat the domestic markets. These were: unicorn and surgeon fishes (Acanthuridae), squirrelfishes (Holocentridae), wrasses (Labridae), emperors and seabreams (Lethrinidae), seaperches (Lutjanidae), goatfishes (Mullidae), sweetlips (Haemulidae), parrotfishes (Scaridae), rabbitfishes (Siganidae), seapikes (Sphyraenidae), drummerfishes (Kyphosidae), rock-cods (Serranidae), silver-biddy (Gerreidae), triggerfishes (Balistidae), bullseyes (Priacanthidae) and majors (Pomacentridae). A survey conducted in the same year (Lui et al. 1994) indicated that parrotfishes, emperors, rabbitfishes, surgeonfishes, unicornfishes, soldier/squirrelfishes and groupers were the most important families in the shallow-water reef artisanal fishery. Even if these data concern the whole of Tonga, they highly contrast with the results of our survey.

The fish communities in Vava'u are largely dominated by surgeonfishes (Acanthuridae) and parrotfishes (Scaridae), which together constitute half of the overall fish on these reefs. These families were represented by only a small number (two to three main species) of small-sized individuals. Together with two other families (snappers and fusiliers), which were more rarely seen and forming small shoals, these constitute almost three quarters of the overall fish. The other families were represented either by species frequently seen but in very low proportions or species observed anecdotally. While surgeonfishes and parrotfishes were highly dominant on these reefs, snappers, goatfishes, soldiers and squirrels were poorly represented and groupers, emperors, rabbitfishes and jacks were underrepresented. All of these families were mainly represented by only two or three species. Moreover, some families such as the Haemulidae (sweetlips – only three individual spotted during the whole survey) seem to be at the edge of extinction.

From a more practical perspective, while a great diversity of fish have contributed in the past to Vava'u's fisheries and could still do so if properly managed, only a very narrow variety of small-sized and lower commercial values species is currently available for fishing.

10.5.2. SIGNS OF IMBALANCE WITHIN THE TROPHIC STRUCTURE

In coral reef ecosystems, the relationship between algae and corals is characterised by intense competition for space (Knowlton 2001). The grazing action of herbivores curbs algal development and promotes growth and occupation of space by corals (Crossman et al. 2001; Wismer et al. 2009). On the other hand, predation is a well known factor affecting the structure of assemblages through top-down effects (direct and indirect). Apex predators and top predators such as sharks, large groupers, large snappers and jacks feed on the animals below them in the food web. They help to regulate and maintain the balance of marine ecosystems as they directly limit the populations of their prey, which in turn affects the prey species abundance and distribution and ultimately influences the community structure. Comparisons of areas with and without apex predators show that apex predators lead to greater biodiversity and higher densities of fish, while areas without apex predators experience species absences (Sergio et al. 2006). As these species usually have a slow growth and a low reproductive rate when compared to smaller species, overfishing effects can quickly impact their structure and can be easily detected.

A bigger proportion of herbivore species compared to piscivores is a common pattern on most coral reef ecosystems and the fish population of Vava'u observe the same trend. Indeed, herbivores in Vava'u are only represented by four families (surgeonfishes, parrotfishes, chubs (records anecdotic) and rabbitfishes (only observed a few times)) but are by far the most abundant fishes observed. Note that within the herbivores group, the small species were the bigger contributor to this high biomass. The proportions seem then to be unbalanced. Indeed, piscivores and bigger carnivores such as the groupers (Serranidae), snappers (Lutjanidae), jacks (Carangidae) or emperors (Lethrinidae) were observed at very low densities and biomasses. These families were observed in greater abundances on remote and distant reefs and as food source does not appear to be a limiting factor , these observations may suggest a strong influence of fishing pressure on these fish families. Results from other studies in the region confirm that large Serranidae, Lutjanidae and Acanthuridae (*Naso* spp.) dominate under little impact, but small herbivorous species become increasingly dominant as fishing pressure increases (Kronen et al. 2003). In the case of Vava'u the population structure confirm the existence of an important fishin pressure and as substantial increase in catches of parrotfishes, unicornfishes and surgeonfishes have occurred in the past years, even these families have become scarce. Only a few species with fast life history traits remain abundant.

10.5.3. MEAN SIZE REDUCTION

The small sizes observed as a general trend for species belonging to different families highlight fishing pressure across a wide range of species and a general overfishing situation. The mean sizes recorded for at least 20 species, including some belonging to the family of surgeonfishes (Acanthuridae), parrotfishes (Scaridae), goatfishes (Mullidae), snappers (Lutjanidae), groupers (Serranidae), soldier and squirrelfishes (Holocentridae), jacks (Carangidae) and rabbitfishes (Siganidae), were either equal or under the minimum maturity length. This means that most of the fish observed were under the size where they can reproduce. As maturity size data do not exist for all the species observed, this status could cover more species. These observations are even more worrying for fast growing species (parrotfishes). In addition, a great number of species showed a very narrow range of sizes. As several species change sex during their lifetime these trends could highlight an unbalanced sex ratio which can lead to critical situations for conservation of fishes stocks. Also, when considering the quantitative analysis, the few species showing greater abundance were systematically the smaller. This may suggest either (1) only the species with the faster growth rate and reproduction patterns may remain on Vava'u's reef and/or (2) these small-sized species may present lower value for fishing and are less targeted. Fishing typically removes the largest fish first, leaving the small fish, since small fish provide less benefit to fishers.

As the surveys were conducted in shallow water, these observations have to be interpreted with caution as larger individuals may be found in deeper water. However, these conclusions still mean that part of the stock easily accessible to fishermen is impacted at the reproduction level and only small-sized and lower value species remain available. However, given the lack of comparative data, trends cannot be determined.

10.5.4. OVERFISHING IN VAVA'U

The effects of intensive exploitation of fishing stocks are well documented (Gell and Roberts 2003) and lead to:

- Decrease in densities of fish resulting in a decline in the number of catch per unit effort for fishers;
- Decrease of mean sizes of catches, as a result of selective fishing;
- Depletion of the genetic stock and reduced fertility;
- Loss of species and a decline in biodiversity;
- Overfishing, defined as fishing more than the maximum sustainable yield, which means that over the long term fish catches will be smaller than could be sustained with less fishing.

Rapid assessment programmes such as the methodology used here are not intended to accurately determine the status of the resource stocks in the area sampled, or to properly understand the fish population dynamics and how it is affected by external factors. However, these surveys do provide a fairly accurate representation of biodiversity and help to understand the general status of organisms surveyed. The observations discussed above give strong signs of fishing pressure in Vava'u, confirming observations in previous reports.

Although there appears to be a trend of intense fishing pressure on Vava'u's reefs, the fish community does not seem to be affected in the same way around the whole archipelago. More remote and less accessible locations seems to present good quantities and diversities of fish and may be considered as high priority for conservation, and their proper management may also benefit adjacent locations with poorer status. Rules and regulations may however be adopted to ensure proper enforcement of fisheries management at a greater scale. These recommendations are discussed below.

10.5.5. VAVA'U 'S LONG HISTORY OF FISHING.

Understanding the history of fishing at one place help with understanding its current situation and may help with defining conservation strategies. This part aim to briefly summarizs the long history of fishing in Vava'u archipelago.

As across the region, fishing has always been an important subsistence activity for the people of Vava'u with the lagoons and reefs providing an essential source of protein for the communities. The first signs of marine resources exploitation in the Vava'u archipelago date from the Lapita (around 2,700 years ago) and reveals casual harvest of large bodied Serranidae and Lethrinidae, which seem to be at that time the preferred food fish (Densmore 2010). Although at that time the fish assemblages in Vava'u did not indicate an intensive fishery, the temporal patterning indicates a general decrease in fish abundance corresponding to the shift to the Polynesian Plainware Phase (around 1,500 years ago) (Densmore 2010). Over time and during the pre-Christian polytheist religion, traditional fishing practices were part of a strong cultural heritage that was linked to the social structure of communities and at the same time may have provided sustainable use of resources. Several species such as the goatfish or mullets were strongly linked to local beliefs and held in special regard by Tongan fishermen (Bataille-Benguigui 1988). In the 19th century, ownership of fishing rights in Tonga belonged only to people leaving next to fishing ground and remained under the chief control (Malm 2001). This, however, changed with the abolishment of chiefly privileges between 1839 and 1862, and the country's first constitution in 1875. As a result the Tongan community lost any exclusive fishing rights or responsibilities over marine areas and the resources within (Vunisea and Labrosse 2001 in Friedman et al. 2009). The sea and its resources became common property where all people have the right to fish wherever they like and community management controls became limited (Malm 2001).

More recently, reef fisheries in Vava'u have been described as subsistence and small-scale artisanal fisheries best characterised as hand-operated, multi-geared (spear fishing, hand-line fishing, gill and drive-in netting, fish fencing), and multispecies. Fishing is mostly restricted to the local coastal areas, and involves small informal groups of both men and women (Kronen 2002), small fishing vessels (motorised boats and paddling canoes), low capital investment and correspondingly low productivity (Kronen and Samasoni 2006). Even with the change from a barter system to a cash economy, fishery resources have been subjected to increasing pressures (Lui and Bell, 1994), the traditional system of regarding reef fish as a non-monetary commodity prevails in Vava'u (Kronen and Samasoni 2006). Indeed, despite developments including fishing vessel construction, harbours, on-shore market and cool storage facilities (Lui and Bell, 1994) the remoteness of most fishing communities from an urban market reduces the chances for fishermen to be compensated for the additional transport and labour costs required to serve regional rural markets where fish prices are still comparatively low (Kronen and Samasoni 2006). Thereby, a proportion of the catch is consumed by the fisher or shared with his extended family and does not enter the market (Hunt 1997; Tu'avao et al. 1994).

With such a long history of fishing, as the level of exploitation is the dominant factor in structuring the fish populations (Jennings et al. 1998; Russ and Alcala 1998), the increasing human population density combined with degradation of key habitats due to coastal development led to the depletion of resources. As detailed in several studies conducted over the last 20 years, the reef fishes of Tonga are nowadays moderately to seriously overexploited and some species have become less abundant or even scarce while others have decreased in average size (Lui, A. et Bell, J. 1994):

- In the report 'Fisheries resources profiles – Kingdom of Tonga' from 1994, Lui and Bell reported a shift in the fish landing between 1987 when emperors were the main reef fish species caught and 1993 when the parrotfishes became the major fish species landed. They also stated that mullets were believed to be on the verge of extinction.
- In the country report for the Kingdom of Tonga produced by the Secretariat of the Pacific Community in 2004 under the DemEcoFish project and including underwater surveys in Vava'u, the dominance of parrotfishes and surgeonfishes compared to the poor diversity and density of groupers, emperors and sharks was already highlighted. Snappers were stated as very poor. As a global trend, density and length of commercial fishes already indicated moderate to high fishing pressure on the whole area surveyed.
- In 2008, the study 'Shifting dominance among Scarid species on reefs representing a gradient of fishing pressure' conducted by Clua in Vava'u, alerted readers that the Tongan islands had already reached a warning stage with the removal of key parrotfish species.

These observations confirm the trends we observed during this BIORAP.

10.6. Conservation recommendations

"*[There is] an imperative need for us to take immediate and decisive collective action to ensure that we secure our peoples' future livelihoods, regional food security, and the environmental sustainability of our seas and their ecosystems.*" (Pacific Islands Forum, The Vava'u Declaration on Pacific Fish Resources, 2007)

Fish are clearly one of the most important marine resources, particularly for developing countries and Pacific Island nations, as they provide both food and income and contribute to the health and welfare of island communities. Managing the marine resources of Vava'u is not only a matter of environmental conservation but also vital for food security and livelihoods. Management has to be undertaken in a way that ensures a sustainable livelihood for local communities overtime.

EXISTING PLAN AND STRATEGIES

The original legal framework for fisheries management in Tonga was the Fisheries Act 1989, which established a central management authority with powers exercised through the Ministry of Fisheries. This act was updated with the Fisheries Management Act in 2002 to incorporate provisions to govern amongst other things, community-based management and food safety. Rules and regulation that were defined are conventional ones and as efficient as they can be mainly focus on high-seas or deep-bottom fisheries. The ones concerning reef and lagoon resources seem however to have a very limited impact regarding the current status of resources and are definitively insufficient to ensure a sustainable management of Vava'u's fishes' stocks. Results from this study and observations revealed from past studies for 20 years now are urging for a proper enforcement of the Kingdom of Tonga's Reefs and Lagoons Fisheries' Policy.

In a context where compliance and enforcement can be hard to ensure effectively with many reefs and islands constituting much fishing grounds for communities, many Pacific countries including the Kingdom of Tonga adopted a more participative and responsible approach involving communities in the management of their natural heritages. With the support of the Ministry of Lands, Survey and Natural Resources, the Ministry of Fisheries included in the Fishery Management Act enacted in 2002, provisions for the creation of Special Management Areas (SMAs). As defined in the act, an SMA grants a community management control of its inshore resources; in effect, providing a community with the basic tools and skills for better management initiatives. Just like the two SMAs already existing within the Vava'u Archipelago (Ovaka and Taunga communities) and as mentioned later in this document, this management approach and the involvement of communities can only be strongly encouraged to be further developed in a context where fishing remain primarily for subsistence.

The following recommendations will try to suggest realistic management measures to move forward.

Recommendations for further management options

The productive reef fisheries of Vava'u group changed greatly in recent decades as human development and both intensive fishing and reef harvesting increased. Vava'u typifies the increasingly common condition of resource depletion and marine community structure change with expanding human activities and population growth. Even if it is difficult to evaluate the proportion and importance of the decline in fish resources, the results described here and in previous studies strongly suggest declines of specific groups or species and a collapsing fishery around Vava'u Archipelago. As the population is largely dependent on the marine resources for both subsistence and income, there is a strong need for the Tongan Government to take action and adopt strategies to ensure resource maintenance and improvement as well as sustainable exploitation. The following recommendations for management options aim to provide reasonable and relevant guidelines that should be applied overtime.

Immediately reduce fishing pressure and encourage good practices

Fishing gears restriction are usually the easiest way for a government body to reduce fishing pressure as it is easy to control and has no need for strong baseline studies and scientific guidance. Spearfishing at night seems to be a common practice around Vava'u that can have great impacts as most of the fish are sleeping and very easy to catch. Spearfishing is therefore a very selective practice that leads the fishermen to pick fish regarding species and sizes' preferences. This practice should be prohibited.

Spearfishing however concern only a limited part of subsistence fishery while cast nets; drag nets, seine nets, gill nets or handlines are the principal gears used. Following the existing regulation regarding dragnets and seines (mesh size < 38mm), another gear restriction could be applied to gill nets: prohibiting the use of small-sized mesh (under 45mm) for gillnets may be a means to avoid catching the juveniles of several species found on the reefs (e.g. snappers, surgeonfishes, parrotfishes). Usually, smaller mesh sized nets are only allowed for the catch of species such as mackerels or mullets (32mm min), and sardines or anchovies (5mm min). Just like for the fish fence (140m length) a maximum length and width restriction could also be applied for the use of gillnets to reduce the quantity of fishes caught per trip.

In addition to these gear restrictions, restrictions regarding the quantity of fish per person or per boat per trip could be defined. If further stock assessments are needed to properly estimate the available fishing stock for targeted families, however general instructions could be given for the number of fish or the total weight of fish caught per trips. Based on a household's fish consumption survey, basic regulation could be define by the Ministry of Fishery allowing fishermen to catch sufficient fishes for their needs while avoiding excessive catch in the meantime.

As efficient as these global rules and regulations can be, they will necessarily induce a reduction of available resources for fishing that will have impacts on local communities and fishermen. To ensure compliance, people need to see benefits from the strategies that are undertaken and in Vava'u case, more integrated management approach should be promoted as described below.

Further protect reproduction as a critical ecological process to ensure stock recovery overtime

Protecting early life stage and reproduction is essential when considering stock recovery. Sustainable fishing means allowing adult fish to live long enough, and protecting the habitats on which the fish species rely during their different life stages. Numerous species recorded during this survey were under or barely equal to the minimum maturity length (MML). In other words, this means that each fish caught under mml never had a chance to produce offspring to be caught in future years. To protect this critical ecological process, several options can be considered.

The first measure to consider is the minimum size limit. Some of these sizes are presented in this report while others can be found on the online database FishBase (Froese, R. and Pauly, D. 2013) or asked to the Secretariat of the Pacific Community. Typically, such measurements should be applied for poorly or under-represented families as highlighted in this report as well as main species in fish catch composition as highlighted in the Ministry of Fisheries' inshore fisheries statistics. Priority should be given to the five species presented in this report and in Annex 10.1 with mean sizes greatly under the MML. The minimum maturity length given in this report can be used to define minimum size limits. Further investigation should be undertaken for the species with mean sizes lower or equal to the minimum maturity length (Annex 10.1). While species-specific minimum sizes can be define to protect species with critical status, for a wider impact and easier appliance, some minimum sizes can be defined at the family/genus level (however be careful as some exceptions can occur):

- Rabbitfish : MML = 250mm
- Squirrels & soldierfishes = 150mm / (!) *Myripristis murdjan* = 200mm
- Sweetlips = 500mm
- Goatfish = 150mm / (!) *Parupeneus barberinus* & *Parupeneus indicus* = 200mm
- Emperors = 250mm / (!) *Gymnocranius sp.* = 310mm ; *Lethrinus olivaceus* = 350mm
- Snappers – Sea perch = 250mm / Large snappers (eg. *Lutjanus gibbus*) = 450mm

As bigger fish are the best reproducers, some limitation regarding the large specimen could be applied as well. As an example, a 30cm long goatfish will releases the same number of eggs as 2,000 15cm long goatfishes. As well, a 66cm bluefin trevally will release 86 times more eggs than a 33cm one. While a 20cm coral trout grouper won't be reproductive, 50cm individual will release 1 million eggs and 60cm individual will release 3 times more (Green et al., 2013).

More data are needed to efficiently monitor the sizes' trends of finfish overtime. As discussed later in this report, if monitoring survey were undertaken on a regular basis, special attention should be paid to the evolution of mean and maximum sizes overtime. Also, participative survey involving professional fishermen could help recording periods of the year when eggs are found in fish's body and size of mature fish. As efficient as minimum sizes limits can be, they can't be applied by themselves and they must be completed with other management options focusing on reproduction.

Another strategic approach should then be developed to identify and protect breeding and spawning aggregation sites. A fish spawning aggregation is a grouping of a single species of fish that has gathered together in greater densities than normal with the specific purpose of reproducing. Typically such aggregations form at the same place at approximately the same times each year. In a group of islands like Vava'u where fishing seems to be a usual activity for both men, women and kids, local knowledge from fishers and communities could be used to identify where and when fish breed and help protect these critical habitats. A first survey based on the local knowledge of fishers and communities may allow to highlight potential spawning grounds, species of interest and months when these events are known to occur. Then, further underwater surveys would be needed to confirm and better characterise the composition and length of these events. Once identified and confirmed, marine protected areas could be implemented temporarily every year (as seasonal enclosure) to protect sites where this critical ecological process (i.e. spawning aggregation) occurs. Meanwhile, communication and awareness campaign could help to inform people and promote good practices. For further reinforcement, total fishing ban can be consider for a specific family during the reproduction peak.

Two spawning grounds where identified during the BIORAP (Joe's Spit, Fonualei). They should be part of an MPA network that could be implemented in Vava'u as further explained after.

Rapidly create protected areas that will allow resource recovery while benefitting adjacent fisheries through the spill over effect

Marine Protected Areas (MPAs) are well known as an efficient management tool for their contribution to food security and sustainable livelihoods while protecting resources and restocking adjacent fisheries. The benefits of MPAs are well documented, including an increase in the diversity, density, biomass, body size and reproductive potential of many species (particularly key fisheries species) within their boundaries (Babcock 2010; Lester et al. 2009; Halpern, 2003; Palumbi, 2004; Russ, 2002). MPAs can also provide conservation and fisheries benefits to surrounding areas through the export of eggs, larvae and adults to other reserves and fished areas. However, to be effective, MPAs have to be correctly designed and developed from an ecosystem perspective integrating adjacent communities (when existing) in its implementation and monitoring.

A usual principle in designing MPA is to consider a total area large enough to include 20-40% of the fishing stock and to ensure that the species' home range pattern is protected. While surgeonfishes, goatfishes, parrotfishes or groupers have a home-range from 1 to 5 km, larger parrotfishes, small snappers and emperors have a home-range over a length of 10km and large snappers, emperors as well as sharks and jacks can have a home-range way bigger than 10km (Green et al. 2013). It doesn't seem very realistic to consider implementing such a large MPA in Vava'u's main group of island. However, given the repartition of reefs and islands of Vava'u, a network including different types of small reserves not distant from each other for more than 10km may have a significative impact in resource recovery. Indeed, distance between MPAs, is important because it influences the degree to which populations are connected through adult, juvenile and larval movements. This connectivity among populations helps maintain fish stocks, diversity and build ecosystem resilience by ensuring that marine reserves are mutually replenishing to facilitate recovery after disturbance (Green et al. 2013). Several priority areas for conservation stand out from this survey and the following management options are suggested for further conservation strategies in Vava'u

- The islands of Maninita and Fangasito stand out from the analysis as locations of particular interest for conservation due to the comparatively higher abundance and diversity of fish and better balanced fish community structure. The existing network of reefs surrounding the sites and the influence of oceanic waters may contribute to provide a set of various habitats and good conditions allowing a greater range of species – including planktivores, piscivores and apex predators' species - to settle on these sites. Both located closed to a site that could benefit from a protection status (respectively Taula Island and Fonua'one'one Island), an integrative management including neighbours sites is advised. Different management approach can be suggested to ensure efficient conservation and recovery of fishes 'stocks. A permanent enclosure could be considered for both areas. However permanent enclosure is usually badly perceived by fishermen while in the meantime, given the distance of these sites from the first villages, only a limited number of fishers actually fish on these reefs and the impact of such a strong regulation will be limited. Another option would then be to consider protecting specific families. Several groups were highlighted in this survey as poorly or underrepresented and this two sites could constitute Marine Protected Area where, as an example, fishing of groupers, snappers, emperors, rabbitfishes, sweetlips and/or jacks could be prohibited. While including two neighbour sites within one area will ensure protection and connectivity of species with a small home-range, the protection of two adjacent area (Maninita Island - Taula Island / Fangasito Island - Fonua'one'one Island) will ensure protection and connectivity of species with a greater home-range.
- With the same configuration as the previous locations, 'Euakafa Island and Euiki Island stand out from the analysis as sites that could be included within the same management strategy with 'Euakafa being a priority island for conservation and Euiki Island that could benefit from such a protection status. However, these two islands are located right next to two Special Management Areas (SMA) including Fish Habitat Reserve (FHR) (Ovaka and Taunga). In a context where these two sites may already benefit from an efficient management of the adjacent SMAs, it seems interesting to support these benefits by applying simple and light regulations. While it doesn't seems necessary to ban fishing for any specific families, it might be interesting however to ban the use of nets and spears and only allow line fishing (with a limited number of hooks per boat). By doing so, fishing pressure may be reduce as well as selectivity and the whole area (including two SMAs with two FHR and one Gear Restriction Area) with its central position in the Vava'u group may contribute to stock recovery through spill over effect.
- Umana Island wasn't standing out from the analysis as a high priority site for conservation. However, despite a low species richness, the site presents quite good characteristics and could quickly presents higher quantities and diversity of fishes from a proper management. As 'Euakafa Island and Euiki Island, this island is located closer from villages which could benefit from such a management. Even more and for better results adjacent villages could be involved in the management of the site which could be identified as a Special Management Area. Both Ofu and Olo'ua are located closed by Umana island with Ofu being the closer. According to local social organisation one of the two sites or both if feasible, could be involved in the management of an SMA located in this area and including Umana Island. An FHR would be in this case

highly recommended on the island of Umana and including both lagoon and reef-slope seaward in order to protect larger carnivores and piscivores species.

- Remotely located from the main group of islands, the area including Fonualei Island, Toku Island and Joe's Spit could easily constitute a marine park with different type of zoning corresponding to different management objectives. While both Fonualei Island and Joe's Spit appears to be spawning aggregation grounds, Joe's Spit is also richer and more abundant location of the whole survey while Toku Island is pretty much poor and may benefit from a protection status. Even if the whole area is far from the main group of island and may not be submitted to high fishing pressure, a management strategy may definitely worth it. Indeed, recent studies for a range of species (including key fisheries species), have shown that some larvae move long distances (10s to 100s of km), while other stay close to home (10s to 100s of m). So varying the spacing of marine reserves from one to more than 20 km apart (with a mode of 1 to 10 km) will accommodate the larval dispersal patterns of most species (Green et al. 2013). While potential MPAs in the main group of Vava'u will be relatively closed to each other, a large and distant MPA like this may have significant impact for the stock recovery. As protecting a big area like this with specific zoning may also have an "attractive" effect for fishermen as it is distant and hard to survey, managers have to be careful with their strategy. Indeed, protecting Joe's Spit on its own will put under the spotlight an isolated reef which is quite hard to find otherwise. Thus, including Joe's Spit in a zone that include a wider area (As an example including Fonualei) may be more strategic. Whatever the management strategy that could be adopted for this area, it seems important to 1) protect the spawning grounds (prohibit fishing on reefs for 6 month a year between August and February for example), 2) Limit the fishing pressure (allowing bottom-fishing and offshore fishing but limiting reef fishing to line-fishing) 3) make sure that the area remain a sanctuary for large-bodied under represented fishes families such as groupers, snappers, jacks, sharks, mackerels, barracudas…

These are just recommendations from a two weeks survey and are based on a snapshot of reefs showing various states of richness at one time of the year. Further options for management would be to identify and protect key habitats such as mangroves, seagrass beds, fringing reefs as they constitute nurseries for a great number of reef species as well as they constitute the main habitats of several species such as the Emperors.

No matter which management strategy is chosen, MPAs should be designed from a long term perspective. Indeed, MPA's primary benefits such as an increase in size of fish, offspring production and spill-over effects can be realised within a short period (>0-5 years). However, as the Vava'uan fisheries are heavily overfished, long term protections should be considered (20 years at least) to ensure effective stock recovery and benefit to Vava'u's fisheries at the global level overtime. Using these guidelines to design the MPAs, several community consultations should be conducted to ensure acceptance of the various projects. Moreover, management initiatives that involve communities in the planning and monitoring activities such as the SMAs must be encouraged and further more develop. As implementation of MPA's with fishing restriction may impact the fishing ground of many fishermen, strong incentives have to be developed to provide new alternatives for local communities' livelihood. As examples, such alternatives could include:

- The MPA monitoring to ensure that rules and regulations are respected. This implies mediation, communication and awareness trainings as part of a capacity building project.
- The monitoring of the protected resources overtime to evaluate the efficiency of the MPA. This implies underwater visual census, organism identification and data collection as trainings for part of a capacity building project. As highlighted in this report, the lake of previous studies on the same sites limit the comparisons and it is very difficult to identify any trends of evolution of fish stocks overtime. It seems absolutely necessary to consider further surveys on the same sites in the years coming.
- The development of touristic and educational activities. Guides from local communities could be trained and involved.

These are only few examples of what can be developed within such a MPA. A comprehensive guide "economic incentives for marine conservation" was developed by Conservation International to help better understanding how to motivate sustainable behaviour by constructing economic alternatives. This approach may help in understanding how to distribute cost and benefits from conservation. The Locally Managed Marine Areas (LMMA) Network established in 12 Pacific Island countries could also represent an efficient help for the Ministry of fisheries to benefit as well as sharing experience with other community-based management projects and help identifying important milestones.

Supporting measures

Making decisions on possible management options isn't that easy giving the facts that most of the fishing is for subsistence purpose and most of the fishing pressure occurs on the sheltered coastal reef areas as most of the fishermen can't afford the price of a boat or fuel for outer reef or long distance fishing.

Indeed, any management options that will be adopted will necessarily have short-term impacts on households and on livelihoods by limiting the quantity of fish available for fishing. These restrictions should be offset overtime by the recovery of stocks if management options are efficiently applied. To ensure an efficient conservation of reef resources, rules and regulations aren't sufficient by themselves. People need to understand why management measures are undertaken, how their reef and resources work, what affects them and why the adopted measures will help the reef to produce more resources overtime. Raising awareness and involving communities in the management of their resources are essential. This can be done through simple actions such as billboards, posters, radio communications or public meeting as well as more complex actions such as including environmental awareness as part of in the school program, developing participative resources monitoring activities with communities or professional fishermen. As mentioned earlier in this document, resource users need to see tangible rewards from changing behaviour if sustainable management and conservation of marine biodiversity is to be achieved. Indeed, since people are facing pressing socio-economic needs, such a potential loss can hamper the acceptance and sustainability of conservation interventions. This is usually the case, unless conservation programs address economic needs and propose good incentives for alternative livelihoods. The Ministry of fisheries can be only encouraged to continue its effort in developing alternative fisheries and aquaculture projects even though several attempts may be needed. Besides rules and regulations, endorsement and acceptance by Vava'uan people won't be sufficient by itself to ensure compliance and enforcement. The Ministry of fisheries will as well have to ensure that rules and regulations are respected overtime through effective control in a long term perspective. In the case of SMAs, this duty can be shared with local community. Fishing pressure isn't the only reason for the loss of fish in the Vava'u group. The loss of habitats (Reefs, mangroves, seagrass beds) is also an important factor linked to the depletion of fish's populations and as efficient as the fisheries management can be, fish won't recover if habitats don't. In this specific case, the Government has to be an example and ensure controlled coastal development to manage efficiently erosion, siltation and pollution issues.

One of the greater challenges commonly faced by environmental managers is to raise sufficient funds in order to reach the initially fixed conservation objectives. Vava'u is no exception to the rule. However, sustainable financing mechanisms is a topic that has been widely studied in recent years. The Tongan government should easily find support with NGO's and other available programs to help build such mechanisms and raise funds for conservation.

To conclude, protecting the fish resources in Vava'u is as urgent as it is delicate given the importance of fisheries as source of food as well as economical incomes. Whatever measures to be adopted, will necessarily affect the local communities by limiting the quantity of fish available for fishing. However, in her PhD thesis from 2003 (which includes an exhaustive list of interesting recommendations for resources management), N. Pelesikoti realised a survey on "views on the appropriateness of environmental regulations" where she sought opinions as to whether environmental regulations affecting various sectors of the community were too strict, too lax or about right. The results regarding the fisheries management were for 63.4% of the people considering the environmental regulation as too lax. This means that people may be ready as well as waiting for more resources management. As overfishing has been occurring for over 20 years, urgent compulsory action is needed. More than an environmental matter, managing the fish stocks around the island has become more and more a matter of food and health security. As a Polynesian Pacific Island country, Tonga can find the support and the resources to face this challenge and become a fish "friendly island".

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CHAPTER 11

REEF CONDITION OF VAVA'U

FIONA WEBSTER

TEAM MEMBER: PENIKONI ALEAMOTU'A

11.1. Summary

- A total of 27 sites were assessed and reefs grouped into six classifications based on exposure to swell and wave energy. Reef health was assessed based on percentage coral cover and the frequency of bleaching, disease, coral predators, physical damage and pollution.
- Coral cover was variable. The lowest cover (1.9%) was observed on volcanic reefs at Fonualei Island, north of the Vava'u archipelago, and the highest on moderately exposed reef types in the southern part of the Vava'u island group (70.6%).
- A bleaching event was just starting to occur at the time of survey, with 16 of the 27 sites showing signs. At each of the 16 sites less than 5% of the reef was affected but bleaching was likely to have intensified as the summer progressed. At the time of survey the water temperature was 29–30oC. It is recommended that prior to final decisions in regard to which reefs are to be protected as marine protected areas (MPAs), the reefs are resurveyed for live coral cover and coral health.
- Predation by the crown of thorns starfish and the corallivorous snail *Drupella cornis* was generally low. Four sites (3, 23, 24, and 8) had one or two crown of thorns starfish and two sites had slightly more (2 and 25). Previously site 25 had over 22 crown of thorns starfish removed in a separate scientific survey. *Drupella* was observed at 12 of the 27 sites, although most sites had only one or two affected colonies. Site 8 was heavily infested with *Drupella* with over 500 affected colonies observed.
- The urchin *Diadema* can indicate reef disturbance and very high densities were observed at one site only (27).
- Generally the evidence of disease was low with no coral disease observed at 12 of the 27 sites. Symptoms consistent with white band disease were observed on one or two colonies at sites 3, 10, 16, 17, 18, 19, 21, 22, 23, 25, 27 and 26. Sites 9 and 24 had higher incidence with around ten affected colonies. Site 8 was exceptional with over 50 colonies affected by white band and many colonies showed advanced stages of coral tissue damage and mortality. Evidence of diseased corals with growth anomaly was low; it was observed at four sites only (13, 15, 18 and 22) with all sites having three or fewer observed cases. Only two isolated incidences of diseased coralline algae were observed (coralline lethal orange disease) at sites 13 and 20.
- Physical damage to the reefs was negligible at all sites and Cyclone Ian which passed through Tonga in January 2014 appeared to have had little impact. One exception was site 19 where over 50 colonies were dislodged but were in a healthy condition.
- Observations of rubbish and fishing debris was highest at the sites closest to the town of Neiafu (sites 1, 2 and 3). The incidence of rubbish was low at all other sites. Site 27 showed evidence of eutrophication from septic tanks associated with a nearby tourist resort.
- Large marine fauna including sharks, dolphins and turtles were more frequently observed at the more remote northern sites which were sites 4, 5, 6, 7 and 8. For most other sites there were very few if any sightings of large marine fauna.
- A reef condition index was calculated based on coral, fish and invertebrate biodiversity, coral cover and the density of target fish. Sites with a reef score of more than 85% and a low incidence of disease, predation and pollution are considered the most eligible reefs for MPA status. In total seven sites (sites 12, 14, 16, 18, 18, 22, 23 and 24) all located in the southern part of Vava'u scored more than 85% and are considered the most suitable areas for protection as MPAs.

11.2. Introduction

The Kingdom of Tonga has 174 islands clustered into three main groups, Tongatapu, Ha'apai and Vava'u. Most islands are surrounded by reef and Tonga has over 1,500 km^2 of reef area comprised of fringing, barrier and submerged reef types. Coral reefs are an important resource to Tongans for income, food security, tourism and associated ecosystem services. Despite the large area and importance of reefs to Tongan people there is little scientific monitoring and assessment of most reef areas (Holthus 1999;Lovell and Palaki 2002;Chin et al. 2011).

This study summarises the available information on coral reefs in the Kingdom of Tonga and presents the results from a field survey which assessed the health of 27 selected reefs in Vava'u. Situated in the north of Tonga, the Vava'u island group (referred hereafter simply as Vava'u) has one main island – 'Uta Vava'u – and around 70 smaller islands which spread over 21 km from east to west and 25 km from north to south. The main town Neiafu, located on the island Vava'u Lahi (meaning big Vava'u), has a population of around 6,000 and is situated adjacent to a large natural deep water harbour called the Port of Refuge.

Reef health was assessed by looking at benthic cover, in particular coral cover, and the incidence of disease, predators, pollution, rubbish and bleaching. Information on reef health was combined with other biological surveys based on coral, fish and invertebrate biodiversity, and targeted fish densities to give an overall assessment of reef condition for each site. Based on the reef condition value and taking into consideration the incidence of threats such as predators and disease, recommendations are made for the future designation of marine protected areas (MPAs).

11.2.1. BIODIVERSITY

Tonga is situated at the eastern end of the Pacific-wide biodiversity gradient and the number of coral species found is lower than reefs in the northwest in locations such as Fiji and Vanuatu. There are 192 species of scleractinian coral described from 11 reefs around Tongatapu (Lovell and McLardy 2008). There are few existing studies examining the status of reefs throughout Tonga and the information available suggests that there is a mix of healthy, degraded and recovering reef communities (Lovell and Palaki 2002;Friedman et al. 2009;Chin et al. 2011).

11.2.2. GOVERNANCE AND LEGISLATION

Tonga has open access to fishery resources, with customary marine tenure abolished in 1887 with the introduction of the constitution. This means that Tongans may fish anywhere, and there are few restrictions imposed by fisheries regulations. Open access fishing creates a mentality of "If I don't get it today, somebody may get it tomorrow" and does not promote sustainable practices (Lovell and Palaki 2002). The marine resources of Tonga are managed through the Fisheries Management Act (2002), the Fisheries Management and Conservation Regulation (2008), the Environment Act (2003), the Parks and Reserves Act (1976) and planning instruments such as the National Biodiversity Strategy and Action Plan (2006) (Chin et al. 2011). Restrictions imposed by the fisheries regulations are minimal and there are few limitations on the quantities or sizes of reef fish caught in inshore areas. Most management controls are for offshore commercial fisheries.

The government established five marine protected areas (MPAs) around the Tongatapu island group (the southernmost of the groups) in 1979 to protect important ecosystems such as coral reefs and their economic, cultural and educational values. The area of these MPAs varies from 8 to 260ha within which all extractive activities such as fishing and gathering are banned. Compliance with regulations is generally low in Tonga with most regulations poorly understood or observed. Fishing and collecting for the aquarium trade is often seen within the reserves with people sometimes not even knowing of the no-take status of the areas. Furthermore, enforcement is generally lacking due to low government will and a lack of resources (Lovell and Palaki 2002;Nakaya and Palaki 2007).

Recently Tonga has introduced a more traditional style of reef management. Designated areas, known as special management areas (SMAs), involve communities in the co-management and conservation of marine resources with the Department of Fisheries. Presently there are eight designated SMAs in Tonga:two in the Tongatapu group, three in the Ha'apai island group, two in Vava'u, and one in Noumea. This management arrangement reports a high degree of success with communities having a more active role in fisheries management, sustainable practices and conservation (Gillet 2009;Webster 2013). At the time of writing negotiations were underway to implement six more SMAs in Vava'u.

11.2.3. IMPACTS AND THREATS TO CORAL REEFS

Effects of fishing

Reef fish and invertebrates are moderately to seriously overexploited throughout Tonga, with the most intensive overfishing occurring around the main island of Tongatapu (Bell et al. 1994;Clua and Legendre 2008;Bell et al. 2009;Friedman et al. 2009;Anon. 2010). There are strong signs of overfishing with catches becoming characterised by fish in lower trophic levels. For example the dominant catch for inshore areas are herbivorous species such as parrotfish, surgeonfish and unicornfish (Bell et al. 1994) all of which are important for maintaining low algal abundance and a healthy coral reef system (Hughes et al. 2006). Destructive fishing practices such as overturning corals for reef gleaning are still common and illegal dynamite fishing may still occur (Chin et al. 2011).

Eutrophication and pollution

Tonga does not have a sewerage system and eutrophication is a problem especially in the more densely populated areas such as the Fanga'iuta Lagoon in Tongatapu and Port of Refuge Harbour in Vava'u (Chesher 1984;Zann 1994). There are also concerns about waste from boats, with regular visits from inter-island ferries, containerships and private yachts of which approximately 500 anchor in the Port of Refuge in Vava'u every year. Farming is another source of eutrophication with run-off from fertilisers and pesticides. An additional major form of pollution is solid waste, with rubbish often dumped on beaches and vacant land (Lovell and Palaki 2002;Chin et al. 2011).

Land use and coastal development

Poor land use practices can lead to increased sediment run-off, and deforestation is a significant issue in some areas in Tonga. The Port of Refuge Harbour in Vava'u has suffered a high degree of sedimentation and coral mortality in the past, which is likely to have been related to poor land use practices. The construction of several causeways in Tonga, one in 'Uta Vava'u, has resulted in disruption of natural water flows and build up of mud causing mangrove mortality. Coastal development either for houses or tourism, if unplanned and unregulated, can pose a significant threat to the marine environment, however such impacts are little documented in Tonga (Chin et al. 2011).

Cyclones, tsunamis and effects of climate change

In Tonga the marine environment is periodically affected by cyclones, tsunamis and volcanic activity (Lovell and Palaki 2002). Cyclone Ian passed through Tonga in January 2014, but the majority of damage was in the middle island group of Ha'apai with little damage to the islands of Vava'u. In 2009 a tsunami affected the Nia islands to the north, with reefs experiencing physical damage and smothering with sediment. Climate change is a threat to reefs and Tonga experienced a bleaching event in February 2000 with the most extensive bleaching reported around the Tongatapu and Ha'apai groups (Lovell and Palaki 2002). Sea level rise is a real risk to many islands in Tonga through seawater intrusion and coastal erosion.

Predator outbreaks

The only reported outbreak of the crown of thorns starfish (*Acanthaster planci*) was in the harbour near the town of Neiafu. Chronically elevated numbers of crown of thorns starfish and associated coral deaths were observed in the Port of Refuge Harbour in the early 1970s and 1980s. Eutrophication and algal blooms in the harbour have been suggested as contributing factors to these outbreaks (Lovell and Palaki 2002).

Coral and live rock harvest

Tonga has an active aquarium trade. Previously fish were the main target but harvests of live rock and corals have increased since the late 1990s. Due to concerns over the effects of the live rock trade, its export was banned in 2008 by the Department of Fisheries (Chin et al. 2011). The aquarium trade is centred on the Tongatapu group where there is access to aquarium facilities and the airport and presently there is no industry in Vava'u. In the late 1980s coral harvesting occurred in Vava'u – mainly *Gonipora* and *Porites* corals for export for medical technology. This operation was suspended in 1990 due to concerns of impacts to reef habitats and the naturally low abundance of these genera (Holthus 1999).

11.3. METHODS

At each site, the reef was assessed for benthic cover and reef health along four replicate 20m long transects. The transects were laid along a 100 m tape measure at a consistent depth of 12–15m, with the four 20 m replicates each separated by 5m intervals.

Benthic cover was assessed using the point intercept method consistent with the Reef Check manual (Hill and Loder 2013). Along each 20m transect the reef biota/substrata was assessed at 0.5m intervals so that there was a total of 40 points per transect. Below each sampling point, the type of substrata/biota is identified or characterised as follows: hard coral (hc), soft coral (sc), sponge (sp), macroalgae (ma), crustose coralline algae (cca), turf algae (ta), cyanobacteria (cyano), rubble (rb), other (ot), dead coral (dc) and bare substrata (bs). The category turf algae included filamentous and turf algae. The 'other' category includes invertebrates such as tunicates, sea stars, sea cucumbers, etc.

Any visible signs of damage, threats or disturbance at each reef site were noted. The divers looked for evidence of damage from fishing (nets, spear guns, lines), boating activities (anchor damage, grounding scars, fin marks from snorkelers), and storms or cyclones. Damage from the coral predators was detected by counting the number of individuals of the crown of thorns star fish (*Acanthaster planci*) and the number of colonies affected by the corallivorous snail *Drupella cornis* (the *Drupella* were not counted as they were too numerous at some sites and are also cryptic during the day). The needle spined sea urchin *Diadema* can be an indication of reef degradation, and the number of these was also counted at each site. Other divers of the BIORAP team supplemented observations on reef condition after the site survey dive had been completed. Charismatic marine fauna and other marine related red-listed species were also noted at each reef site; these include sharks, dolphins, manta rays, turtles, etc.

The number of bleached or extremely pale corals was counted at each reef site. Bleaching occurs when the symbiotic relationship between a coral host and the microscopic algae which live within the coral is disrupted. Extreme events such as stress from elevated water temperatures can cause the coral to expel the algae resulting in the coral having a much paler or white appearance (Hoegh-Guldberg et al. 2007). The number of colonies showing signs of bleaching and the level of tissue discoloration indicate the extent of the bleaching on the reef.

The reefs were also assessed for evidence of coral pathogens or disease. Whilst disease types can only be formally identified by analysing tissue samples in the laboratory there are some characteristic morphological features of different types of disease which allow them to be broadly classified, such as black band disease, white band disease and growth anomaly (Raymundo et al. 2008). Any symptoms of disease or pathogens observed during the survey were classified according to the Coral Disease Handbook: Guidelines for Assessment, Monitoring and Management (http://gefcoral. org/LinkClick. aspx?fileticket=BshMDpVe%2blk%3d&tabid=3260&language=en-US).

Crustose coralline algae is also vulnerable to disease and the presence of coralline lethal orange disease (CLOD) and coralline white band syndrome (CWBS) was recorded (Littler and Littler 1995;Miller et al. 2013).

Evidence of and potential threats of eutrophication, siltation and pollution were also recorded. Potential sources of eutrophication such as sewerage pipes and coastal developments were noted, along with sources of siltation such as deforested areas and rivers. Visible changes in water quality such a change in colour and turbidity were noted, along with potential reef indicators such as decreased coral cover and increased turf or macroalgal cover.

An index of reef condition was calculated for each reef site based on assessments of the number of coral (Chapter 7), macroinvertebrates (Chapter 8), fish species (Chapter 9), the abundance of targeted and commercial fish species (Chapter 10) and percentage coral cover (this chapter). The reef condition index was calculated by ranking each of the attributes from highest to lowest, for example, for coral diversity the site with the lowest number of species was scored 1 and the site with the highest value 27. If any sites had the same value, for example if two sites had the same number of coral species, then they were given the same rank value. This was done for each of the reef attributes and the reef condition index was calculated from the summed rank for each biological value. For comparative purposes the total score was then expressed as a percentage of the maximum score. For example site 18 had the highest ranking score of 80 points – this site therefore was scored as 100% and all other sites were relative to this value.

For some of the sites the full dataset was not available for all values, for example coral species diversity is lacking for sites 6 and 7 due to the taxonomist being unable to dive on these days. Rather than these sites being omitted from the analysis they were given a proxy score, which was the average value for that particular condition for all sites.

11.4. Results

11.4.1. REEF CLASSIFICATIONS AND BENTHIC COVER

A total of 27 reefs were assessed for benthic cover and coral health. It was noted that the benthic composition on reefs was influenced by exposure to wave and swell energy. For example sites more exposed to swell and wave energy (9, 10, 11, 13 and 26) tended to have a higher crustose coralline algae and soft coral cover, whereas the more sheltered sites (1, 2 and 3) were characterised by sediment and turf algae. Sites exposed to moderate wave energy (6, 7, 12, 14, 15, 16, 17, 18, 19, 22, 23, 24, 25 and 27) had variable benthic cover. Table 11.1 provides a list of all the sites and a description of each of the reef classifications and benthic characteristics. A more detailed description of the benthic cover for each site is provided in Figure 11.1.

11.4.2. CORAL COVER

Coral cover varied between sites and reef types (Figure 11.2). The sheltered reefs (1, 2 and 3) had around 17% coral cover – but site 3 appears to have been affected by coral bleaching, with only 3.8% coral cover and large stands of dead coral. The reefs along limestone drop-offs, sites 20 and 21, had 19.9% and 16.1% coral cover respectively. The moderately exposed reefs (6, 7, 12, 14, 15, 16, 17, 18, 19, 22, 23, 24, 25 and 27) had variable coral cover ranging from 5% at site 22 to 70.6% at site 17. The exposed reef sites (9, 10, 11, 13 and 26) had approximately14% coral cover, with site 27 having notably higher cover. The volcanic reefs (4 and 5) had the lowest coral cover at between 1.9% and 8.1%.

11.4.3. BLEACHING

There were indications of coral bleaching with white or very pale colonies observed at 16 of the 27 sites (Table 11.2). Most bleaching was observed between 1 and 10m depth, however individual bleached colonies were also observed at 30m. On each reef bleaching was generally low with less than 5% of the colonies affected. There did not appear to be any one species or genus of coral which was more susceptible to bleaching.

11.4.4. CORAL PREDATORS

Evidence of coral predation was generally absent on most of the reefs surveyed (Table 11.2). The crown of thorns starfish was not observed at most sites, but one or two individuals were noted at sites 3, 8, 23 and 24. At site 2, five crown of thorns starfish and at site 25 six were counted. Prior to the present survey, site 25 had been extensively impacted by crown of thorns starfish with over 22 individuals removed during a scientific survey in October 2013 (personal observation). Predation by *Drupella cornis* was also generally low at all sites. *Drupella* was observed at sites 3, 7, 16, 20, 24, 25 and 26 with all of these sites having less than five affected colonies. Site 12 had ten affected colonies and at site 9 more than 20 colonies were affected by *Drupella*. Site 8 was severely affected with over 500 coral colonies observed with *Drupella* with very high densities for some corals (i.e. over 50 *Drupella* per colony).

Table 11.1. Description of each of the reefs types and their benthic characteristics.

Reef type	Site no.	Description	Benthic cover (point intercept method)
Sheltered reef	1, 2, 3	Sheltered reefs were located in the inner part of the archipelago and were very protected. These reefs tended to be on a gentle slope, with more delicate branching coral species and finer sediments. Some of these sites appeared to have been affected by bleaching in the past, with numerous intact dead coral colonies covered with turf algae	Biota/substrata was typically dominated by turf algae (on dead coral) and sediment. Coral cover varied from 3.8% to 18.8%
Limestone coast drop-off	20, 21	Vertical limestone walls were a continuation of islands with sheer limestone cliffs located in the middle of the archipelago. These reefs were exposed to some wave and swell energy	Characterised by crustose coralline algae and turf algae. Coral cover was around 16%
Moderately exposed reef	6, 7, 12, 14, 15, 16, 17, 18, 19, 22, 23, 24, 25, 27	The fringing reefs typically surrounded sandy islands and were exposed to moderate energy. Most of these reefs were in the southern part of the archipelago, although two reefs existed in the north	Benthic cover was highly variable. For example at one site coral cover was low (5.0%) whereas another site had the highest coral cover (70.6%)
Exposed reef	9, 10, 11, 13, 26	Exposed reefs were on the outer part of the Vava'u archipelago, mainly in the northern region. These reefs were very exposed to high swell and wave energy	Most sites were characterised by a high cover of crustose coralline algae and soft corals. Coral cover was variable (8.7% to 27.5%)
Other	8	One reef was an oceanic pinnacle, occurring in the middle of the ocean. This reef was highly exposed to wave and swell	This one site hadmainly turf algae on reef with 23.1% coral cover
Volcanic reef	4, 5	Two sites were composed of volcanic rocks, which had little benthic cover except for a fine layer of turf. These sites were highly exposed to wave and swell energy	These reefs were characterised by high turf algae cover (on volcanic rock), low coral cover (<10%) and sediment

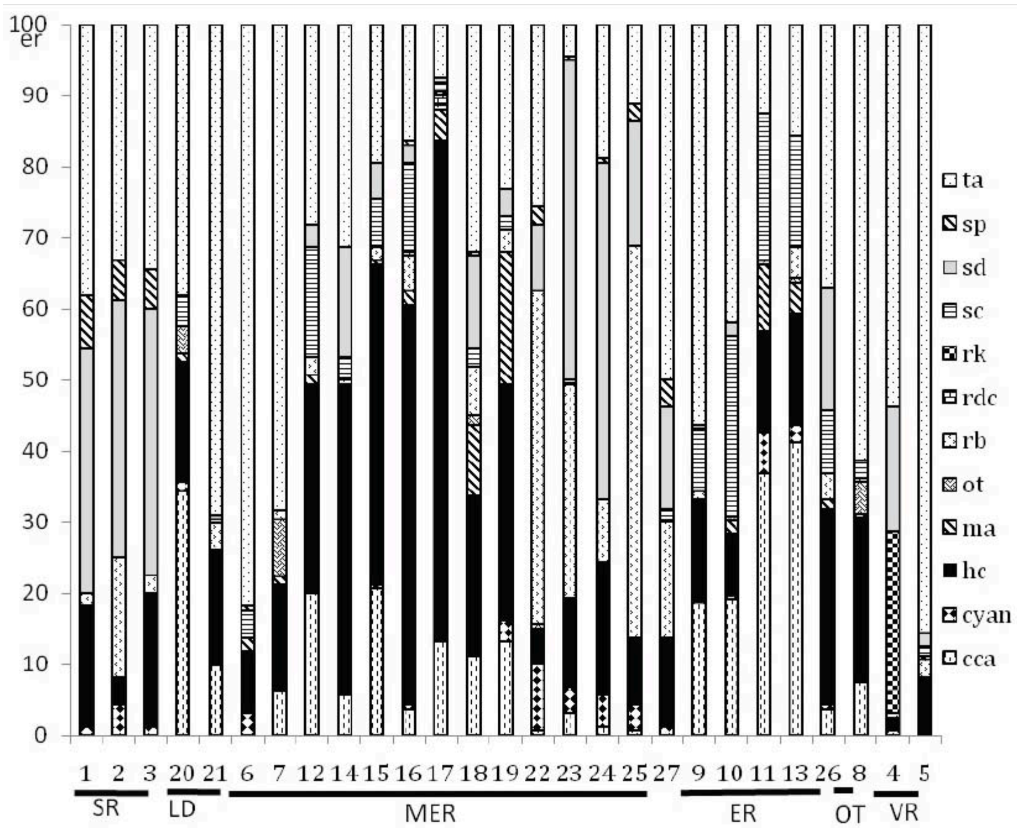

Figure 11.1. Benthic composition as recorded along transects at each site. Sites are ordered according to reef type (Table 11.1): SR = sheltered reef, LD = limestone drop-off, MER = moderately exposed reef, ER = exposed reef, OT = other, VR = volcanic reef. For all sites, n = 4 twenty meter transects. Types of substrata: hard coral (hc), soft coral (sc), sponge (sp), macroalgae (ma), crustose coralline algae (cca), turf algae (ta), cyanobacteria (cyan), rubble (rb), other (ot), dead coral (dc) and bare substrata (bs). The category turf algae included filamentous and turf algae. The 'other' category includes invertebrates such as tunicates, sea stars, sea cucumbers, etc.

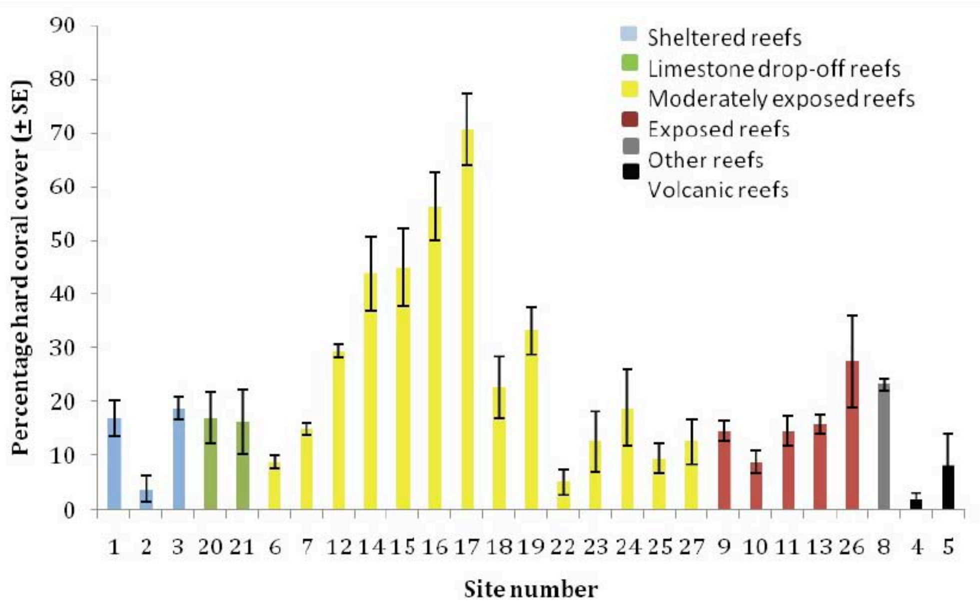

Figure 11.2. Average hard coral cover (%,+ SE) for the 27 sites, classified by reef type.

Diadema were absent from the majority of sites and low densities were observed at sites 1, 2, 3, 5, 21, 22 and 25. Site 24 had high *Diadema* densities with over 200 individuals counted in a 100m reef stretch.

11.4.5. DISEASE

Generally the evidence of disease was low with no disease observed at 12 of the 27 sites (Table 11.2). Symptoms consistent with white band disease were observed on one or two colonies at sites 3, 10, 16, 17, 18, 19, 21, 22, 23, 25, 26 and 27. At sites 9 and 24 around ten colonies appeared to be affected by white band disease. Site 8 was severely affected with over 50 colonies shown signs of white band mainly *Pocillopora* and many of these affected colonies had 25–50% mortality. One or two colonies were observed with symptoms consistent with growth anomaly at sites 13, 15, 18 and 22. Only two incidences of crustose coralline lethal orange disease were observed, at sites 13 and 23.

11.4.6. PHYSICAL DAMAGE

Most sites surveyed had little evidence of recent physical damage (Table 11.2). Tropical Cyclone Ian passed through Tonga in January 2014 but appeared to have had little effect on the reefs in the Vava'u island group. However, at site 19 over 50 colonies were dislodged and this is likely to be due to the effects of the cyclone. Despite the colonies being dislodged, this reef appeared to be in good condition, with relatively high coral cover, low coral mortality and most of the dislodged colonies alive and healthy.

11.4.7. EUTROPHICATION AND POLLUTION

There appeared to be signs of water pollution at only one site (25) with water being highly turbid and slightly brown in colour especially in shallow areas close to shore. This site was located adjacent to a tourist resort which is known to have had problems with their sewage disposal and septic tanks in the past (Karen Stone, personal communication).

Rubbish, mainly cans, bottles and fishing debris, was observed at sites 1, 2 and 3. These sites are closest to the main town of Neiafu and are likely to be popular recreational and fishing sites. Apart from these locations, the incidence of rubbish was relatively low at all other sites.

Table 11.2. Assessment of reef health in terms of bleaching, disease, predation and rubbish at each of the 27 reefs sites surveyed. Data were collected along 4 x 20 m transects at each site and supplemented with sightings by other members of the BIORAP team.

Type	Site no.	No. of bleached colonies	No. of crown of thorns starfish	No. of colonies with *Drupella*	No. of *Diadema*	No. of colonies with white band disease	No. of colonies with growth anomalies	Incidence of CCA disease	No. of colonies with physical damage	No. of pieces of rubbish counted	No. of fishing lines and nets counted	Comments
Sheltered reef	1	5	0	0	1	0	0	0	0	15	0	Lots of rubbish
	2	4	5	0	7	0	0	0	0	17	1	Large dead stands of *Acropora*, lots of rubbish
	3	2	2	2	2	2	0	0	0	40	12	Sediment runoff causing brown bloom along shoreline, lots of rubbish and fishing debris
Limestone drop-off	20	5	0	2	0	0	0	1	0	0	1	1 white tip reef shark
	21	15+	0	0	12	1	0	0	0	0	0	
Moderately exposed reefs	6	0	0	0	0	0	0	0	0	0	0	1 white tip reef shark
	7	0	0	2	0	0	0	0	0	0	0	2 white tip reef shark
	12	0	0	10	0	0	0	0	0	0	0	1 white tip reef shark
	14	0	0	5	0	0	0	0	0	0	4	Isopods seen on *Chromis*
	15	0	0	0	0	0	3	0	0	0	0	
	16	30+	0	3	0	2	0	0	0	0	0	1 black reef tip shark, 1 green turtle
	17	50+	0	0	0	2	0	0	0	0	0	
	18	15+	0	0	0	1	2	0	0	0	0	
	19	20+	0	0	0	1	0	0	50+	0	0	Reef damage, probably from cyclone
	22	50+	0	0	7	1	1	0	0	0	2	Lots of old coral rubble, eagle ray
	23	50+	1	0	5	1	0	0	0	3	2	Good aggregations of snappers, groupers, surgeonfish
	24	5+	1	1	200+	10	0	0	0	0	2	Reef top pale Spotted ray, white tip reef shark
	25	20+	6	2	10	3	0	0	0	0	2	Branching coral bleached
	27	8	0	0	0	5	0	0	0	0	0	Eutrophication in water, stands of *Acropora* bleached
Exposed reef	9	0	0	20+	0	10+	0	0	0	0	4	1 grey reef shark, 1 giant trevally
	10	0	0	2	0	2	0	0	0	0	3	2 spotted rays, fishing line and net observed
	11	0	0	0	0	0	0	0	0	0	0	
	13	0	0	0	0	0	1	1	0	0	0	1 grey reef shark, 1 white tip, giant trevally
	26	10	0	2	0	2	0	0	0	0	0	
Other	8	1	1	500+	0	50+	0	0	0	0	1	1 grey reef, 3 white tipsharks sharks, 1 hawksbill turtle, grouper spawning aggregation,
Volcanic reef	4	0	0	0	0	0	0	0	0	0	0	Sediment runoff –r turbidity highnear island
	5	0	0	0	0	0	0	0	0	0	0	Grouper and snapper spawning. Bottlenose dolphins on surface between dives. White tip reef shark, 4 green turtles on surface, two underwater

CCA = crustose coralline algae.

11.4.8. SIGHTINGS OF LARGE MARINE ANIMALS INCLUDING INCLUDE SHARKS, DOLPHINS, MANTA RAYS AND TURTLES

The white tip reef shark was observed at sites 5, 6, 7, 8, 12, 13, 15 and 20. Grey reef sharks were observed at sites 8, 9 and 13. One black tip reef shark was observed at site 16. Spotted rays were observed at sites 10 and 24, and one eagle ray was seen at site 23. Six green turtles were observed at site 5, one at site 16, and one hawksbill turtle was seen at site 8. A pod of bottlenose dolphins was observed near sites 4 and 5.

11.4.9. REEF CONDITION SCORES

Reef condition scores were calculated from a synthesis of five different reef parameters: the numbers of coral, fish and invertebrate species, hard coral cover and the abundance of targeted and commercially important fish species (Figure 11.3, Table 11.3). The sheltered reefs (sites 1, 2 and 3) had low reef condition index values (28–56%). These reefs, situated in the inner part of the Vava'u archipelago, are relatively close to the town and appear to be affected by past bleaching events and severe overfishing.

The condition of the limestone drop-off reefs (sites 20 and 21) was relatively high compared to other reef systems (78–83%). Coral reef fish diversity was moderate to high but the abundance of targeted and commercially important species was low. Coral cover and diversity were generally low along the steep walls of the limestone drop offs.

The moderately exposed reefs (6, 7, 12, 14, 15, 16, 17, 18, 19, 22, 23, 24, 25 and 27) were in variable condition having some of the highest and lowest condition indexes (52–100%). Three of the moderately exposed reefs scored more than 90% condition values (sites 12, 18 and 22). These reefs are mostly situated in the southern part of the archipelago and had a relatively high diversity of fish, coral and invertebrate species. Other moderately exposed reefs which also had a relatively high reef condition index, i.e. > 85%, were sites 7, 14, 16, 23 and 24.

The reef pinnacle or 'other' (site 8) had a high condition index (91%) relative to other sites. Located in a remote area north of the archipelago, this reef had the highest diversity of fish and the highest density of targeted fish, more than twice the density of the next highest site. However, site 8 was observed to have low coral biodiversity, relatively low percentage coral cover and a high incidence of coral colonies exhibiting symptoms of white band coral disease (more than 50 colonies counted) and predation by *Drupella* (more than 500 affected colonies estimated). Therefore this site, whilst valuable in terms of fish biomass and diversity, had low reef condition values otherwise.

Exposed reefs (sites 9, 10, 11, 13 and 26) had moderate to high reef condition values (54–81%). Exposed reefs generally had moderate to high diversity values for coral, fish and invertebrates, but were lower ranked for coral cover and abundance of targeted and commercially important fish.

The volcanic reef sites adjacent to Fonualei Island to the north (sites 4 and 5) also had relatively low reef condition values (30–39%). These sites had a high abundance of targeted and commercial fish species, but the total index score was lowered by the very low scores for coral cover and coral species diversity.

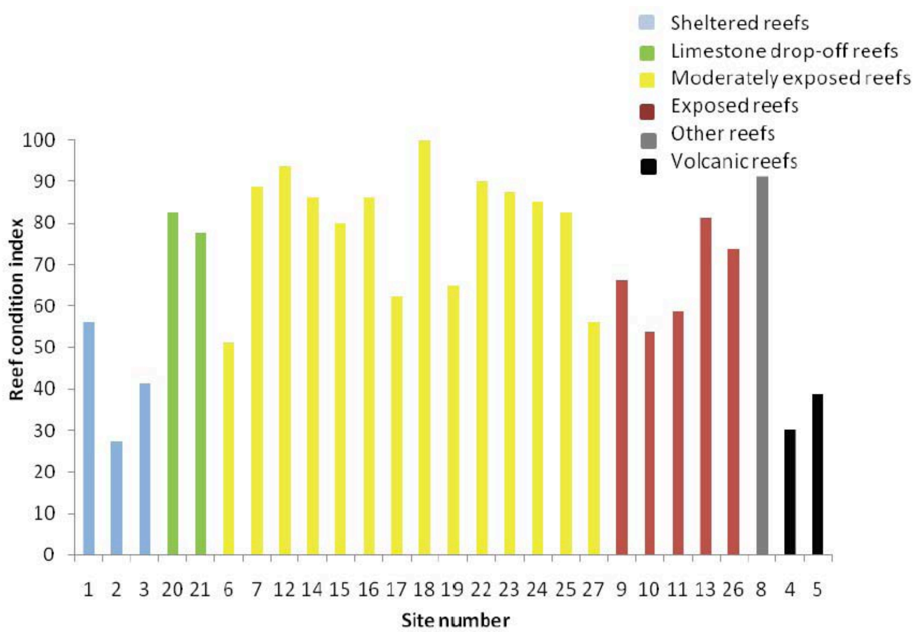

Figure 11.3. Reef condition index based on the cumulative rank scores for coral, fish and invertebrate diversity, coral cover and density of targeted fish (expressed as a percentage of the highest score).

Table 11.3. The parameters used to get the reef condition index scores

Reef type	Site no.	No. of coral species	Coral diversity ranked	No. of fish species	Fish diversity ranked	No. invertebrate species	Invertebrate diversity ranked	Percent coral cover	Coral cover ranked	Targeted fish abundance	Targeted fish ranked	Rank scores summed	Rank scores expressed as percentage
Sheltered reef	1	47	11	119	9	26	4	16.9	14	230	7	45	56
	2	43	8	100	4	26	4	3.8	2	201	4	22	28
	3	40	7	102	5	25	3	18.8	15	173	3	33	41
Limestone drop-off	20	36	6	147	18	33	11	16.9	14	358	17	66	83
	21	32	4	136	14	37	15	16.1	13	357	16	62	78
Moderately exposed reef	6	50	12	98	3	31	9	8.8	6	281	11	41	51
	7	50	12	126	12	35	13	14.9	11	425	23	71	89
	12	53	13	116	7	36	14	29.4	19	418	22	75	94
	14	45	10	145	17	29	7	43.8	21	334	14	69	86
	15	64	17	128	13	25	3	44.9	22	246	9	64	80
	16	75	20	137	15	27	5	56.3	23	227	6	69	86
	17	64	17	80	2	28	6	70.6	24	135	1	50	63
	18	60	15	140	16	30	8	22.5	16	554	25	80	100
	19	61	16	117	8	27	5	33.1	21	163	2	52	65
	22	50	12	151	20	38	16	5.0	3	391	21	72	90
	23	33	5	163	21	32	10	12.4	8	623	26	70	88
	24	47	11	128	13	27	5	18.8	15	428	24	68	85
	25	68	18	121	10	34	12	9.3	7	369	19	66	83
	27	60	15	122	11	24	2	12.5	9	239	8	45	56
Exposed reef	9	61	16	116	7	29	7	14.4	10	307	13	53	66
	10	60	15	107	6	24	2	8.7	5	336	15	43	54
	11	44	9	126	12	26	4	14.4	10	306	12	47	59
	13	59	14	150	19	32	10	15.7	12	271	10	65	81
	26	74	19	122	11	28	6	27.5	18	214	5	59	74
Other	8	26	2	200	22	27	5	23.1	17	1252	27	73	91
Volcanic reef	4	16	1	70	1	15	1	1.9	1	379	20	24	30

11.5. Discussion and conservation recommendations

The surveys found that most coral reefs were in relatively good condition, with a moderate to high coral cover and a low incidence of natural and anthropogenic impacts (with the exception of overfishing). Some sites had naturally low coral cover, notably the volcanic reefs (4 and 5), and site 2 appears to have been affected by bleaching and mortality in the past. Most other reefs had moderate coral cover and the highest was observed at site 17 with 70.6% cover. The incidence of predators was generally low at most sites with a few exceptions. Sites 2 and 25 had a higher incidence of crown of thorns starfish, and site 25 also showed signs of eutrophication from septic tanks associated with a nearby tourist resort. Increased nutrients in the water column have been linked to outbreaks of crown of thorns starfish through increased phytoplankton which are an important food source for the larvae (Brodie et al. 2005; Fabricius et al. 2010). Site 8 was heavily infested with *Drupella*, mainly on *Pocillopora* corals. Symptoms of white band disease were also high at site 8, where more than 50 colonies appeared to be affected with many showing signs of tissue damage and mortality. At most other sites disease symptoms were generally low with only one or two colonies per site affected, but sites 9 and 24 had around 10 affected colonies. There were no signs of physical damage at most sites with the exception of site 19 where some of the corals had been dislodged presumably by Cyclone Ian, but were still in healthy condition. Rubbish was highest at the sites close to the town of Neiafu, mainly cans, bottles and old fishing lines. Large marine fauna including sharks, dolphins and turtles were more frequently observed at the more remote northern sites which were sites 4, 5, 6, 7 and 8. For most other sites there were very few if any sightings of large marine fauna.

Almost all sites were overfished with low abundances of targeted fish and invertebrates and this is discussed in further detail in Chapters 8, 9 and 10. The other major threat to the coral reefs in Vava'u is coral bleaching with 16 of the 27 sites showing signs of bleaching during the survey. For most of these sites bleaching was low with less than 5% of colonies affected but it is likely that bleaching intensified during the summer as water temperatures increased. Whilst it is difficult to control bleaching, ensuring reefs are well managed so that they in as good a condition as possible increases their capacity to recover from disturbances such as thermal stress and cyclonic damage (Hughes et al. 2007). The establishment of MPAs will strongly contribute to promoting coral reef resilience by reducing overfishing and protecting important ecosystem processes such as grazing by herbivorous fish (Hughes et al. 2010;McCook et al. 2010).

Presently there are no MPAs in Vava'u (there are five MPAs in the southern Tongatapu group) and a purpose of this rapid biodiversity assessment was to recommend areas considered most suitable for marine protection. Using a synthesis of the information obtained from the assessments of coral, invertebrate and fish species diversity, targeted fish abundance and coral cover, reefs were assigned a condition score. Reefs with the highest scores are considered the most suitable to be established as MPAs. In particular sites 12, 18 and 22 had a reef condition index of more than 90% with little or no disease or predators recorded. These reefs are all in the southern part of the Vava'u archipelago in the moderately exposed reef category. Other reefs with high condition scores (>85%) and low disease, and also suitable for marine protection, were sites 7, 14, 16, 23 and 24. These reefs are also located in the southern part of Vava'u.

The reef pinnacle (site 8) also had a very high condition index score of 91% due to the high abundance of targeted and commercially important fish species. However, this site also had low coral diversity and was badly affected by disease and predators. It is thought that due to the remote location and exposed nature of this reef, it has some natural protection from fishers. Therefore this reef is not a high priority for formal conservation status and the potential declaration of the reef as a conservation site could attract fishers. Enforcement in this very remote location would also be difficult.

It is recommended that prior to any designation of MPAs in Vava'u the reef condition is reassessed as the coral bleaching observed during the survey is likely to have intensified as the summer progressed with coral mortality increasing as a consequence. Furthermore the incidence of pathogens may have increased in relation to bleaching as marine infectious diseases have been linked to human and natural disturbances (Burge et al. 2014).

Extensive community consultation and education, and marine spatial planning, are recommended prior to the declaration of any MPAs. There are presently five MPAs in the southern group of Tongatapu and the success of these areas in terms of marine conservation is questionable. A series of interviews with fishermen and women in the region revealed that most had no knowledge of the MPA, and tourism operators reported that fishers and aquarium collectors operated within the boundaries (Nakaya and Palaki 2007). A lack of enforcement by government agencies is common in Tonga, partially due to lack of operational budgets. An extensive education programme informing the public and fishers of the establishment of the MPAs should be a priority so that fishers are aware of the no-take zones and also to foster community ownership and enforcement.

Long term monitoring programmes for reefs both inside and outside of the MPAs for reef condition, fish and invertebrate densities are also recommended. Information collected from such surveys can track long term trends, provide a measure of impacts from stressors such as bleaching and cyclones, and also provide important information demonstrating the benefits of MPAs which may enhance community support and stewardship. Both monitoring and enforcement programmes will require operational budgets which will be an important commitment that needs to be made for any future MPAs.

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CHAPTER 12 CETACEANS AND MARINE TURTLES OF VAVA'U

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12.1. Summary

The Vava'u island group has long been a renowned spot for humpback whales (*Megaptera novaeangliae*) but it also hosts marine turtle nesting sites and its waters are likely used by numerous other species of cetaceans. The BIORAP project has provided the opportunity to gain further knowledge on the status of these species.

A total of nine boat surveys was conducted around the Vava'u island group, Fonualei and Toku. A distance of 852 km was travelled in shallow and deep waters during 56 hours and 23 minutes at sea. Weather conditions were mostly good (Beaufort Sea State ≤ 2, 82% of the time).

Ten groups of small cetaceans were encountered, representing at least three species: spinner dolphin (*Stenella longirostris*), short-finned pilot whale (*Globicephala macrorhynchus*) and bottlenose dolphin (*Tursiops* sp.). Group encounter rate was relatively low (1.2 groups per 100 km of effort) although similar to that found in some other archipelagos of Oceania (e.g. Fiji and Vanuatu).

Spinner dolphin was the main species observed in coastal waters (n = 6 groups). They are likely to form small resident populations around the islands. However, no area was found to be consistently used by groups of this species.

Biopsy samples were collected from 19 individuals. Preliminary analyses indicate higher mitochondrial DNA (mtDNA) diversity in spinner dolphins than in short-finned pilot whales. Also, phylogenetic reconstructions show that bottlenose dolphins around the Vava'u island group belong to the species *T. truncatus*.

Evidence was found of the presence of two species that were not previously recorded in the waters of Tonga: the Cuvier's beaked whale (*Ziphius cavirostris*) and the rough-toothed dolphin (*Steno bredanensis*). With these findings, there are now 14 cetacean species officially listed forTonga.

The humpback whale population for Tonga has recently been estimated at over 2,000 individuals. Some movement of individuals between other regions of Oceania occurs but a high level of site fidelity has been shown within the region that is also supported by genetic analyses of population structure.

Recent predictive habitat modelling around the Vava'u island group has shown that favourable habitat for mother–calf pairs of humpback whales included shallow, nearshore regions, whilst areas of predicted suitable habitat for adult-only groups included deeper areas further offshore around the periphery of the island region and including seamounts and banks.

Few turtles were seen during the BIORAP boat surveys and these were mostly green turtles (*Chelonia mydas*). However, sighting data from the Vava'u Turtle Monitoring Program has helped identify potential foraging habitat of importance in the Vava'u island group.

Past and recent surveys of turtle nesting sites suggest that Maninita, Fonua'one'one and Taula islands are important for hawksbill turtles (*Eretmochelys imbricata*). Turtle nesting has historically occurred on many islands throughout the Vava'u island group but it is likely that decades of egg poaching from turtle nests and catches of large female green turtles have greatly impacted the local populations.

12.2. Introduction

Tongan waters are well known for humpback whales (*Megaptera novaeangliae*) that migrate every winter from Antarctica to overwinter in the Pacific islands. Over the past two decades, extensive studies have been conducted during winter months in the Vava'u island group (hereafter referred to as Vava'u) by the South Pacific Whale Research Consortium (SPWRC) and their work has demonstrated that this is one of the most important overwintering areas in Oceania (Constantineet al. 2012). As the reputation of Vava'u as a destination for humpbacks has spread, whale watching and swimming with whales has become a very important economic activity during the winter months (Orams 2001, 2013).

However, many other cetacean species are also found around these islands, some of them year round. So far, 12 species have been officially reported in Tonga (Miller 2007) but more than 30 species are known to occur in Oceania. It is therefore likely that many other cetacean species live in these waters, but their presence remains to be confirmed. Furthermore, despite years of research on Tonga's humpback whale population, little is known on the population status of other cetaceans largely due to low numbers of opportunistic sightings.

Similarly, the current conservation status of marine turtles is poorly understood. Anecdotal evidence, supported by literature (Wilkinson 1979; Bellet al. 1994), lists hawksbill turtles (*Eretmochelysimbricata*) as the most common nesters in Tonga, while green turtles (*Chelonia mydas*) are the most commonly caught species (Wilkinson 1979). Turtles occur throughout Tonga but studies from the 1970s suggested that the island groups of Ha'apai and Vava'u support the largest populations (Braley 1974; Wilkinson 1979). The general consensus is that Ha'apai has the largest of the turtle populations and this has led to more studies being carried out in these islands. However, efforts are now being undertaken to map the distribution and abundance of turtles in Vava'u and recent mapping studies have been able to document several key foraging habitats within the group for green turtles (VEPA, personal communication).

As part of the BIORAP expedition carried out in Vava'u, Tonga, in February 2014, an assessment was undertaken of the cetaceans and marine turtles found in coastal and offshore waters through a systematic survey. The main objective of this survey was to gather new information on cetacean and marine turtle diversity, density and habitat. Humpback whales were not a focus of the survey since they were still on their Antarctic feeding grounds at the time of the BIORAP. We also collected DNA samples from as many small cetaceans as possible in order to integrate Tonga into a genetic seascape project called aPOD (standing for 'a Pattern Of Dolphins'). aPOD is a large scale regional project led by Professor C. S. Baker (Oregon State University and SPWRC) looking at the degree of reproductive isolation between dolphin populations across Oceania. Because of a lack of samples Tonga was not initially planned to be included in this study, however the Vava'u BIORAP provided the opportunity to integrate Tonga into the study.

In addition to the boat surveys, a desktop study was also conducted to compile currently available information on cetaceans and marine turtles. We provide a summary of the latest findings on Vava'u humpback whale population (Lindsay 2014) and cetacean diversity records. We also report on the data collected by the Vava'u Turtle Monitoring Program (VTMP) over the last few years.

12.3. Methods and sites visited

12.3.1. BOAT SURVEYS

Boat surveys were carried out from the 15 to 25 February 2014 (Table 12.1). The main research vessel was the *Dev Ocean*, from which seven systematic surveys were conducted. This vessel is a 10 metre launch with a flying bridge approximately 3 m above sea level, powered by a 335 hp inboard Cummins diesel engine. Two to four observers were on board during each survey, scanning 360° using the naked eye and binoculars from the flying bridge. The boat was launched from Neiafu (n = 3) or Foeata Island (n = 4). In addition, two opportunistic surveys were conducted from the 50 metre vessel *Plan B* on 15 and 16 February. One observer, situated at approximately 7 metres above sea level, looked for animals using the naked eye and binoculars, covering 180° in front of the boat. All surveys were conducted at an average speed of 9–10 knots.

Table 12.1. Summary of survey effort and number of cetacean groups sighted during the Vava'u BIORAPboat surveys, February 2014.

Survey no.	Date	Boat	Time at sea (h:min)	Distance covered (km)			Beaufort	No. of groups sighted
				Coastal	Inner	Oceanic		
1	15/02/2014	*Plan B*	03:02	15.7	0.0	30.8	1–2	1
2	16/02/2014	*Plan B*	01:38	20.5	0.0	7.2	0–3	0
3	18/02/2014	*Dev Ocean*	07:13	24.6	8.3	41.6	1–3	1
4	19/02/2014	*Dev Ocean*	07:06	60.6	46.8	0.0	1–3	0
5	20/02/2014	*Dev Ocean*	07:40	45.4	36.2	32.5	1–3	2
6	21/02/2014	*Dev Ocean*	07:51	17.8	77.2	38.7	1	0
7	22/02/2014	*Dev Ocean*	07:10	48.2	18.7	44.0	1–3	1
8	24/02/2014	*Dev Ocean*	07:56	76.9	33.5	0.0	1–4	5
9	25/02/2014	*Dev Ocean*	06:47	14.2	63.0	49.3	1–3	0
		Total	**56:23**	**323.9**	**283.7**	**244.1**	**–**	**10**

In total, we covered a distance of 852 km at sea, spending 49h 48min looking for marine mammals and marine turtles, and 6h 35min following focal dolphin schools for data collection (Table 12.1). Survey vessels did not follow predefined transects but we attempted to cover each type of habitat within the surrounding waters of Vava'u (Figure 12.1). Here, we consider three main types of habitats, defined as follows:

- Coastal habitat: waters within 1 km from shoreline or outer barrier reef (usually <500 m deep), opening on slope and oceanic waters (representing 38% of total distance covered);
- Inner waters: shallow waters (<200 m) roughly delimited by the Vava'u island group and barrier reefs spreading south of the main islands (33% of total distance covered);
- Slope and oceanic waters: deeper waters (>500 m) offshore coastal areas or barrier reef (29% of total distance covered).

Opportunistic surveys from *Plan B* provided the opportunity to cover oceanic waters north of Vava'u, as well as the coastal waters of Toku and Fonualei, two small islands located at 50 and 70 km from the northern tip of Vava'u, respectively. *Dev Ocean* survey tracks starting from the Vava'u group (either Neiafu or Foeata) were designed on a daily basis, depending on areas that had been not previously surveyed, as well as on the wind and sea conditions. Coastal waters around both large and small islands of the group were extensively covered. The main island was circumnavigated twice. Offshore surveys were mostly on the western side of the group but on one occasion we also covered oceanic waters to the southeast (Figure 12.1).

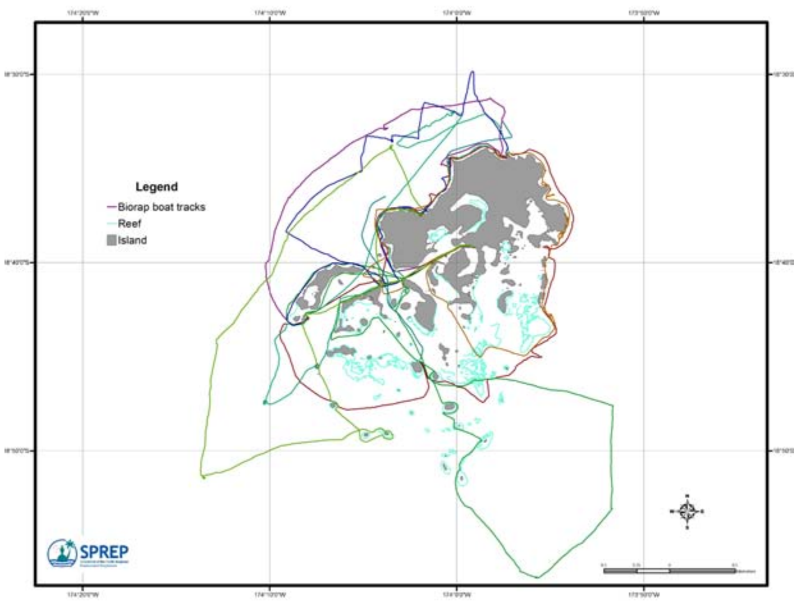

Figure 12.1. Cetacean and marine turtle boat survey tracks around the Vava'u archipelago, February 2014.

12.3.2. DATA COLLECTION

Beaufort Sea State (BSS) was recorded continuously, as it changed during the surveys. When cetaceans were sighted, groups were slowly approached and animals were photographed to confirm species identity. For each encounter, the time, GPS position, group size (minimum and maximum visual estimations) and group behaviour were recorded. Cetacean behavioural states were classified based on the usual categories used for dolphin species, i.e. socialising, resting, foraging, travelling and milling. The presence of any calves in the groups was noted (i.e. individuals with total length less than two-thirds of an adult). Photographs of dolphin dorsal fins were also collected for the purpose of individual identification (Würsig and Jefferson 1990). We used digital SLR cameras equipped with a 75–300 mm lens.

Skin samples for genetic analyses were collected from dolphins and short-finned pilot whales using small biopsy darts fired from a modified veterinary biopsy system equipped with a variable pressure valve. This system was especially developed to assure minimal impact on small cetaceans (Krützenet al. 2002). Samples were preserved in 70% ethanol and stored at −4°C for subsequent analyses.

Attempts to record underwater cetacean vocalisations were regularly made by dipping a hydrophone in the water from the boat at about 5 m depth for periods of 5 min.

In addition to the sightings made during the BIORAP, we also included the opportunistic sightings of small cetaceans made during humpback whale surveys conducted between 1991 and 2009 by the SPWRC (R. Constantine, personal communication).

12.3.3. GENETIC ANALYSES

Total DNA was isolated from skin tissue by digestion with proteinase K followed by Gentra Pure Gene extraction kit protocol. A fragment of the 5′ end of the mitochondrial DNA (mtDNA) control region was amplified via polymerase chain reaction (PCR) using the primers lightstrand, tPro-whale M13-Dlp-1.5 (5′-TCACCCAAAGCTGRATTCTA-3′; Daleboutet al. 1998) and heavy strand, Dlp-8G (5′-GGAGTACTATGTCCTGTAACCA-3′; Daleboutet al. 2005). PCR reactions and sequencing were conducted as reported in Oremus et al.(2007). The sex of each sampled dolphin was identified by multiplex amplification of the male-specific *Sry* gene with *ZFY/ZFX* as a positive control (Gilsonet al. 1998).

Newly generated sequences were aligned using the MUSCLE alignment method with the default setting (Edgar 2004), as implemented in the software GENEIOUS v.6(Drummond et al. 2009). Variable sites were identified and confirmed by visual inspection of peak heights.

12.3.4. VAVA'U TURTLE MONITORING PROGRAM

Data on turtle sightings at sea have been collected in a variety of ways by the Vava'u Turtle Monitoring Program (VTMP); to date all of these sightings have been incidental encounters rather than through targeted surveys. There have been three primary methods of data collection for turtle sightings. One is direct observation by the project leader with location, date, species (where possible) and behaviour noted. The second method is through participation by tourism business operators. Selected operators are provided with identification guides to the two more common turtle species found in Vava'u (green and hawksbill turtles) and also with a data collection sheet. These sheets are completed and returned to VTMP for data entry. The third method of data collection is through public participation at the VTMP office. Members of the public are able to complete a sighting form under supervision at the office. For all described methods, where the observer was unable to identify the turtle species or there was sufficient doubt over the identification, it was recorded as 'unconfirmed'. The project leader has, where possible, visited areas of multiple sightings to confirm turtle species.

Due to the patterns emerging in different level of turtle activity in different areas of Vava'u, VTMP methodology has been to place turtle species sightings in the following categories: occasional (n = 2–4), few (n = 5–9) and many (n = 10+). n = 1 has not been included in this dataset to enable areas of multiple sightings, and therefore increased importance, to be highlighted.

VTMP and historical nesting survey data are also included here, as the BIORAP survey was conducted outside the turtle nesting season (November to January). VTMP has so far conducted two nesting surveys, covering the 2012/13 and 2013/14 nesting seasons. Due to the remote nature of the nesting islands, targeted daytime beach surveys were conducted on potential nesting islands (Walker 2013) looking for evidence of successful nesting or nesting activity. Multiple island surveys were scheduled weekly during the peak nesting months of December and January; however, weather and sea conditions determined final survey effort. For each nesting activity identified, average track width, location, nesting stage and species, where possible, was recorded.

12.4. Results

12.4.1. CETACEAN SIGHTINGS

During the BIORAP boat surveys, weather conditions were good overall with a BSS 1 or 2 for 82% of the time. Conditions were thus largely favourable to detect the presence of cetaceans and marine turtles. In total, there were ten sightings of cetaceans, representing at least three taxa (Figure 12.2, Table 12.2). These were the spinner dolphin (*Stenella longirostris*, n = 5), the short-finned pilot whale (*Globicephala macrorhynchus*, n = 1) and the bottlenose dolphin (*Tursiopstruncatus*, n = 1). For the last two sightings, the species could not be identified because the individuals were too far from the boat (sighting from *Plan B*) or because the animals disappeared soon after the initial sighting, before a species identification could be made. These most likely belonged to the delphinid family.

Table 12.2. Summary of cetacean group encounters during the Vava'u BIORAP surveys, February 2014.

Group code	Date	Species	Group size		Behaviour
			Min.	Max.	
P14-001	15/02/2014	Delphinid sp.	2	?	Feeding
P14-002	18/02/2014	*Stenella longirostris*	10	15	Resting
P14-003	18/02/2014	Delphinid sp.	?	?	?
P14-004	20/02/2014	*Globicephala macrorhynchus*	40	50	Travelling
P14-005	20/02/2014	*Tursiops truncatus*	20	25	Travelling
P14-006	22/02/2014	*Stenella longirostris*	11	13	Socialising
P14-007	24/02/2014	Delphinid sp.	2	?	?
P14-008	24/02/2014	*Stenella longirostris*	6	?	?
P14-009	24/02/2014	*Stenella longirostris*	20	25	Resting
P14-010	24/02/2014	*Stenella longirostris*	50	60	Socialising

Overall, the cetacean encounter rate was 1.2 groups per 100 km of effort. These were mostly seen in coastal areas (n = 6, 1.9 groups/100 km of effort), but the offshore encounter rate was only slightly lower (n = 4 groups, 1.6 group/100 km of effort). On the other hand, no cetacean was observed in the inner shallow waters of Vava'u despite covering 284 km of track line in this habitat. However, opportunistic sightings made by the SPWRC over several years of research on humpback whales (n = 19) show that dolphins are occasionally seen in the inner waters of Vava'u (Figure 12.2). SPWRC sightings were mostly of spinner dolphins (n = 8) but bottlenose dolphins and short-finned pilot whales were also observed once each in this habitat.

The only cetacean species identified incoastal waters during the BIORAP surveys was the spinner dolphin (n = 5). However, there were opportunistic sightings from the SPWRC of two groups of false killers (*Pseudorca crassidens*) and two groups of bottlenose dolphins close to the coast in 2003 and 2004.

During the BIORAP surveys, spinner dolphin group sizes ranged from 10 to 60 with an average of 20–30 per group. Short-finned pilot whales and bottlenose dolphins were seen offshore with group sizes estimated at 40–50 and 20–25 respectively.

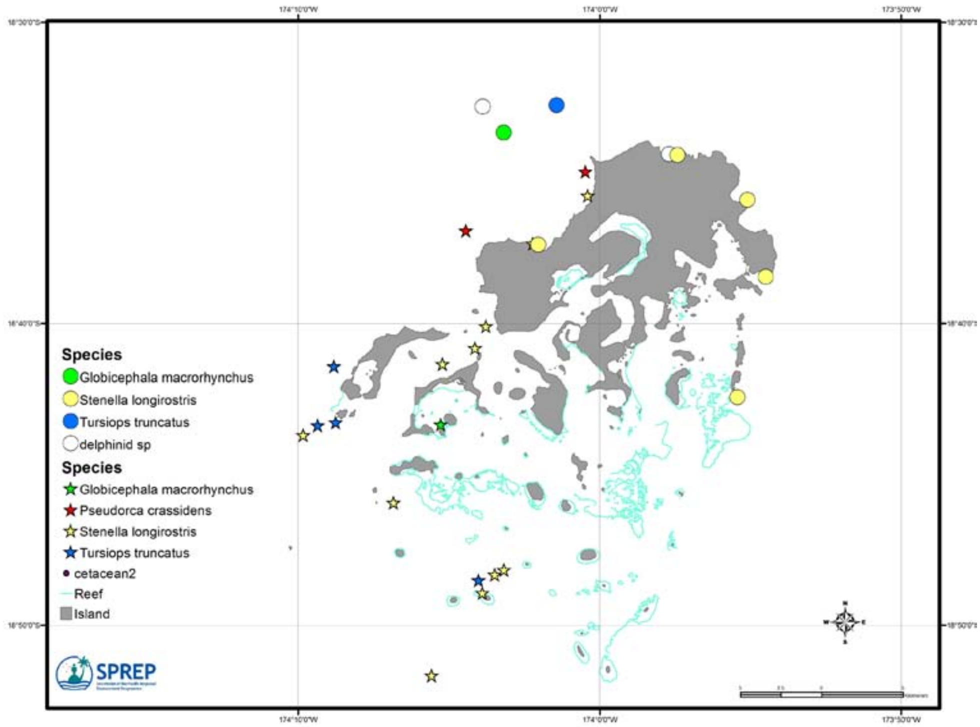

Figure 12.2. Location of small cetacean groups encountered around Vava'u during the BIORAP surveys (circles) and during the SPWRC humpback whale surveys (stars).

12.4.2. GENETIC ANALYSES

A total of 19 biopsy samples was collected – seven samples from spinner dolphins, eight samples from short-finned pilot whales and four samples from bottlenose dolphins. DNA was extracted from all the samples. Molecular sexing revealed that samples were collected from 11 females and eight males. Mitochondrial DNA(mtDNA) control region sequences (650 base pairs long) were obtained from 11 samples (five spinner dolphins, five short-finned pilot whales and one bottlenose dolphin). Each of the five spinner samples carried a different haplotype and a total of 27 polymorphic sites were identified among them. On the other hand, the five short-finned pilot whales had the same haplotype for the same fragment.

The sequence obtained from the bottlenose dolphin was used to clarify the taxonomic status of this population, previously referred to as *Tursiops* sp. (Miller 2007). The sequence was submitted to the web-based program DNA-surveillance (Rosset al. 2003) which assists in the identification of the species of unknown specimens by aligning user-submitted DNA sequences with a validated and curated data set of reference sequences for all know cetaceans. Phylogenetic analyses were performed and results clearly indicate that the bottlenose dolphins observed in Vava'u are common bottlenose dolphins (*T. truncatus*).

12.4.3. MARINE TURTLE SIGHTINGS AT SEA

Only four sightings of marine turtles were made around the Vava'u island group during the BIORAP boat surveys, providing a low encounter rate of 0.5 turtles per 100 km of effort. Three additional opportunistic sightings were made by members of the BIORAP marine team: one around the island of Vava'u, one in Fonualei and one at Joe's Spit off Toku Island. The species was visually identified in six instances. They were all green turtles (*Chelonia mydas*) except for the sighting at Joe's Spit which was a hawksbill turtle (*Eretmochelys imbricata*) (Figure 12.3).

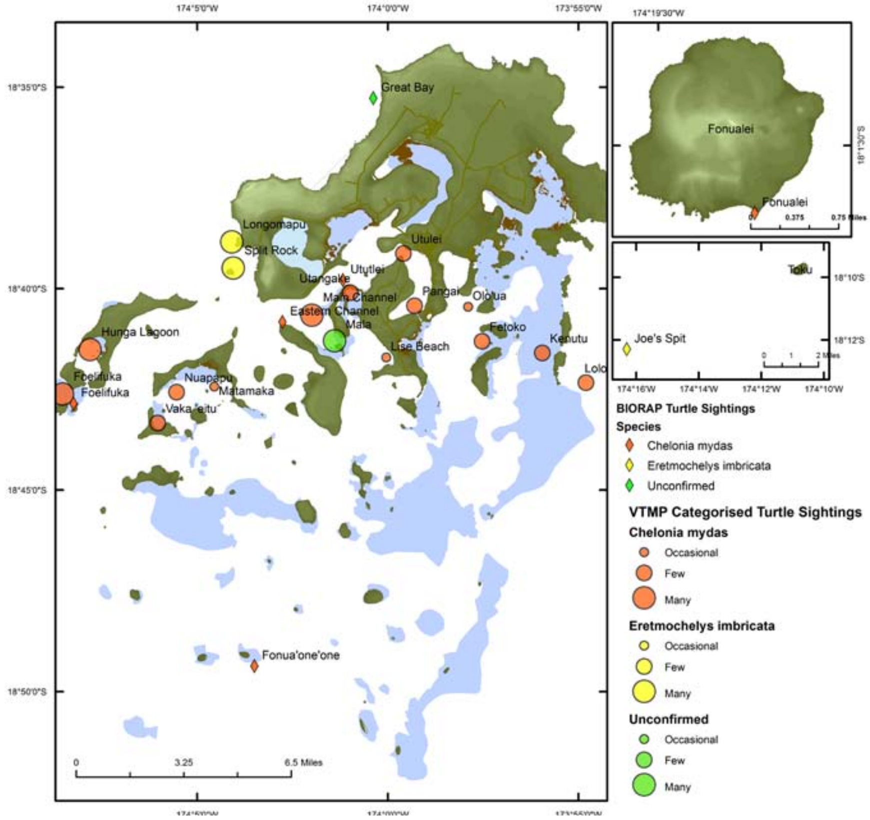

Figure 12.3. BIORAP (diamond) and VTMP (dot) marine turtle sighting locations. The VTMP sightings are categorised into 'occasional' (n= 2–4), 'few' (n = 5–9) and 'many' (n>10).

The VTMP sightings data indicate several important foraging areas in the main island group (Figure 12.3). In this context 'important' is defined as areas with many (n > 10) sightings of turtle species. For green turtles, the important areas are Hunga Lagoon, Foelifuka (also referred to as the Blue Lagoon) and the main channel into Neiafu harbour. Longomapu and the Split Rock dive site are recorded important areas for hawksbill turtles. Mala Island is an important area for an unconfirmed species of turtle; both hawksbills and green turtles have been recorded at this location, but these are not yet confirmed.

Of the five BIORAP turtle sightings within the main island group of Vava'u (excluding Fonualei and Toku), three coincide with the key areas identified by the VTMP data: the village of 'Utelei, the area known as Blue Lagoon, and the main channel to the west of Mala Island.

12.4.4. MARINE TURTLE NESTING SITES

The 1974 survey (Braley 1974) visited four of Vava'u's outer islands, Maninita, Taula, Fonua'one'one and Fangasito, over the course of several days to look for evidence of turtle nesting. Of these islands, nesting activity was found on three, with Fangasito being the only island without observed activity. In total, five nests were identified on Maninita, two on Taula and two on Fonua'one'one, all of varying ages, with six of these nests showing signs of egg poaching (Figure 12.4). In addition, anecdotal evidence gathered from informal interviews conducted by VTMP in 2012 with local fishermen, island communities, Tongan Ministry of Fisheries representatives, longterm residents and island resort operators suggests that nesting of unconfirmed species occurred on many of the southern islands and some beaches near villages on the western islands (Figure 12.4).

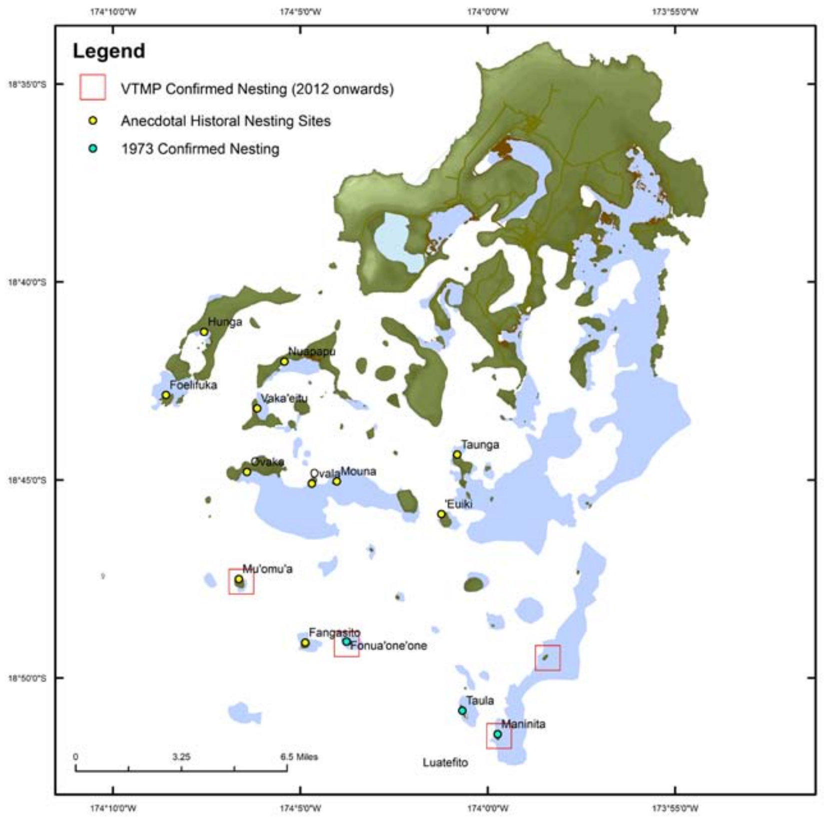

Figure 12.4. Anecdotal, historical (Braley 1974) and recent (VTMP data from 2012-2013) turtle nesting records for Vava'u.

More recently, the 2012/13 nesting surveys by VTMP identified nesting activity on four islands: Maninita, Fonua'one'one, Mu'omu'a and Luatafito (Table 12.3, Figure 12.4). Of these islands, successful nesting occurred only on Maninita and Fonua'one'one. The 2013/14 nesting survey was disrupted by rough sea conditions in December and Cyclone Ian in early January, resulting in a low survey effort pre-cyclone and no evidence of nesting activities post-cyclone. Any evidence of nesting before the cyclone would have been obscured by the significant changes to the outer island beaches with notable accretion and/or erosion of the beaches surrounding the islands.

Table 12.3. Summary of the Vava'u Turtle Monitoring Program nesting survey 2012/13.

Island	Date	Activities	Notes
Maninita	09/01/13	1–5 day old nest, track width 23.5 inches	Probably hawksbill
		1 very old hawksbill track, track width 23inches	No down track but this is possibly obscured by newer track adjacent to it. Possible lay
		1 old hawksbill track, potential false crawl or egg poaching. Track width 27 inches	Holes dug at this nesting site but cannot confirm human activity relating to this – minimal disturbance in area. Poor nesting site with lots of roots so possible false crawl
Fonua'one'one	10/01/13	1 new nest, hawksbill. Track width 29.5 inches	Probable nest as track were broken by camouflage area
		1 very old track	No ID or measurements possible. No downward track observed. No signs of human on beach. Possible lay
Luatafito	18/01/13	1 false crawl	2 body pits but probably no nest
		1 possible false crawl	Very old so no tracks but evidence of body pits
Mu'omu'a	19/01/13	Potential false crawls	Some potential body pits observed. After tropical storm so no tracks present

12.4.5. SPECIES DIVERSITY

Cetaceans

The three cetacean species observed during the systematic surveys were already known from this region (Table 12.4). However, we opportunistically found evidence of the presence of two other species that had not been previously recorded in Tonga. First, while visiting the Blue Lagoon Resort, Foeata Island, we noticed that marine mammal bones, including skulls, were displayed at the reception. They appeared to be from beaked whales. The owner explained how two whales, presumably a mother and her calf, were found stranded on the resort's beach in August 2009. A photograph taken ofone of the animals clearly supports species identification as Cuvier's beaked whale (*Ziphius cavirostris*) (Figure 12.5). Second, two independent sightings at sea were made by K. Stone (VEPA) of rough-toothed dolphin (*Steno bredanensis*), a small delphinid easily identified by the conical shape of its head.

Overall, there are now 14 marine mammal species officially confirmed as occurring in Tonga, including two baleen whales, nine dolphins and one sperm whale (Table12.4). On the IUCN Red List, seven of these are listed as Least Concern, five are listed as Data Deficient, one is listed as Vulnerable and one is listed as Endangered (the humpback whale).

Table 12.4. List of cetacean species reported in Tonga, including the species identified during the Vava'u BIORAP, February 2014.

Common name	Latin name	Suspected habitat around Vava'u	IUCN Red List category	Source
Dwarf minke whale	*Balaenoptera acutorostrata*	Oceanic	Least Concern	SPWRC 2004
Humpback whale	*Megaptera novaeangliae*	Coastal	Endangered	Dawbin 1964, SPWRC 2004
Pygmy killer whale	*Feresa attenuata*	Oceanic	Data Deficient	SPWRC 2004
Short-finned pilot whale	*Globicephala macrorhynchus*	Oceanic	Data Deficient	Hoyt 2001, BIORAP
Risso's dolphin	*Grampus griseus*	Oceanic	Least Concern	SPWRC 2004
Killer whale	*Orcinus orca*	Oceanic	Data Deficient	Visser and Bonoccorso 2003
Melon-headed whale	*Peponocephala electra*	Oceanic	Least Concern	SPWRC 2004
False killer whale	*Pseudorca crassidens*	Oceanic	Data Deficient	Reeves et al. 1999
Pantropical spotted dolphin	*Stenella attenuata*	Oceanic	Data Deficient	SPWRC 2004
Spinner dolphin	*Stenella longirostris*	Coastal	Least Concern	UNEP-WCMC 2003, BIORAP
Common bottlenose dolphin	*Tursiops truncatus*	Oceanic/coastal	Least Concern	BIORAP
Sperm whale	*Physeter macrocephalus*	Oceanic	Vulnerable	Dufault and Whitehead 1995
Cuvier's beaked whale	*Ziphius cavirostris*	Oceanic	Least Concern	BIORAP
Rough-toothed dolphin	*Steno bredanensis*	Oceanic	Least Concern	BIORAP (K. Stone, personal comunication)

Figure 12.5. Photograph of a Cuvier's beaked whale (*Ziphius cavirostris*) stranded at Foeata Island, Vava'u, in August 2009 (photo by the Blue Lagoon Resort, Vava'u).

Marine turtles

Within Tonga, the green turtle (*Chelonia mydas*) and the hawksbill turtle (*Eretmochelys imbricata*, known locally as Fonu Tu'akoloa) are the two most commonly recorded species. There has also been a reliable reported 2009 sighting in Vava'u of the leatherback turtle (*Dermochelys coriacae*) (K. Stone, personal communication), one recent documented sighting of a loggerhead turtle in Tongatapu (*Caretta caretta*) (J. Kupu, personal communication) and historical reported sightings of the Eastern Pacific green turtle subspecies (*C. agassizii*) in Tongan waters (Wilkinson 1979). Table 12.5 summarises reported marine turtle diversity and IUCN Red List status (2008) in Vava'u over the past 30 years.

Table 12.5. Summary of sea turtle diversity in Vava'u.

Common name	Latin name	Notes	IUCN Red List category
Green turtle	*Chelonia mydas*	Commonly seen throughout Vava'u and commonly targeted byfishers	Endangered
Hawksbill turtle	*Eretmochelys imbricata*	Reported sightings in select locations in Vava'u. Recorded as more common nesting species	Critically Endangered
Leatherback turtle	*Dermochelys coriacae*	One recorded sighting in 2009	Critically Endangered
Loggerhead turtle	*Caretta caretta*	Purchased from local fisherman in Tongatapu and photographed in 2011	Endangered

12.5. Discussion

12.5.1. MARINE MAMMAL DIVERSITY IN VAVA'U

The BIORAP survey provided an opportunity to gain further knowledge on cetacean diversity in Vava'u. In her inventory of cetacean diversity in the Pacific islands region, Miller (2007) reported 12 confirmed species in Tonga (Table12.4). As a result of the BIORAP, two additional species are now officially added to that list: the Cuvier's beaked whale and the rough-toothed dolphin. Cuvier's beaked whale is the only species of the Ziphiidae family (beaked whales) confirmed in Tonga. A report of another species, the Antarctic minke whale (*Balaenoptera bonaerensis*), has been made but this requires confirmation.

Genetic analyses have helped to clarify the taxonomic status of bottlenose dolphins around Vava'u as *Tursiops truncatus*. Two distinct species of bottlenose dolphin are known to occur in Oceania: the widely distributed common bottlenose dolphin (*T. truncatus*) and the Indo-Pacific bottlenose dolphin (*T. aduncus*), the distribution of which appears to be restricted to the western part of Oceania and beyond. While the theoretical distribution of the two species as well as the overall morphological description suggested that bottlenose dolphins from Tonga are the *T. truncatus* species, the paucity of sightings had prevented a definite conclusion. This has now been clarified.

We note that 32 cetacean species have been recorded so far across the whole of Oceania, including ten baleen whales, 16 dolphins, three sperm whales (including the dwarf and pygmy species) and three beaked whales. The majority of these species are known to have a wide distribution that most likely includes the waters of Tonga. However, many of them have not been recorded in this region yet, perhaps because of their sparse distribution, elusive habits and remote oceanic habitat.

12.5.2. SMALL CETACEANS AROUND VAVA'U

The small cetacean group encounter rate around Vava'u (1.2 groups/100km) was relatively low. In comparison, cetacean surveys were recently conducted in the Solomon Islands and in the Marquesas Islands following the same protocol, resulting in an overall encounter rate of 2.4 and 5.5 groups per 100 km, respectively (Oremuset al. 2012; Pooleet al. 2013). However, similar encounter rates have been found in archipelagos of Oceania located at similar latitudes, such as Fiji and Vanuatu (M. Oremus, personal communication).

As for most archipelagos of Oceania, the spinner dolphin appears to be the most common species in the coastal waters of Vava'u. As such, they deserve particular attention since their coastal habitat is likely to be impacted by anthropogenic pressures. This species usually forms small resident populations, feeding offshore at night but approaching the coast during the day in order to rest in shallow waters. Our results suggest that in Vava'u, spinner dolphins use 'coastal habitat' more than 'inner waters' (as described in the methods), but further studies are needed to describe the preferred habitat around this island group. It is likely that some bays or reefs are visited more than others, as has been described elsewhere (e.g. Poole, 1995). Spinner dolphins are the focus of dolphin watching activities around many islands of the Pacific Ocean (e.g. in French Polynesia and Hawai'i), and this could provide an opportunity for local operators in Vava'u to work all year round, rather than just during winter when humpback whales are present. However, it appears that no area is constantly used as a resting site and the probability of finding a group might be too low to sustain a commercial activity in this region.

Common bottlenose dolphins could also be regular users of coastal and inner waters although we found no evidence for this during the boat surveys in Vava'u. However, opportunistic sightings by the SPRWC as well as the BIORAP sighting along the coast of Fonualei suggest it may be the case. Unlike spinner dolphins they might rely on coastal resources. All other small cetacean species occurring or likely occurring in the area are probably specialised in offshore waters (Table 12.4). While their habitat makes them somewhat less under threat than coastal species, they can potentially be impacted by fisheries activities and by-catch.

The dolphin DNA samples collected during the BIORAP will be added to the aPOD database. Preliminary analyses of genetic diversity indicate contrasting levels of mtDNA diversity in spinner dolphins and short-finned pilot whales. This was to be expected based on previous studies conducted in the Oceania region (Oremuset al. 2007, 2009). The aPOD project aims at providing information that can help in the design and implementation of marine protected areas (MPAs) for long-lived, highly mobile top predators such as dolphins. In that respect, the BIORAP samples are an important contribution to this large scale project although further sampling is needed.

12.5.3. VAVA'U HUMPBACK WHALE REVIEW

Humpback whales were hunted by 19th century sail whalers in the South Pacific, including Tonga, but it was the industrialised whaling fleets of the 20th century that brought Oceania humpbacks to the verge of local extinction, leaving only a few hundred whales in the entire region. Subsistence whaling in Tonga was an added impact on this severely depleted population, continuing in Vava'u until 1978 when whaling was banned by Royal Decree. The Tongan population may by then have been reduced to as few as 60 adult whales.

Extensive studies on the habitat use of Vava'u by humpback whales have been carried out by the SPWRC over the past two decades. Non-systematic boat-based surveys were initiated in Tonga in 1991 (Abernethyet al. 1992) for the purpose of collecting fluke identification photographs and biopsy skin samples from individual humpback whales.

Over one thousand skin samples have been collected from humpback whales in Tonga and five other wintering areas of the Southern Hemisphere (New Caledonia, Cook Islands, eastern Polynesia, Colombia and Western Australia), to investigate the genetic structureof the Oceania humpback whale population. Significant genetic differences are evident between whales from the discrete breeding grounds of the South Pacific/east Indian Ocean, demonstrating the presence of genetically distinct subpopulations across Oceania (Olavarría et al. 2007).

Fluke photographs from humpbacks in Vava'u and other South Pacific wintering areas has revealed connectivity between Oceania breeding grounds, with Tonga at the hub (Figure 12.6). Individual movements between wintering areas may be exploratory rather than reflective of permanent changes in site fidelity, as they involve both males and females and do not appear to be directional (Garrigueet al. 2002, 2011). The between-region interchange suggests that humpback whales of Oceania may be considered a single population (albeit with varying levels of subpopulation structure). Regional return of humpbacks to Vava'u between seasons has been documented through both genotype and photograph matches, and the level of regional return is higher than between-region interchange (Garrigueet al. 2011).

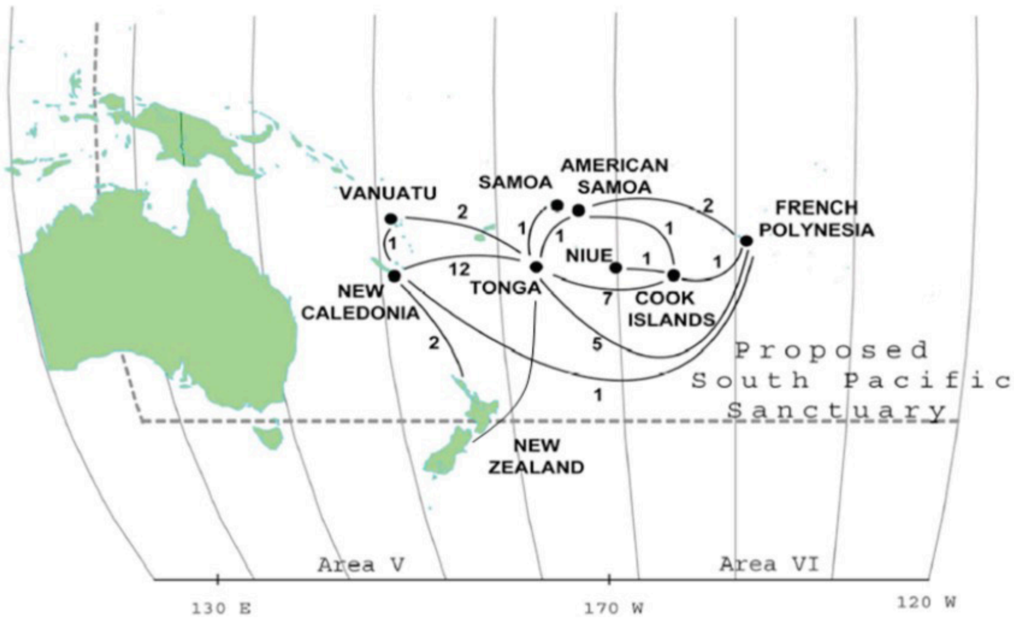

Figure 12.6. Migratory interchange of humpback whales in Oceania 1999–2004, based on photo-identification (from Garrigue et al. 2011).

Both fluke identification photographs and microsatellite genotypes have been used to estimate abundance for the endangered Oceania humpback whales using a sex-specific POPAN super-population model. The total abundance for Oceania humpback whales in 2005 was estimated at 4,329 (3,345–5,313) whales (Constantineet al. 2012). The estimated population for Tonga has recovered from less than 100 forty years ago to about 2,000 whales now.

12.5.4. PREDICTIVE HABITAT MODELLING FOR HUMPBACK WHALES IN VAVA'U

Suitable habitat for humpback whale breeding in Vava'u has recently been examined using spatial analysis tools (Lindsay 2014). By identifying areas of particular importance at a finescale, focussed recovery effort may facilitate more effective protection for humpback whales in their Tongan breeding grounds.

Predictive habitat modelling was undertaken using the software Maximum Entropy (MaxEnt) (Phillips and Dudık 2008), to identify areas of importance for humpback whales in Vava'u. The geographic positions of mother–calf pairs (1996–2007, n= 109, Figure 12.7) and adult-only groups (1996–2007, n= 305, Figure 12.7) that were collected during the annual winter photograph and biopsy collection surveys, together with five environmental variables of the Vava'u region (depth, distance to coral reef, distance to the 200m contour, slope of sea floor, and rugosity of sea floor), were used to predict areas of suitable habitat for humpback whales in Vava'u waters.

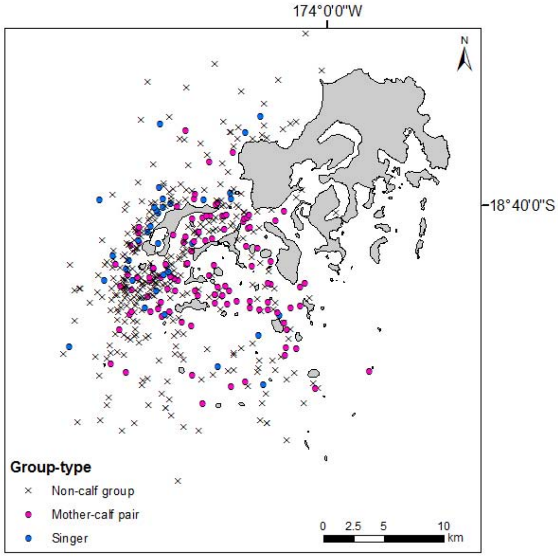

Figure 12.7. The geographic location of the humpback whale grouptypes entered into the habitat models (from Lindsay 2014).

MaxEnt predicts areas of suitable habitat based on the values of environmental factors associated with animal occurrences. The generated output from this modelling technique is a probability surface of predicted habitat suitability. Habitat models were developed separately for mother–calf pair occurrences and adult-only occurrences, to investigate whether there were differences in the geographic extent of suitable habitat for these grouptypes. The predicted habitat for mother–calf pairs includes shallow, nearshore regions of the larger islands such as Hunga and Kapa, as well as the waters surrounding the many smaller islands in the southern region of Vava'u (Figure 12.8A). On the other hand, areas of habitat predicted to be suitable for adult-only groups include deeper areas further offshore around the periphery of the island region (Figure 12.8B). The area predicted to have the highest habitat suitability (>80% probability) for adult-only groups corresponds to an underwater seamount south of the Vava'u islands. This finding is similar to the results from satellite tagged humpback whales in New Caledonia, where the majority of the tagged individuals travelled to Antigonia, a seamount southeast of New Caledonia, previously unknown to be an important habitat for the whales (Garrigue et al. 2010). This illustrates the value of predictive habitat modelling for informing the design of future systematic surveys in Vava'u. Predictive accuracy of the models was tested with bootstrapping analysis, where 25% of the sighting data were withheld and used as test data. Both models performed with good to excellent discriminatory power (Hosmer and Lemeshaw 2000).

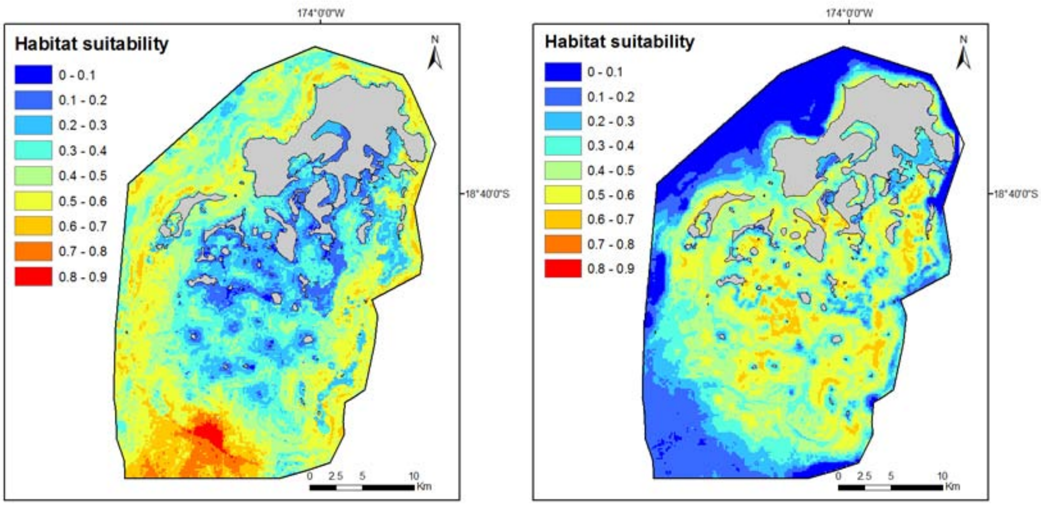

Figure 12.8. Predicted habitat suitability for humpback whale mother–calf pairs (A), and predicted habitat suitability for adult-only groups (B) (from Lindsay 2014).

Caveats

This modelling technique predicts habitat suitability based on environmental composition. This is not equivalent to probability of species presence, which is influenced by a complex interaction of many factors such as inter- and intra-species interactions, human influences, and barriers to dispersal. This does not undermine the insights revealed from this analysis; it just requires caution when interpreting the results. That is, based on the environmental composition of the region it could be assumed that humpback whales are more likely to be present in the areas of higher probability of habitat suitability.

12.5.5. MARINE TURTLE CONSERVATION STATUS

The VTPM has helped to identify important areas for marine turtles. However, further studies are needed to confirm species, habitat use, localised distribution and approximate numbers.

Turtle nesting has historically occurred on many islands throughout the Vava'u island group. However, this brief survey indicated that there is now only limited turtle nesting in Vava'u and the nests that do occur are subject to poaching. The results of the 1974 survey indicated that nest poaching in Vava'u was a worrying trend, and this may have continued in the interim years between Bradey's 1974 study and the VTPM survey.

It is evident from the 1973/74 and 2012/13 nesting surveys that Maninita and Fonua'one'one are key nesting beaches for hawksbill, and potentially for green turtles. Ongoing surveys by the VTMP will seek to confirm this and will continue to survey other potential nesting islands.

Illegal direct take is a documented threat to all turtle species occurring in Vava'u (Wilkinson 1979; Bellet al. 1994). It may be that these direct takes represent the single greatest threat currently facing Vava'u's turtles, due to the relatively low occurrence of other common threats such as coastal development and the absence of nesting activity on inhabited islands where invasive species such as pigs or dogs would usually pose a threat to nest survival. Rats, which are present on some of the nesting beaches, have been recorded as preying on turtle hatchlings in New Caledonia in the absence of breeding seabirds (Cautet al. 2008). In Vava'u however, a successful rat eradication programme was carried out on the most populous nesting island (Maninita) in 2009, and there is an abundance of breeding seabirds on all of the turtle nesting islands. The Fisheries Management (Conservation) Regulations of 2008 define the permissible fishing activities associated with turtles. In summary, these regulations state that females of all species are protected year round; leatherback turtles are protected year round; male turtles of other species, with a minimum carapace length of 45cm, can be caught between 1 February and 31 July; all nests and eggs are protected; turtles cannot be caught with spear guns; and all landed turtles must be presented in their shells to the Ministry of Fisheries for certification. However there is little enforcement of the regulations in the outer island groups of Tonga. There are significant and immediate concerns over the long term effects of two illegal turtle fishing practices: egg poaching from turtle nests and the catching of large female green turtles for important cultural events.

12.6. Conservation recommendations

Small cetaceans

Involve local whale-watch operators and regular sea users to gain further knowledge on cetaceans other the humpback whales. A workshop could be organised to raise awareness on this issue and to provide basic training for species identification and simple data collection. Communication through the local media would also be useful.

Areas for protection of humpback whales

Increasing protection for mother–calf pairs may be most beneficial in shallow nearshore waters surrounding the islands of Luaui, Fangasito, Fonua'one'one, Lape, Mala and Ofu.

The Lalolomei Banksouth of Vava'u has been predicted as highly suitable habitat for adult humpback groups, which is consistent with results from satellite tagged humpback whales of New Caledonia (Garrigueet al. 2010). This is an area where protection efforts may be most valuable for adult humpback whales.

Other specific areas within Vava'u have been identified as being potentially important for all group types, indicating where protection efforts may be most beneficial, but with a note of caution about the efficacy of static boundaries for wideranging animals (Hartel et al. 2014). These areas include up to approximately 3km off the western and northern coasts of Hunga Island, up to 3km south of Foelifuka and Foeata islands, and the triangular region between the islands of Fonuafo'ou, Luatafito and Tahifehifa. We note, however, that delimiting protected areas is unlikely to be efficient or practical for long range and fast moving humpback whales. Therefore, considering that humpback whales are observed in most shallow waters of the Vava'u islands group, it is recommended that all waters less than 200m deep and north of the Lalolomei Bank be considered in the ongoing humpback conservation strategies in Vava'u.

Marine turtles

Protect the beaches of Maninita, Fonua'one'one and Taula islands either as part of a system of marine managed or protected areas or during the turtle nesting season.

Limit and regulate fishing methods and activities in documented important turtle foraging grounds such as Blue Lagoon of Foeata Island, Hunga Lagoon of Hunga Island and the waters surrounding Mala Island. Currently gill netting is practised in these areas by the local communities (K. Walker, personal observation) and the nets are often laid across areas of open, deep water where turtles are known to surface regularly. These netting activities need to be either banned or regulated by zoning of the key foraging areas. Another fishing practice which needs to be banned is fishing for sleeping turtles on the reef at night by fishermen using scuba gear.

Instigate a nationwide awareness programme on the Fisheries Management (Conservation) Regulations 2008 focusing on the protection of female turtles all year round and a guide to identify male from female turtles.

Practice active monitoring and enforcement of the above mentioned regulations.

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CHAPTER 13 CONSERVATION RECOMMENDATIONS & CONCLUSIONS

This BIORAP report focuses on presenting the findings of the biological survey and in particular the biological values of the sites surveyed. The report is not a strategic conservation plan for Vava'u and therefore does not go into detail on the specific actions for each site nor does it attempt to rank sites or actions in order of priority. Additionally, since the survey did not visit all sites of conservation value in the archipelago and because it was conducted over a relatively short period of 16 days, it should be considered a spatial and temporal snapshot of the full biodiversity of Vava'u.

Nevertheless, the BIORAP was the most comprehensive biological survey conducted on Vava'u to date and generated a huge volume of useful information on the biodiversity of the archipelago. The information has been used by the survey teams to generate a number of conservation recommendations, given in detail within the repective chapters. In this chapter these recommendations are consolidated along with justifications for the measures recommended.

13.1. Recommendations

13.1.1 CONSERVE SITES OF SIGNIFICANT CONSERVATION VALUE

Terrestrial sites recommended for conservation

While many areas on 'Uta Vava'u and its outlying islands retain natural values worthy of protection, eight terrestrial sites are recommended as priorities for conservation action. Local knowledge, historical reports and survey interpretation of landforms, vegetation, birds and other animals underpin this assessment. Although Fonualei was not included in the terrestrial BIORAP, previous surveys highlight its importance for forest and as one of only two sites where the Polynesian megapode (*Megapodius pritchardii*) is found.

Details of the eight recommended sites for conservation are given in Table 13.1, including their approximate area, conservation values, ownership, threats and recommended conservation actions. The sites are shown in Figure 13.1 along with the high value marine sites. Note that the boundaries shown are approximate and will need to be defined more accurately later as part of a strategic conservation planning exercise. Terrestrial conservation areas on 'Uta Vava'u should ideally be larger than shown and marine sites should extend out from the coastline to include adjacent lagoons and reefs.

Areas of native forest on Vava'u arekey habitats for native plants, reptiles, birds, insects and land snails. However, indigenous woodland (including mangroves) has been extensively cleared, with around 10% now remaining as a patchy fragmented cover. Surviving forest remnants are continually at risk from destruction or degradation from a variety of causes, including land clearance, browsing and trampling by cattle, pigs and goats, soil disturbance by pigs, weed invasion, fire and cyclone damage. In general, any coastal forest that remains should be conserved as it retains some outstanding values and is at most risk of being developed. Forest in low-lying coastal areas (e.g. on beach flats, and the southern atoll-like islands) is also at risk from storm waves, tsunami and sea level rise.

Some of the terrestrial sites have some existing protection, for example the Mt Talau National Park, although this park is still to be gazetted and managed as such. Most of the proposed sites must clearly be valued and managed by their attendant communities. All remaining large patches of native forest (greater than 10ha) deserve conservation, but in particular the following eight sites.

Table 13.1. Recommended terrestrial sites for conservation and recommended conservation actions.

Site name	Approximate area	Land tenure	Native vegetation cover (%)*	Key conservation values	Main threats	Recommended actions
A'a and 'Oto islands	A'a (51 ha) 'Oto (28 ha)	Government Estate	Aa (58%) 'Oto (70%)	Friendly ground doves Coastal heathand pandanus	Invasive weeds and ants Agriculture? Goats and pigs	Invasive species management (e.g. goats and pigs) Managed development
'Euakafa Island	75 ha	Akau'ola Estate	51%	Blue-crowned lory and other native birds Flying foxes Potential iguana habitat Representative coastal steepland and back-beach vegetation	Invasive weeds and ants Tourism development	Invasive species management Managed development
Maninita, Taula and Lualoli islands	Maninita (7 ha) Taula (9 ha) Lualoli (1ha)	Govt Estate	Maninita (76%) Taula (70%) Lualoli (31%)	Seabird colony Native *Pisonia* forest and strand plants No rats Potential for ecosystem restoration	Rats and many other invasive species Bird and crab harvesting?	Invasive species monitoring (e.g. rats) Invasive species management Enforce harvesting bans?
Mo'ungalafa	177 ha	Ulukalala Estate (Tuanuku)	71%	Blue-crowned lory and other native birds Native forest on limestone and on deep soils Native snails and insects	Invasive species Agriculture?	Invasive species management Managed development and agriculture
Mt Talau	49 ha	Govt Estate (Neiafu)	94%	Sole location of *Casearia buelowii* Native birds Landscape	Invasive plants(e.g. lopa) Agriculture?	Invasive species management (e.g. lopa) Restricted agriculture? Native tree planting
Talehele	>15 ha	Fotu Estate (Leimatu'a)	99%	Native forest Native snails	Invasive species	Invasive species management Expand to cover adjacent bluff forest
Utula'aina Point	>22 ha	King's Estate (Holonga)	94%	Outstanding natural complex of integrated coastal ecosystems Native forest Native snails and insects Flying foxes Lizards and potential iguana habitat Outstanding landscape	Land development/ resort Roading Invasive species Agriculture? Flying fox and other species overharvest?	Invasive species management Managed development Link to marine area
Vai Utu Kakau	>14 ha	Afu Estate (Haalaufuli)	90%	Native forest Native snails	Invasive species Agriculture?	Invasive species management Managed development Link to marine area

*Native vegetation cover includes mangroves, woodland and scrubland, and not areas dominated by introduced plants such as coconut palms, croplands or grasslands.

Mount Talau

Foremost of sites that would benefit from increased conservation is Mount Talau. This hill has visual impact as well as being a vantage point, located on the edge of Neiafu, the main city of Vava'u. Mt Talau has a unique shape and geological formation, and has a secondary forest covering the top. The critically endangered shrub *Casearia buelowii* (no Tongan name) is known only here. The Tongan whistler and many common forest birds are found in good numbers. The site can be accessed easily for education and advocacy.

Mt Talau is not prime land for agriculture, but disturbance in the forest shows it is used for pig ranching as well as recent agroforestry. It will be important to monitor the endangered shrub, and to manage pigs where needed. The invasive red-bead tree *Adenanthera pavonina* (lopa) threatens to dominate the tall woody vegetation and may need a control programme. True recognition and value of the land status and purpose and limiting encroachment would be achieved by giving the park full legal recognition.

Mo'ungalafa

This mountain, like Mt Talau, is on the western end of the main island of Vava'u. Parts of it, especially the steep slopes, cliffs and part of the top, are covered with native lowland forest. This was the most significant forest area on Vava'u for birdlife with both the friendly ground dove (*Gallicolumba stairii*) and the blue-crowned lory (*Vini australis)* present, and it is also important for insects and two species of Critically Endangered land snails endemic to Vava'u (*Sinployea paucicosta* and *Sturanya cuulminans)*. Because of its topography and the presence of skeletal soils on bare rough limestones, the Mo'ungalafa unit values might be easier to preserve compared to other more accessible areas on the island. The downside is that much of the top and surrounding area is highly disturbed, and valued for pigs and cattle.

Utula'aina

This area is one of few places where undisturbed mature lowland forest occurs on flat land. It is situated between the steep coastal slopes and the sea, and is a long walk down from the nearby village of Holonga (see Figure 5.10). Utula'aina is a narrow shape but, contained by extensive natural boundaries, has unparalleled natural continuity of ecosystems with both sheltered and exposed seascapes, and includes a complex of integrated habitats. The BIORAP surveys noted Utula'aina's importance for highly representative but significantly under-protected forest, lack of weed invasion, presence of flying foxes (*Pteropus tonganus*), nymphalid butterflies and other insects, as well as two species of Critically Endangered land snails endemic to Vava'u. Its cultural associations and values are also likely to be highly significant, and the local community have valued its retention which may align well with more formal recognition.

Other important forest remnants on 'Uta Vava'u

The areas of native forest on the coastal cliffs at Tahelele and on the beach flat and coastal cliffs at Vai-utu-kakau Bay are smaller in scale but have high biodiversity values and should be protected. Both these locations have extensive areas of relatively unmodified native vegetation, and are important habitats for insects, birds, reptiles and two species of Critically Endangered land snails endemic to Vava'u.

Outer islands

Several of the outer islands should be protected to retain Vava'u's distinctive natural heritage. Maninita is home to many seabirds, and is also interesting botanically. Several strand plants found on the island are rare elsewhere in Tonga, including *Sesbania coccinea* (ohai), *Boerhavia albiflora* (a new record for Tonga), *Portulaca lutea* (tamole; a new record for Vava'u), *Sesuvium portulacastrum* (a new record for Vava'u), and *Suriana maritima* (rare in Vava'u). 'Euakafa, which is uninhabited, is a good candidate for protection, since the slope and upper regions of the island are covered in mature native forest, and it is home to the blue-crowned lory (*Vini australis*) and flying fox (*Pteropus Tonganus*). At the time of the visit, however, there was construction work near the landing site and a threat of ant and weed invasion and fragmentation. 'Oto and A'a Islands are also conservation candidates, but the goats and pigs present would have to be managed.

Marine sites recommended for conservation

A summary of the species richness and reef heath of all 27 coral reef sites surveyed is given in Annex 13.1. The priority sites for marine conservation are those that have significant conservation values for one or more of the taxonomic groups or indicators assessed (i.e. corals, fish biomass, marine invertebrates, reef fish, reef health, cetaceans and turtles). The top 16 sites for marine conservation are shown in Table 13.2, along with their conservation values and some recommended conservation actions. These sites are mapped in Figure 13.1.

Of the coral reef sites surveyed, several are identified as having a high conservation value based on the data from the focal taxa and overall reef health. It is important to note that for marine invertebrates, due to their incredible diversity, highlighted sites are based on targeted invertebrates only. Indeed, further comprehensive assessments are needed by specialised taxonomists for specific invertebrates.

The cetacean and sea turtle group team recommended several areas for protection based on their findings. For humpback whales, the shallow nearshore waters surrounding the islands of Luaui, Fangasito, Fonua'one'one, Lape, Mala and Ofu were identified as important areas for mother and calves. The Lalolomei Bank south of Vava'u has been predicted as highly suitable habitat for adult humpback groups, and this is an area where protection efforts may be most valuable for adult humpback whales. Other specific areas within Vava'u have been identified as being potentially important for both mother–calf and adult-only groups, indicating where protection efforts may be most beneficial. These areas include up to approximately 3km off the western and northern coasts of Hunga Island, up to 3km south of Foelifuka and Foeata Islands, and the triangular region between the islands of Fonuafo'ou, Luatafito, and Tahifehifa.

It is noted, however, that delimiting protected areas is unlikely to be efficient or practical for long range and fast moving humpback whales. Therefore, considering that humpback whales are observed in most shallow waters of the Vava'u islands group, it is recommended that all the waters less than 200m deep and north of the Lalolomei Bank be considered in the ongoing humpback conservation strategies in Vava'u.

Figure 13.1 Recommended sites for terrestrial and marine conservation efforts in Vava'u.

For marine turtles, the beaches of Maninita, Fonua'one'one and Taula islands are recommended for being included as a system of marine managed or protected areas especially during the turtle nesting season. Other areas critical areas include the documented turtle foraging grounds such as Blue Lagoon of Foeata Island, Hunga Lagoon of Hunga Island and the waters surrounding Mala Island.

Table 13.2. Recommended marine sites for conservation and recommended conservation actions.

Site name	Key conservation values	Recommended actions
'Euakafa Island	Reef health, reef fish, fish biomass (sites 22 and 23)	Include as a system of marine managed or protected areas
'Euaiki Island	Corals, reef health, reef fish, fish biomass (sites 24 and 25)	Include as a system of marine managed or protected areas
Fangasito Island	Corals, reef health, reef fish andfish biomass (site 18) Whales	Include as a system of marine managed or protected areastoapproximately 3kmoffshore
Fonualei Island	Invertebrates* and fish biomass Fish breeding and spawning aggregations	Included as a system of marine managed or protected areas
Fonua'one'one Island	Corals, reef health, reef fish, fish biomass (sites 16 and 17) Whales Sea turtle nesting beaches	Included as a system of marine managed or protected areastoapproximately 3kmoffshore
Foelifuka	Whales	Included as a system of marine managed or protected areastoapproximately 3kmoffshore
Foeata island	Whales Sea turtle foraging grounds in lagoon	Included as a system of marine managed or protected areastoapproximately 3kmoffshore
Hunga Island	Whales Sea turtle foraging grounds in lagoon	Protect area including lagoon to approximately 3kmoff shore
Lape Island	Whales	Included as a system of marine managed or protected areas
Luaui Island	Whales	
Mala Island	Seaturtle foraging grounds in lagoon Whales	Included as a system of marine managed or protected areas
Maninita Island	Reef health, fish biomass (site 12) Sea turtle nesting beaches	Included as a system of marine managed or protected areas
Taula Island	Corals Sea turtle nesting beaches	Included as a system of marine managed or protected areas
Toku Island	Invertebrates*, reef health, reef fish, andfish biomass (sites 7 and 8) Fish breeding and spawning aggregations (site 8)	Included as a system of marine managed or protected areas Institute seasonal and temporary restrictions during breeding and spawning
Triangular region between the Islands of Fonuafo'ou, Luatafito, and Tahifehifa	Whales	Reduce the number of visitors to facilitate fewer disturbances during resting, nursing and mating activities
Vaka'eitu islands	Corals (site 26)	Included as a system of marine managed or protected areas

*Invertebrates include non-cryptic marine invertebrates; assessment based on targeted species only (e.g. trochus, clams and sea cucumbers).

Marine and terrestrial conservation synergies and site consolidation

Given the close interlinkages between terrestrial and marine ecosystems and biodiversity all sites should be managed to ensure that the health and vitality of adjacent ecosystems are maintained under a 'ridge to reef' approach. Special attention should be made to ensure that sites which are particularly important for both marine and terrestrial values such as 'Euakafa, Maninita and Taula are managed holistically to maintain all important environmental values.

Consideration should also be made to joining adjacent sites and islands into larger conservation areas with specific objectives. This might apply for example with A'a and 'Oto, 'Euakafa and 'Euaiki, Toku and Fonualei, Fangasito and Fonua'one'one, and Taula, Maninita and Lualoli, as well as some small sites on 'Uta Vava'u that could be enlarged to cover adjacent forest (e.g. Talehele). Combining sites into larger conservation units will simplify management, increase resilience, encourage species movements and for marine sites, enhance the spillover effect.

It is recommended that:

- A review of different conservation approaches that have been applied both in Tonga and the wider Pacific be conducted by SPREP and partners, identifying their strengths and weaknesses, to come up with relevant and sustainable approaches for Vava'u.
- A conservation planning process in Vava'u be supported by SPREP and partners to develop a detailed action plan for the conservation of the sites, including the possible merging of sites into larger conservation units, to determine specific management objectives for each site, and where appropriate to develop site management plans and funding proposals for further support.

13.1.2. IMPROVE CONSERVATION OF THREATENED SPECIES

Approximately 74 species recognised as globally threatened (i.e. Vulnerable, Endangered or Critically Endangered) on the IUCN Red List of threatened species are found in Vava'u, including 33 corals, three sharks, nine other fish, two marine turtles, one mammal, five bird species, one reptile and one plant. There are many other species that are considered to be threatened but are not yet on the IUCN Red List due to a lack of data to prove their threat status. A preliminary finding of this survey is that some landsnail data are sufficient to formally rank and assign a status on the IUCN Red List.

It is recommended that:

- The Tongan Government considers signing the Convention on International Trade in Endangered Species (CITES), which would help it to control any present or future international trade in organisms that might threaten biodiversity on land or in the sea, while allowing trade that is not a threat. This could be of particular value for some marine species such as clams, sea turtles and trochus.
- Conservation management be implemented for the highly threatened species that require special attention in addition to site based conservation efforts. This may involve a range of complementary actions, such as raising awareness amongst local communities on these threatened species and what is threatening them, enforcing harvest bans, controlling the spread of invasive species as well as conserving key island habitat.

Terrestrial species

Several plant species occurring in Vava'u are rare and in need of special protection. The rarest of them is probably *Casearia buelowii* (no Tongan name) that is known only from Mt Talau. It was found in flower there in January 2013 and in young fruit in February 2014. The seeds should be collected and propagated to save this rare species. A good place for this might be the Ene'io Botanical Garden, whose owner, Haniteli Fa'anunu, shows a keen interest in the flora of Tonga. A second species, *Atractocarpus crosbyi* (no Tongan name), is also endemic to Vava'u. It has attractive flowers that look like small gardenias, and could be a good candidate for propagation as a native ornamental. It was not found during the present survey, but has been found a number of times in the recent past. For both of these shrubs unique to Vava'u, protecting and sustaining populations in their natural setting remains vital and almost certainly protects additional and very ancient values not assessed here.

Two tree species should also be considered for propagation. *Serianthes melanisica* (mohemohe) is an attractive leguminous tree that would do well in cultivation. It is rare in Tonga, and is known in the wild only from Vava'u and Late. A small population of this species is found on the east end of Utungake, and is an easy seed source. A Tongan endemic tree, *Syzygium crosbyi*, should also be propagated since it is rare on Vava'u. Its seeds can also be collected at the same Utungake site noted above. Another leguminous plant, *Sesbania coccinea*, is known in Tonga only from Maninita Island. This can easily be propagated, and should perhaps be planted on other nearby (rat-free) islands. Other rare species will be helped by keeping intact what little native vegetation remains in Vava'u.

At least two endemic land snails are considered Critically Endangered and deserving of special attention because of fragmented populations, population declines and the small area of occupancy. The remaining habitats of *Sinployea paucicosta* and *Sturanya cuulminans*need protection, and further surveys are needed to determine if *Lamprocystis vavauensis*, *Thaumatodon vavauensis* and *Tuimalila infundibulus* are still extant.

Two butterflies, the Tongan leafwing butterfly (*Doleschallia tongana tongana*) and the Fiji glasswing butterfly (*Acraea andromacha polynesiaca*) are of concern for Vava'u and also more widely among Tongan and Fijian islands. A follow-up survey for these and their plant hosts is recommended to identify their threat status and conservation needs.

The Lau banded iguana (*Brachylophus fasciatus*) is the only land reptile from Vava'u that has a classification on the IUCN Red List. It is classified as Endangered with a decreasing population trend. It is persisting on Vava'u but almost nothing is known about this species in Tonga. Iguana specific surveys should be conducted across the Vava'u island group to understand their current distribution and abundance. This information is required to make informed management decisions on proposed locations of forest management areas or where restoration projects should occur. Compiling a checklist of iguana occupied islands is important as many of the islands have more intact forests than the main island. These islands could serve as refugia populations in the event of a catastrophic loss of the species within Vava'u, the rest of Tonga, or in Fiji.

Marine species

There are a number of marine species that are in need of special conservation effort.

It is recommended that:

- Fish breeding and spawning aggregation sites such as the two identified during the BIORAP (i.e. Joe's Spit located off of Toku Island and Fonualei Island) be identified and protected. A temporary closure of identified sites can be instituted during the known time for breeding and spawning activities of particular species (e.g. lutjanids).
- Full species protection be given for the Maori wrasse (*Cheilinus undulates*) and humphead parrotfish (*Bolbometopon muricatum*) and all species of shark. Not only are these species critical for healthy ecosystem functioning, but they are economically valuable as their presence attracts divers boosting tourism.
- Shark finning and associated trade be banned with heavy fines instituted for violators.
- Special studies, population monitoring and protection be carried out for the several endemic fish species have been identified from Tonga. These species include *Meiacanthus procne*, *Meiacanthus tongaensis*, *Praealticus multistriatus*, *Salarias nigrocinctus*, *Cirrhitus albopunctatus*, *Amblyglyphidodon melanopterus*, *Epinephelus chlorocephalus*, *Siganus niger* and *Canthigaster flavoreticulata*.

13.1.3. IMPROVE MANAGEMENT AND USE OF MARINE RESOURCES

In order to improve the management and use of marine resources it is recommended that:

- A temporary or permanent moratorium be introduced on all commercially valuable sea cucumbers.
- A comprehensive stock assessment of giant clams, sea cucumbers and trochus species around Vava'u be conducted.
- Fishing gear restrictions be introduced, including the ban of spearfishing at night and prohibiting the use of small-sized mesh (under 45mm) for gillnets. A full ban on all spearfishing with scuba is recommended. A maximum length and width restriction could also be applied for gillnets to reduce the quantity of fish caught per trip.
- The quantity of fish caught per person or per boat per trip be regulated. General instructions could be given for the number of fish or the total weight of fish allowable per trip based on a household's fish consumption with basic regulations defined by the Ministry of Fisheries.
- The size of fish permitted to be caught be regulated by legislation setting minimum size limits for species. Protecting early life stages and reproduction is essential for stock recovery. Some of these sizes are presented in this report while others can be found on the online database FishBase (www. fishbase. org) or by contacting the Secretariat of the Pacific Community. As bigger fish are best at reproducing, some limitation regarding the larger specimens, especially for the top predators (e.g. groupers), should also be applied.
- Public compliance to fishing regulations and other harvesting restrictions be encouraged through education, awareness and enforcement.

13.1.4. MANAGE THE THREAT TO KEY SITES FROM INVASIVE SPECIES

Invasive species, in particular goats, rats, mice, cats, pigs, insects (especially ants) and weeds, are a major threat to the ecological integrity of the Vava'u islands. Furthermore, biosecurity is not well understood by the local Vava'u community and should be the focus for awareness and training opportunities in the future, especially for ecotourism operators, farmers, fishers and hunters.

It is recommended that:

- A baseline assessment of invasive species be conducted throughout the archipelago, focusing on goats, pigs, rats, yellow crazy ants and weeds as already identified in the Tonga National Invasive Species Strategy and Action Plan (Government of Tonga 2014). The assessment could emphasise the priority conservation sites mentioned in this report, especially the remote outer islands.
- MEC, VEPA and MAFFF monitor the spread of priority invasive species especially to islands with significant conservation values.
- MEC, VEPA and MAFFF conduct practical biosecurity training with local communities, resource owners and tourism operators to obtain support and community understanding over the long term on the risks of introduction or spread of invasive species to new islands or within larger islands.
- Rat management programmes be conducted at relevant sites such as Mt Talau and on offshore islands with the assistance of experienced organisations such as SPREP and Birdlife International.

13.1.5. RAISE PUBLIC AWARENESS ONTHE CONSERVATION VALUES OF THE VAVA'U ARCHIPELAGO

Awareness of the conservation values and threats to the biodiversity of the Vava'u Archipelago is not high among all local public and community groups and therefore needs to be raised.

It is recommended that:

- MEC, VEPA and partners initiate discussions with landowners, communities, resource owners and tourism operators on the biodiversity and conservation values of significant sites and the need for site management so that those values are preserved.
- MEC, VEPA and partners implement conservation education and awareness programmes with Vava'u communities, schools, resource owners and tourism operators, particularly those having ownership over the land, reef and lagoon areas that have significant biodiversity.
- Information from this BIORAP be developed into a resource for both teachers and school children in Tonga. Messages could include the nature of the present harvest ethic; the importance to livelihoods; and the relationship between marine and land management approaches and sustainability for future generations.
- Local whale-watch operators and regular sea users are assisted to gain further knowledge on cetaceans other than humpback whales. A workshop could be organised to raise awareness on this issue and to provide basic training for species identification and simple data collection. Communication through the local media would also be useful.
- Mt Talau is used as a field demonstration site to raise public awareness on environmental values, for example by developing nature trails and environmental interpretation.

13.1.6. RAISE AWARENESS OF AND ENFORCE EXISTING ENVIRONMENTAL LAWS

Tonga has numerous environmental laws that regulate a range of activities including land development, harvesting of endemic wildlife, logging, the extraction of water resources, etc. However, the public is often not aware of these laws and many of them are not adequately enforced.

It is therefore recommended that:

- MEC, VEPA and partners raise the awareness of local communities, resource owners and tourism operators on the existence and purpose of environmental laws and the particular activities that are restricted or regulated. The nature of the present harvest ethic and importance to livelihoods and for future generations could be explored in discussing marine and land reserve approaches.
- Environmental laws, such as those regulating the harvest of birds, fish, flying foxes and turtles, and regulating developments such as new resorts (including requirements for environmental impact assessments), be enforced by the government.

13.1.7. IMPROVE KNOWLEDGE OF THE ECOLOGY AND BIODIVERSITY OF THE VAVA'U ISLANDS

More information is needed to establish a fuller understanding of the ecology of the Vava'u islands and their biodiversity in order to aid species and site conservation and management. Not all important islands and sites were visited during the 16 day BIORAP survey; a number of geographic and taxonomic gaps are therefore priorities for future survey efforts.

It is recommended that:

- Follow-up surveys be encouraged to sites not visited by the survey teams. Areas of woodland on the northern tips of Kapa and Nuapapu would be worth exploring to see whether there is continuity between the birds at Mo'ungalafa and those at A'a and 'Oto (e.g. the friendly ground dove). The three distant offshore islands Late, Fonualei and Tokuwere not visited by one or more BIORAP teams. Fonualei and Late have been recently surveyed for birds only and Fonualei and Toku for marine values only. Furthermore, the survey did not cover wetlands including mangrove areas. All of these gaps are therefore recommended to be addressed in future surveys.
- The following taxonomic groups and species be the focus of future research in order to establish their conservation status: terrestrial –the friendly ground dove (*Gallicolumba stairii*) and blue-crowned lory (*Vini australis*), land snails (*Lamprocystis vavauensis*, *Thaumatodon vavauensis* and *Tuimalila infundibulus* in particular), ants and other insects, reptiles (e.g. the Lau banded iguana, *Brachylophus fasciatus*) and plants (e.g. *Atractocarpus crosbyi*, and the 61 other plant species not recorded in the BIORAP but recorded on Vava'u in the past);marine –more comprehensive macroinvertebrate species surveys by specialised taxonomists are needed.
- Plans for monitoring future coral bleaching events be formulated.
- A comprehensive stock assessment of giant clams, sea cucumbers and trochus species be conducted.
- A survey of the traditional knowledge of local people on their relationship and experiences with their environment and natural resources be conducted. This will provide a baseline on how the diversity of Vava'u looked during the last millennium, and provide MEC and VEPA with important information required to develop appropriate future management approaches.
- Local communities including fishers should be involved in future surveys (e.g. of reef health and spawning grounds). This will ensure local, as well as traditional knowledge is included, and helps to build capacity and increase awareness.

13.1.8. ENSURE ECOTOURISM IS MANAGED SUSTAINABLY

The Vava'u islands are an important ecotourism destination, with thousands of visitors coming every year for whale watching, sailing, diving or simply to sightsee. There is also the potential for growth in terrestrial based ecotourism such as hiking and bird watching. However, ecotourism must be planned properly and managed sensitively in close collaboration with local communities so as not to damage the very values that the industry depends on.

It is recommended that:

- A partnership between the Tonga Visitors Bureau, MEC, VEPA, resource owners, tour operators and local communities be developed, and a sustainable development plan for ecotourism development on Vava'u be prepared and implemented by the partners.
- Ecotourism activities be managed carefully so as to not damage the vulnerable and unique island values. For example, appropriate policies should be put in place to minimise biosecurity risks to islands with large seabird colonies such as Maninita and Taula.
- Environmental guidelines for tourism operators and visiting yachts be developed on the use of coral reef ecosystems in order to reduce anchoring, control the spread of invasive species, stop illegal fishing and improve coral reef awareness within the tourism sector.

13.1.9. REDUCE RUNOFF, POLLUTION AND SEDIMENTATION

Runoff of sediments, nutrients and pollution (e.g. fertilisers, rubbish and sewage) into the sea causes significant damage to marine ecosystems and biodiversity.

It is recommended that:

- Land be managed to minimise runoff of sediments, nutrients and pollution.
- Runoff from coastal developments be reduced by leaving mangroves in place and continuing with replenishment

activities of degraded sites (e.g. planting mangrove trees), and by regulating resorts, restaurants and businesses (including agriculture).

- Monitoring of runoff be conducted where possible (as covered under the Environmental Impact Assessment regulations (Government of Tonga 2010)) and impacts from coastal and large developments be mitigated.

13.2. Conclusion

The BIORAP survey has reconfirmed the critical importance of the biodiversity and native ecosystems of Vava'u's terrestrial and marine environments and the urgent need for follow-up activities to manage and mitigate threats. In the past few centuries the forest cover on Vava'u has declined from close to100% to about 10% today, with concomitant declines in the distribution and abundance of much terrestrial biodiversity, including plants, birds, flying foxes, reptiles, insects and land snails, and the extinction of many species, especially birds and land snails. Fishing pressure in Vava'u has resulted in severe declines in turtles and specific groups of fish and invertebrate species and a collapsing fishery around the archipelago. New invasive species continue to arrive in Tonga while existing invasive species continue to spread to new islands and impact on the structure and function of native ecosystems. Climate change, including the impact of sea level rise and changed weather patterns, is likely to have significant impacts on native biodiversity in the future.

The need to act becomes more urgent every year if biodiversity is to be saved for future generations to utilise and appreciate. Even if all sites recommended for conservation in this report were effectively conserved, they would total less than 4% of the land area of the Vava'u Archipelago. A comprehensive approach to the conservation of the biodiversity of the archipelago would involve a suite of actions in addition to site conservation, such as controlling the spread of invasive species, implementing fishing restrictions, raising awareness on environmental laws, and managing developments such as ecotourism. It is now up to all relevant parties including the Government of Tonga, VEPA and their various development partners, and with the support of the people of Vava'u, to use the findings and recommendations presented in this BIORAP to develop and implement a comprehensive conservation strategy that maintains or even enhances the unique heritage values of the Vava'u Archipelago.

13.3. References

Government of Tonga 2010. Environmental Impact Assessment Regulations. Nukualofa, Tonga:Ministry of Environment and Communication.

Government of Tonga 2014. National Invasive Species Strategy and Action Plan 2013–2020. Nukualofa, Tonga: Ministry of Lands, Environment, Climate Change and Natural Resources.

ANNEXES

Annex 2.1.

INFORMATION ON SITES VISITED BY THE BOTANICAL TEAM FOR THE VAVA'U BIORAP, FEBRUARY 2014

Site name	Date visited	Plot or observation	Start time	Start GPS longitude	Start GPS latitude	Finish GPS longitude	Finish GPS latitude	Plot bearing (magnetic degrees)	Elevation of plot (m)
Mt Talau	13/02/2014	Plot	1.30pm	W174 00.101	S18 38.871	W174 00.094	S18 38.892	140M	128
Utula'aina Point	14/02/2014	Plot	8.50am	W173 56.722	S18 34.511	W173 56.711	S18 34.456	358M	28
Vai utu Kakau	14/02/2014	Obs	3.30pm	W173 55.712	S18 35.808				
Mo'ungalafa1	15/02/2014	Plot	11.40am	W174 03.175	S18 39.246	W174 03.185	S18 39.299	178M	196
Mo'ungalafa2	20/02/2014	Plot	1pm	W174 03.032	S18 39.331	W174 03.036	S18 39.307	340M	166
Kenutu Island	17/02/2014	Obs	10.40am	W173 55.638	S18 41.969				
'Umuna Island	17/02/2014	Obs	2pm	W173 55.446	S18 41.215				
Mafana Island	18/02/2014	Plot	9.30am	W173 57.493	S18 40.920	W173 57.488	S18 40.957	160M	20
Taula Island	19/02/2014	Obs	10.30am	W174 00.682	S18 50.710				
Maninita Island	19/02/2014	Obs	12.15pm	W173 59.776	S18 51.421				
Ngofe marsh	20/02/2014	Obs	9.30am	W174 02.510	S18 39.888				
'Euakafa Island	21/02/2014	Plot	10.20am	W174 02.256	S18 45.421	W174 02.271	S18 45.442	190M	56
'Euaiki Island	21/02/2014	Obs	1.30pm	W174 02.161	S18 45.270				
Vaka'eitu Island	22/02/2014	Plot	10.20am	W174 06.158	S18 43.131	W174 06.171	S18 43.135		24
Talehele (Leimatua seatrack)	24/02/2014	Obs	2.10pm	W174 00.048	S18 35.275				
A'a Island	25/02/2014	Obs	10am	W174 02.557	S18 42.366				
'Oto Island	25/02/2014	Plot	12.12pm	W174 03.360	S18 42.300	W174 03.385	S18 42.299	260M	32
Toafa	26/02/2014	Plot	10am	W174 03.680	S18 37.416	W174 03.654	S18 37.410	80M	216

Annex 2.2.

VEGETATION PLOT DATA

	Species	Tongan name	No.	No.> 15 cm	Basal diameter	Relative dominance
Plot 1. Mt Talau secondary forest						
1	*Alphitonia zizyphoides*	toi	5	5	2,618	22%
2	*Adenanthera pavonina*	lopa	5	2	2,017	17%
3	*Cryptocarya turbinata*	motou	24	1	1,623	14%
4	*Elaeocarpus floridanus*	maamaalava	21	1	1,305	11%
5	*Rhus taitensis*	tavahi	6	3	980	8%
6	*Vavaea amicorum*	ahi vao	19	0	657	6%
7	*Canarium harveyi*	ai	3	1	614	6%
8	*Glochidion ramiflorum*	masi koka	4	1	485	4%
9	*Elattostachys apetala*	gatata	4	0	284	2%
10	*Pleiogynium timoriense*	tagato	3	0	256	2%
11	*Aidia racemosa*	ola maka	4	0	203	2%
12	*Premna serratifolia*	volovalo	1	0	153	1%
13	*Anacolosa lutea*	(none)	1	0	113	1%
14	*Ficus scabra*	masi	3	0	106	1%
15	*Casearia buelowii*	(none)	1	0	95	1%
16	*Zanthophyllum pinnatum*	ake	1	0	95	1%
17	*Tabernaemontana pandacaqui*	te'ete'emanu	2	0	64	1%
18	*Micromelum minutum*	takafalu	1	0	28	+
19	*Mussaenda raiateensis*	monomono'ahina	1	0	28	+
20	*Syzygium clusiifolium*	fekika vao	1	0	28	+
21	*Maniltoa grandiflora*	pekepeka	1	0	28	+
22	*Dysoxylum forsteri*	mo'ota	1	0	20	+
		Per 500 m^2	112	14	11,800	100%
		Per 1,000 m^2	224	28	23,600	78%
Plot 2. Mafana secondary forest						
1	*Rhus taitensis*	tavahi	9	9	4,951	44%
2	*Pleiogynium timoriense*	tangato	3	2	1,806	16%
3	*Hibiscus tiliaceus*	fau	11	1	1,282	11%
4	*Cocos nucifera*	niu	2	2	906	8%
5	*Elattostachys apetala*	ngatata	9	1	800	7%
6	*Zanthophyllum pinnatum*	ake	4	1	489	4%
7	*Alphitonia zizyphoides*	toi	5	2	407	4%
8	*Xylosma smithiana*	filimoto	4	0	202	2%

	Species	Tongan name	No.	No.> 15 cm	Basal diameter	Relative dominance
9	*Vavaea amicorum*	ahi vao	4	0	188	2%
10	*Grewia crenata*	fo'ui	1	0	95	1%
11	*Syzygium clusiifolium*	fekika vao	1	0	28	+
12	*Planchonella grayana*	kalaka	1	0	28	+
		Per 500 m^2	54	18	11,182	100%
		Per 1,000 m^2	108	36	22,364	100%
Plot 3. Mo'unga Lafa secondary forest						
1	*Alphitonia zizyphoides*	toi	24	14	8,883	34%
2	*Rhus taitensis*	tavahi	17	10	5,261	20%
3	*Cryptocarya turbinata*	motou	9	5	2,983	11%
4	*Morinda citrifolia*	nonu	22	1	1,602	6%
5	*Glochidion ramiflorum*	masikoka	16	3	1,543	6%
6	*Ficus scabra*	masi	10	1	1,029	4%
7	*Elaeocarpus floridanus*	ma'ama'alava	2	2	896	3%
8	*Tabernaemontana pandacaqui*	te'ete'emanu	4	1	470	3%
9	*Maniltoa grandiflora*	pekepeka	1	1	415	2%
10	*Grewia crenata*	fo'ui	1	1	355	2%
11	*Elattostachys apetala*	gatata	1	1	346	1%
12	*Canarium harveyi*	ai	1	1	324	1%
13	*Tarenna sambucina*	manonu	8	0	323	1%
14	*Micromelum minutum*	takafalu	10	0	314	1%
15	*Pleiogynium timorense*	tagato	3	1	265	1%
16	*Cordyline fruticosa*	Si	5	0	261	1%
17	*Bischofia javanica*	koka	1	0	154	1%
18	*Anacolosa lutea*	mafua?	1	0	154	1%
19	*Calophyllum neoebudicum*	tamanu	2	0	117	+
20	*Macaranga harveyana*	loupata	1	0	79	+
21	*Diospyros samoensis*	kokauuli	1	0	79	+
22	*Planchonella grayana*	kalaka	1	0	64	+
23	*Zanthophyllum pinnatum*	ake	1	0	64	+
24	*Aidia racemosa*	olamaka	2	0	56	+
25	*Vavaea amicorum*	ahivao	1	0	50	+
26	*Xylosma smithiana*	filimoto	1	0	38	+
27	*Memecylon vitiense*	malamala'atoa	1	0	28	+
28	*Adenanthera pavonina*	lopa	1	0	28	+
29	*Geniostoma rupestre*	te'epilo a Maui	1	0	28	+
		Per 1,000 m^2	149	42	26,209	100

Plot 4. Toafa disturbed lowland forest						
1	*Elattostachys apetala*	ngatata	6	4	4,118	21%
2	*Calophyllum neoebudicum*	tamanu	19	7	3,771	19%
3	*Canarium harveyi*	ai	10	6	3,172	16%
4	*Cycas seemannii*	longolongo	8	6	2,746	14%
5	*Rhus taitensis*	tavahi	3	3	1,446	7%
6	*Elaeocarpus floridanus*	ma'ama'alava	9	1	970	5%
7	*Pittosporum cf. arborescens*	masikona	11	0	636	3%
8	*Meryta macrophylla*	kulukulufa	13	0	445	2%
9	*Alphitonia zizyphoides*	toi	2	1	393	1%
10	*Glochidion ramiflorum*	masikoka	2	0	333	2%
11	*Xylosma smithiana*	filimoto	4	0	314	2%
12	*Vavaea amicorum*	ahi vao	8	0	301	2%
13	*Anacolosa lutea*	mafua	10	0	260	1%
14	*Zanthophyllum pinnatum*	ake	5	0	239	1%
15	*Cryptocarya turbinata*	motou	2	0	114	1%
16	*Pleiogynium timoriense*	tangato	1	0	113	1%
17	*Syzygium clusiifolium*	fekika vao	1	0	50	+
18	*Geniostoma rupestre*	te'e pilo a Maui	1	0	38	+
19	*Tarenna sambucina*	manonu	1	0	28	+
		Per 500 m^2	116	28	19,487	100%
		Per 1,000 m^2	232	56	38,974	100%

Plot 5. Vaka'eitu coastal forest						
1	*Planchonella grayana*	kalaka	9	9	4,274	29%
2	*Zanthophyllum pinnatum*	ake	36	4	2,879	19%
3	*Serianthes melanesica*	mohemohe	5	4	2,273	15%
4	*Guettarda speciosa*	puopua	1	1	1,237	8%
5	*Drypetes vitiensis*	(none)	14	3	1,206	8%
6	*Syzygium* sp.	(none)	1	1	615	6%
7	*Eugenia reinwardtiana*	unuoi	7	0	379	3%
8	*Diospyros elliptica*	kanume	2	1	295	2%
9	*Elattostachys apetala*	ngatata	5	0	271	2%
10	*Neisosperma oppositifolium*	fao	1	1	201	2%
11	*Cryptocarya turbinata*	motou	1	1	177	1%
12	*Memecylon vitiense*	malamala'atoa	2	0	133	1%
13	*Ixora calcicola*	(none)	2	0	102	1%
14	*Vavaea amicorum*	ahi vao	3	0	90	1%
15	*Pleiogynium timoriense*	tangato	2	0	78	1%
16	*Ochrosia vitiensis*	toto hina	1	0	50	+
17	*Micromelum minutum*	takafalu	1	0	28	+
18	*Premna serratifolia*	volovalo	1	0	20	+
		Per 1,000 m^2	94	25	14,803	100%

Plot 6. 'Oto lowland forest						
1	*Chionanthus vitiensis*	afa	22	9	4,433	26%
2	*Maniltoa grandiflora*	pekepeka	13	7	2,737	16%
3	*Planchonella grayana*	kalaka	2	2	2,500	15%
4	*Pleiogynium timoriense*	tangato	2	2	1,508	9%
5	*Planchonella garberi*	(none)	6	1	1,378	8%
6	*Xylosma smithiana*	filimoto	7	1	922	5%
7	*Syzygium clusiifolium*	fekika vao	3	2	821	5%
8	*Premna serratifolia*	volovalo	1	1	754	4%
9	*Ixora calcicola*	(none)	16	0	575	3%
10	*Zanthophyllum pinnatum*	ake	1	1	314	2%
11	*Elattostachys apetala*	ngatata	3	1	267	2%
12	*Eugenia reinwardtiana*	unuoi	5	0	226	1%
13	*Garuga floribunda*	manaui	1	1	177	1%
14	*Ochrosia vitiensis*	toto hina	3	0	94	1%
15	*Aidia racemosa*	olamaka	2	0	88	+
16	*Memecylon vitiense*	malamala'atoa	2	0	48	+
17	*Vavaea amicorum*	ahi vao	1	0	38	+
18	*Diospyros samoensis*	tutuna	1	0	28	+
		Per 500 m^2	91	28	16,908	100%
		Per 1,000 m^2	182	56	33,816	100%

Plot 7. Mougalafa Lowland Forest						
1	*Maniltoa grandiflora*	pekepeka	11	7	6,578	19%
2	*Cryptocarya turbinata*	motou	38	7	4,811	14%
3	*Garuga floribunda*	manaui	2	1	4,794	14%
4	*Pleiogynium timorense*	tangato	7	3	3,717	11%
5	*Chionanthus vitiensis*	afa	2	2	2,189	6%
6	*Vavaea amicorum*	ahi vao	25	3	1,901	6%
7	*Planchonella grayana*	kalaka	1	1	1,520	4%
8	*Dysoxylum forsteri*	mo'ota	4	2	1,491	4%
9	*Elattostachys apetala*	ngatata	7	3	1,420	4%
10	*Serianthes melanesica*	mohemohe	1	1	1,256	4%
11	*Burckella richii*	kau	1	1	1,075	3%
12	*Glochidion ramiflorum*	masi koka	2	2	1,005	3%
13	*Elaeocarpus floridanus*	ma'ama'alava	3	1	928	3%
14	*Canarium harveyi*	'ai	1	1	415	1%
15	*Diospyros samoensis*	tutuna	1	1	314	1%
16	*Rhus taitensis*	tavahi	1	1	283	1%
17	*Pittosporum* cf. *arborescens*	masi kona	1	1	201	1%
18	*Grewia crenata*	fo'ui	1	0	133	+
19	*Anacolosa lutea*	mafua	2	0	84	+

20	*Tarenna sambucina*	manonu	1	0	79	+
21	*Harpullea arborea*	filiamama?	1	0	50	+
22	*Ficus scabra*	masi ata	1	0	50	+
23	*Micromelum minutum*	takafalu	2	0	40	+
24	*Meryta macrophylla*	kulukulufa	1	0	38	+
25	*Aidia racemosa*	ola maka?	1	0	38	+
		Per 1,000 m^2	118	38	34,410	100%

Plot 8. 'Euakafa lowland forest						
1	*Maniltoa grandiflora*	pekepeka	27	9	11,880	43%
2	*Garuga floribunda*	manaui	4	4	9,952	36%
3	*Chionanthus vitiensis*	afa	24	6	2,935	11%
4	*Syzygium* sp.	(none)	1	1	1,134	4%
5	*Dysoxylum forsteri*	mo'ota	2	1	502	2%
6	*Planchonella grayana*	kalaka	2	1	441	2%
7	*Zanthophyllum pinnatum*	ake	1	1	346	1%
8	*Cryptocarya turbinata*	motou	3	0	256	1%
9	*Xylosma smithiana*	filimoto	2	1	254	1%
10	*Ixora calcicola*	(none)	1	0	20	+
		Per 500 m^2	67	24	27,720	100%
		Per 1,000 m^2	134	48	55,440	100%
Plot 9. Utula'aina lowland forest						
1	*Maniltoa grandiflora*	pekepeka	11	5	7,332	23%
2	*Pleiogynium timoriense*	tagato	4	4	7,072	23%
3	*Syzygium clusiifolium*	fekika vao	54	6	5,181	17%
4	*Burckella richii*	kao	2	1	2,570	8%
5	*Crytpocarya turbinata*	motou	4	3	2,429	8%
6	*Zanthophyllum pinnatum*	ake	2	2	1,412	5%
7	*Diospyros samoensis*	kokauuli	1	1	1,075	3%
8	*Canarium harveyi*	'ai	5	2	1,004	3%
9	*Vavaea amicorum*	ahi vao	2	1	934	3%
10	*Garuga floribunda*	manaui	1	1	804	3%
11	*Rhus taitensis*	tavahi	1	1	491	2%
12	*Syzygium richii*	heavula	3	1	351	1%
13	*Tabernaemontana pandacaqui*	te'ete'emanu	2	0	210	1%
14	*Anacolosa lutea*	mafua	3	0	201	1%
15	*Xylosma smithiana*	filimoto	1	0	50	+
16	*Planchonella grayana*	kalaka	1	0	38	+
		Per 1,000 m^2	97	28	31,154	100%

Annex 2.3.

COMPREHENSIVE LIST OF THE FLORA OF VAVA'U

The species are arranged into five groups: (1) dicots; (2) monocots; (3) gymnosperms; (4) ferns; and (5) fern allies. The species in each group were then separated into their respective plant families arranged in alphabetical order, with the species within the families also in alphabetical order. The scientific name of each species is followed in the second column by the authors who named them. The third column comprises the Tongan names (if any). The fourth column comprises the status of each species: I = indigenous; E = endemic; P = Polynesian introduction; and X = alien species. Vouchers are the identification numbers of samples collected during the BIORAP survey.

FAMILY Species	Authors	Tongan name	Status	Vouchers
DICOTS				
ACANTHACEAE				
Blechum pyramidatum	(Lam.) Urb.		X	13611
Graptophyllum insularum	(A. Gray) A. C. Sm.		I	13460
Thunbergia fragrans	Roxb.		X	
AIZOACEAE				
Sesuvium portulacastrum	(L.) L.		I	13555
AMARANTHACEAE				
Achyranthes aspera	L.	tamatama	I	
Alternanthera sessilis	(L.) R. Br. ex DC.		X	13612
Amaranthus viridis	L.	tupu'a	P	13614
Cyathula prostrata	(L.) Bl.		P	
ANACARDIACEAE				
Pleiogynium timoriense	(DC.) Leenh.	tagato	I	13578, 13609
Rhus taitensis	Guillemin	tavahi	I	13551
APIACEAE				
Centella asiatica	(L.) Urban	tono	X	13516
Cyclospermum leptophyllum	(Pers.) Eichler		X	
APOCYNACEAE				
Alyxia stellata	(Forst. f.) R.& S.	maile	I	13523
Cerbera odollam	Gaertn.	toto	I	
Melodinus vitiensis	Rolfe		I	13502, 13562
Neisosperma oppositifolium	(Lam.) Fosb. & Sachet	fao	I	13521
Ochrosia vitiensis	(Markgraf) Pichon	toto hina	I	13520
Tabernaemontana pandacaqui	Lam.	te'ete'emanu	I	13449
ARALIACEAE				
Meryta macrophylla	(Rich ex A. Gray) Seem.	kulukulufa	I	
ASCLEPIADACEAE				
Asclepias curassavica	L.		X	
Hoya australis	R. Br. in Trail	lau matolu	I	

FAMILY Species	Authors	Tongan name	Status	Vouchers
ASTERACEAE				
Adenostemma viscosum	Forst.		P	
Ageratum conyzoides	L.	te'ehoosi	X	
Bidens alba	(L.) DC.		X	
Bidens pilosa	L.	fisi'uli	X	13630
Calyptocarpus vialis	Less.		X	
Conyza bonariensis	(L.) Cronq.		X	
Crassocephalum crepidioides	(Benth.) S. Moore		X	13613
Elephantopus mollis	Kunth		X	13608
Eleutheranthera ruderalis	(Sw.) Sch.-Bip.		X	
Emilia sonchifolia	(L.) DC. in Wight		X	
Erigeron bellioides	DC.		X	13628
Pseudelephantopus spicatus	(B. Juss. ex Aubl.) C. F. Baker		X	
Sigesbeckia orientalis	L.	kakamika	P	
Sonchus oleraceus	L.	longolongo'uha	X	
Synedrella nodiflora	(L.) Gaernt.		X	
Tithonia diversifolius	(Hems.) A. Gray	siola'ā	X	
Tridax procumbens	L.		X	
Vernonia cinerea	(L.) Lessing		X	
Wedelia trilobata	(L.) Hitchc.		X	
Wollastonia biflora	(L.) DC.	ate	I	
BARRINGTONIACEAE				
Barringtonia asiatica	(L.) Kurz	futu	I	
BIGNONIACEAE				
Spathodea campanulata	Beauv.		X	
Tecoma stans	(L.) Juss. ex Kunth		X	
BORAGINACEAE				
Cordia aspera	Forst. f.	tou	P	
Cordia subcordata	Lam.	puataukanave	I	
Tournefortia argentea	L. f.	touhuni	I	13461
BRASSICACEAE				
Rorippa sarmentosa	(DC.) Macbride	akataha	P	
BURSERACEAE				
Canarium harveyi	Seem.	'ai	I	
Garuga floribunda	Dec.	manauui	I	
CAPPARACEAE				
Capparis cordifolia	Lam.		I	13464, 13626
Capparis quiniflora	DC.		I	
CARICACEAE				
Carica papaya	L.	lesi	X	

FAMILY Species	Authors	Tongan name	Status	Vouchers
CASSYTHACEAE				
Cassytha filiformis	L.	fatai	I	
CASUARINACEAE				
Casuarina equisetifolia	L.	toa	P	
CELASTRACEAE				
Gymnosporia vitiensis	(A. Gray) Seem		I	13458
CHRYSOBALANACEAE				
Atuna racemosa	Raf.	pipi fai lolo	P	
Parinari insularum	A. Gray	sea	P	
CLUSIACEAE				
Calophyllum inophyllum	L.	feta'u	I	
Calophyllum neoebudicum	Guillaumin	tamanu	I	
COMBRETACEAE				
Terminalia catappa	L.	telie	I	13527
Terminalia litoralis	Seem.	telie 'a manu	I	13528
CONNARACEAE				
Connarus sp. nova		vavatu	E	
Santaloides samoense	(Lauterb.) Schellenberg	va'a'uli	I	
CONVOLVULACEAE				
Ipomoea alba	L.		X	
Ipomoea cairica	(L.) Sweet		X	
Ipomoea fimbriosepala	Choisy in DC.		I?	
Ipomoea hederifolia	L.		X	
Ipomoea indica	(Burm.) Merr.	fue 'ae puaka	X	
Ipomoea littoralis	Bl.		I	
Ipomoea pes-caprae	(L.) R. Br.	fue tahi, fue kula	I	
Ipomoea violacea	L.	fue hina	I	13499
Merremia peltata	(L.) Merr.	fue mea	I	
Merremia quinquefolia	(L.) Hall. f.		X	
Operculina turpethum	(L.) A. Silva Manso		I	
Operculina ventricosa	(Bertero) Peter		X	
Stictocardia tiliifolia	(Desr.) Hallier f.		X	
CUCURBITACEAE				
Benincasa hispida	(Thunb.) Cogn.	fangu	P	
Cucumis melo	L.	'atiu	P	
Luffa cylindrica	(L.) Roehmer	mafa'i	I	
Momordica charantia	L.		X	
Zehneria samoensis	(A. Gray) Fosb. & Sachet		I	
DICHAPETALACEAE				
Dichapetalum vitiense	(Seem.) Engl.	kili	I	

FAMILY Species	Authors	Tongan name	Status	Vouchers
EBENACEAE				
Diospyros elliptica	(Forst.) P. S. Green	kanume	I	13473
Diospyros samoensis	A. Gray	tutuna, kokau'uli	I	
ELAEOCARPACEAE				
Elaeocarpus floridanus	Hemsley	ma'ama'alava	I	
EUPHORBIACEAE				
Acalypha lanceolata	Willd.		P	13570
Aleurites moluccana	(L.) Willd.	tuitui	P	
Bischofia javanica	Bl.	koka	I	
Chamaesyce chamissonis	(Kl. & Garcke) F. C. Ho		I	13488, 13514
Chamaesyce hirta	(L.) Mill sp.	sakisi	X	
Chamaesyce hypericifolia	(L.) Mill sp.		X	13577, 13595
Chamaesyce hyssopifolia	(L.) Small		X	
Chamaesyce prostrata	(Ait.) Small		X	
Claoxylon fallax	Muell. Arg. in DC.		I	
Croton microtiglium	Burk.		I	13503
Drypetes vitiensis	Croizat		I	
Euphorbia cyathophora	Murray		X	
Excoecaria agallocha	L.	feta'anu	I	13508
Glochidion ramiflorum	Forst. f.	malolo, masikoka	I	13619
Homalanthus nutans	(Forst. f.) Pax	fonua mamala	I	13616
Macaranga harveyana	(Muell. Arg.) Muell. Arg.	loupata	I	
Phyllanthus amicorum	Webster		E	13482
Phyllanthus virgatus	Forst. f.		I	13494
Ricinus communis	L.	lepohina,lepokula	X	
FABACEAE				
Abrus precatorius	L.	matamoho	I	13583
Acacia simplex	(Sparrman) Pedley	tatangia	I	
Adenanthera pavonina	L.	lopa	X	
Alysicarpus vaginalis	(L.) DC.		X	
Bauhinia monandra	Kurz		X	
Caesalpinia major	(Medik.) Dandy & Exell	talatala'amoa	I	
Canavalia cathartica	Thou.		I	
Canavalia rosea	(Sw.) DC.	heketa	I	
Canavalia sericea	A. Gray	fue veli ?	I	13513
Chamaecrista nictitans	(L.) Moench	mateloi Vava'u	X	
Dalbergia candenatensis	(Dennstedt) Prain		I	13531
Dendrolobium umbellatum	(L.) Benth.	lala 'uta	I	13597
Derris trifoliata	Lour.	kavahaha	I	
Desmodium incanum	DC.		X	

FAMILY Species	Authors	Tongan name	Status	Vouchers
Desmodium triflorum	(L.) DC.		X	
Entada phaseoloides	(L.) Merr.	valai, sipi	I	
Erythrina fusca	Lour.	ngatae fisi	X	
Erythrina variegata	L.	ngatae	I	
Glycine tabacina	Benth.		X	
Indigofera suffruticosa	Miller	'akauveli	X	
Inocarpus fagifer	(Park.) Fosb.	ifi	P	
Lablab purpureus	(L.) Sweet		X	
Leucaena leucocephala	(Lam.) de Wit.	siale mohemohe	X	
Macroptilium atropurpureum	(DC) Urb.		X	
Macroptilium lathyroides	(L.) Urb.		X	
Maniltoa grandiflora	(A. Gray) Scheffer	tautau 'a manu, pekepeka	I	
Mimosa diplotricha	C. Wright ex Sauvalle		X	
Mimosa pudica	L.	mateloi	X	
Mucuna gigantea	(Willd.) DC.	valai, pa'anga 'ae kuma	I	13568
Neonotonia wightii	(Arn. in Wight & Arn.) Lackey		X	13547
Pueraria lobata	(Willd.) Ohwi	aka	P	
Schleinitzia insularum	(Guillemin) Burkart	feifai	I	13581
Senna occidentalis	(L.) Link		X	
Senna tora	(L.) Roxb.		X	
Serianthes melanesica	Fosb.	mohemohe	I	13533
Sesbania coccinea	(L. f.) Poir.		I	
Sophora tomentosa	L.		I	13572
Tephrosia purpurea	(L.) Pers.	kavahuhu	P	13474
Vigna adenantha	(G. W. F. Meyer) Maréchal et al.	lautolu 'uta	I	13546
Vigna marina	(Burm.) Merr.	lautolu tahi	I	13484
Zornia diphylla	(L.) Pers.		X	
FLACOURTIACEAE				
Casearia buelowii	Whistler		E	13450
Homalium whitmeeanum	St. John		I	13563
Xylosma orbiculata	(Forst.) Forst. f.	fululupe	I	13472
Xylosma smithiana	Fosb.	fililmoto	E	13465
GENTIANACEAE				
Fagraea berteroana	A. Gray	pua	I	
GOODENIACEAE				
Scaevola taccada	(Gaertn.) Roxb.	ngahu	I	13462
HERNANDIACEAE				
Hernandia nymphaeifolia	(Presl) Kubitski	fotulona, puko	I	13483, 13507

FAMILY Species	Authors	Tongan name	Status	Vouchers
ICACINACEAE				
Citronella samoensis	(A. Gray) Howard		I	
LAMIACEAE				
Leonurus sibiricus	L.		X	
Leucas decemdentata	(Forst. f.) Sm.		P	13618
Salvia occidentalis	Swartz	te'ekosi	X	
Teucrium vesicarium	Mill.		X	
LAURACEAE				
Cryptocarya turbinata	Gillespie	motou	I	
LOGANIACEAE				
Geniostoma rupestre	Forst. f.	te'epilo 'a maui	I	
LORANTHACEAE				
Decaisnina forsteriana	(J. A. & J. H. Schultes) Barrow	topu'ono	I	13589
LYTHRACEAE				
Pemphis acidula	Forst.	ngingie	I	13530
MALVACEAE				
Hibiscus abelmoschus	L.		P	13582
Hibiscus tiliaceus	L.	fau	I	
Sida acuta	Burm. f.	te'ekosi	X	
Sida rhombifolia	L.	te'ehoosi	P	
Sida samoensis	Rechinger		I	
Thespesia populnea	(L.) Sol. ex Correa	milo	I	13585
Urena lobata	L.	mo'osipo Tonga	P	
MELASTOMACEAE				
Melastoma denticulatum	Labill.		I	
Memecylon vitiense	A. Gray	malamala'atoa	I	13453
MELIACEAE				
Dysoxylum forsteri	(Jussieu) C. DC.	mo'ota, mo'ota hina	I	
Vavaea amicorum	Benth.	ahi vao	I	13451
Xylocarpus granatum	Koenig	lekileki	I	
Xylocarpus moluccensis	(Lam.) M. Roem.	lekileki	I	13584
MENISPERMACEAE				
Pachygone vitiense	Diels		I	
Stephania forsteri	(DC.) A. Gray		I	
MORACEAE				
Alchornea scandens	(Lour.) Muell. Arg.	hiehiapo?	I	
Ficus obliqua	Forst. f.	'ovava	I	
Ficus prolixa	Forst . f.	'ovava kulu, 'ovava	I	13579

FAMILY Species	Authors	Tongan name	Status	Vouchers
Ficus scabra	Forst. f.	masi'ata	I	13588
Ficus tinctoria	Forst. f.	masi mole	I	13522
MYRISTICACEAE				
Myristica hypargyraea	A. Gray	kotone	I	
MYRSINACEAE				
Maesa tabacifolia	Mez		I	
Rapanea myricifolia	(A. Gray) Mez		I	
MYRTACEAE				
Decaspermum fruticosum	Forst.	nukonuka	I	13564
Eugenia reinwardtiana	(Bl.) DC.	unuoi	I	13486
Psidium guajava	L.	kuava	X	
Syzygium brackenridgei	(A. Gray) C. Muell.	fekika vao	I	
Syzygium clusiifolium	(A. Gray) C. Muell.	fekika vao, mafua	I	13467
Syzygium crosbyi	(Burkill)	fekika vao	E	13610
Syzygium dealatum	(Burk.) A. C. Sm.	mafua, mafua 'ae lulu	I	
Syzygium richii	(A. Gray) Merr. & Perry	heavula, lepa	I	
NYCTAGINACEAE				
Boerhavia acutifolia	(Choisy) J. W. Moore	akataha kula?	P	
Boerhavia albiflora	Fosb.		I	13553
Pisonia grandis	R. Br.	puko, puko vai	I	
OLACACEAE				
Anacolosa lutea	Gillespie		I	13452
Ximenia americana	L.	vi tahi	I	
Chionanthus vitiense	(Seem.) A. C. Sm.	afa	I	13620
Jasminum didymum	Forst. f.	tutu'uli	I	13480
Jasminum betchei	F. v. Mueller	tutu'uli	I	13505
Jasminum simplicifolium	Forst. f.	tutu'uli	I	
ONAGRACEAE				
Ludwigia octovalvis	(Jacq.) Raven		X	13541
OXALIDACEAE				
Oxalis barrelieri	L.		X	13535
Oxalis corniculata	L.	kihikihi	P	
PASSIFLORACEAE				
Passiflora foetida	L.	vaini ae kuma	X	13519
Passiflora laurifolia	L.	vaini tinetina	X	
Passiflora maliformis	L.	vaini Tonga	X	13476
PIPERACEAE				
Macropiper puberulum	Benth.	kavakava'ulie	I	
Peperomia leptostachya	H. & A.		I	13624

FAMILY Species	Authors	Tongan name	Status	Vouchers
Peperomia pallida	(Forst. f.) Dietr.		I	13603
Peperomia pellucida	(L.) Kunth		X	13536
PITTOSPORACEAE				
Pittosporum arborescens	Rich ex A. Gray	masikona	I	
Pittosporum brackenridgei	A. Gray	masikona	I	13567
PLANTAGINACEAE				
Plantago major	L.	filo	X	
PLUMBAGINACEAE				
Plumbago zeylanica	L.		I	
POLYGONACEAE				
Polygonum dichotomum	Bl.		I	13542
PORTULACACEAE				
Portulaca lutea	Sol. ex Forst. f.	tamole	I	13556
Portulaca oleracea	L.	tamole	X	
Portulaca samoensis	Poell.	tamole?	I	
RHAMNACEAE				
Alphitonia zizyphoides	(Spreng.) A. Gray	toi	I	
Colubrina asiatica	(L.) Brongn.	fiho'a	I	
Rhamnella vitiensis	(Benth.) A. C. Sm.		I	
Ventilago vitiensis	A. Gray		I	
RHIZOPHORACEAE				
Bruguiera gymnorrhiza	(L.) Lam.	tongo lei	I	
Rhizophora mangle	L.	tongo	I	
Rhizophora stylosa	Griffith	tongo	I	
RUBIACEAE				
Aidia racemosa	(Dav.) D. D. Tirvengadum	ola, olamaka	I	13552
Atractocarpus crosbyi	(Burk.) Puttock		E	
Badusa corymbifera	(Forst. f.) A. Gray	tetefa	I	13592
Bikkia tetrandra	(L. f.) A. Richard	siale tafa	I	13489
Cyclophyllum barbatum	(Forst. f.) Halle & Florence	olamaka	I	13456
Gardenia taitensis	DC.	siale Tonga	I	
Gardenia tannaensis	Guillaumin	siale Lotuma	X	
Geophila repens	(L.) I. M. Johnston	tono	I	13468
Guettarda speciosa	L.	puopua	I	13506
Gynochtodes epiphytica	(Rech.) A. C. Sm. & S. Darwin		I	13607
Hedyotis biflora	(L.) Lam.		I	
Hedyotis foetida	(Forst. f.) J. E. Sm.		I	
Hedyotis pumila	L. f.		X	
Ixora calcicola	A. C. Sm.		I	13481, 13569
Morinda citrifolia	L.	nonu	I	

FAMILY Species	Authors	Tongan name	Status	Vouchers
Morinda myrtifolia	A. Gray		I	13591
Mussaenda raiateensis	J. W. Moore	monomono ‘a hina	I	
Psychotria carnea	(Forst. f.) A. C. Sm.		I	
Psychotria insularum	A. Gray	olavai	I	
Psydrax odorata	(Forst. f.) A. C. Sm. & S. Darwin		I	13457
Spermacoce remota	Lam.	‘aselemo	X	
Tarenna sambucina	(Forst. f.) Durand ex Drake	manonu	I	
Timonius polygamus	(Forst. f.) Robinson		I	13487
RUTACEAE				
Euodia hortensis	Forst.	uhi	P	13454
Micromelum minutum	(Forst. f.) Seem.	takafalu	I	13550
Zanthoxylum pinnatum	(Forst.) W. Oliver	ake	I	13455
SANTALACEAE				
Santalum yasi	Seem.	ahi	P	
SAPINDACEAE				
Allophylus timoriensis	(DC.) Bl.	langakali vao	I	13501, 13549
Arytera brackenridgei	(A. Gray) Radlk.		I	13621
Cardiospermum halicacabum	L.		X	
Dodonaea viscosa	Jacq.		I	13565
Elattostachys apetala	(Labill.) Radlk.	ngatata	I	
Guioa lentiscifolia	Cav.		E	13477, 13566
Harpullia arborea	(Blanco) Radlk.	filiamaama?	I	13504, 13599
Pometia pinnata	Forst.	tava	I	
Sapindus saponaria	L.	ngatata hina?	I	13561
SAPOTACEAE				
Burckella richii	(A. Gray) Lam	kau	I	13469, 13627
Manilkara dissecta	(L. f.) Dubard	ngesi	P	13629
Planchonella grayana	St. John	kalaka	I	13600
Planchonella garberi	Christophersen		I	13617
Planchonella membranacea	H. J. Lam		I	
SCROPHULARIACEAE				
Limnophila fragrans	(Forst.) Seem.		I	13537
Lindernia crustacea	(L.) F. Muell.		I	
SOLANACEAE				
Capsicum frutescens	L.	polo fisi	X	
Cestrum nocturnum	L.	lakau po’uli	X	13493
Physalis angulata	L.	polo pā	X	13490
Solanum americanum	Mill.	polo kai	P	
Solanum amicorum	Benth.		I	
Solanum capsicoides	All.		X	

FAMILY Species	Authors	Tongan name	Status	Vouchers
Solanum torvum	Sw.	tisaipale	X	
Solanum viride	Sol. ex Forst. f.	polo tonga	I	
STERCULIACEAE				
Heritiera littoralis	Ait.	ifi 'ae kuma	I	
Kleinhovia hospita	L.	fukofuka	I	
Melochia aristata	A. Gray	mako	I	13576
Waltheria indica	L.		X	
SURIANIACEAE				
Suriana maritima	L.		I	13557, 13559
THYMELAEACEAE				
Phalaria disperma	(Forst. f.) Baill.	huni	I	13534
Phalaria glabra	(Turrill) Domke	huni?	I	
Wikstroemia foetida	(L. f.) A. Gray	lala vao?, lala uta?	I	13478
TILIACEAE				
Grewia crenata	(Forst.) Schinz & Guillaumin	fo'ui	I	13580
Triumfetta procumbens	Forst. f.	mo'osipo?	I	13485, 13558
Triumfetta rhomboidea	Jacq.	mo'osipo	X	
ULMACEAE				
Celtis harperi	Horne		I	
Trema cannabina	Lour.	mangele	I	13532
URTICACEAE				
Laportea interrupta	(L.) Chew	hongohongo	P	
Pilea microphylla	(L.) Liebm.		X	
Pipturus argenteus	(Forst. f.) Wedd.	'olonga	I	13479
Procris pedunculata	(Forst.) Wedd.		I	
VERBENACEAE				
Clerodendrum buchanani	(Roxb.) Walpers	'amo'ula	X	
Clerodendrum inerme	(L.) Gaertn.	tutu hina, tutu tahi	I	13471, 13511
Faradaya amicorum	(Seem.) Seem.	fufula	I	
Lantana camara	L.	talatala	X	
Premna serratifolia	L.	volovalo	I	13529
Stachytarpheta cayennensis	(Rich.) Vahl	hiku 'i kuma	X	
Vitex trifolia	L.	lautolu tahi	I	13509, 13596
MONOCOTS				
AGAVACEAE				
Cordyline fruticosa	(L.) Chev.	sī	I	
ARACEAE				
Amorphophallus paeoniifolius	(Dennst.) Nicolson	teve	P	

FAMILY Species	Authors	Tongan name	Status	Vouchers
ARECACEAE				
Cocos nucifera	L.	niu	I	
CANNACEAE				
Canna indica	L.	misimisi	X	
COMMELINACEAE				
Commelina benghalensis	L.	kaningi	X	
Commelina diffusa	Burm. f.		P	
Tradescantia spathacea	Swartz	fainā kula	X	
CYMODOCEACEAE				
Halodule uninervis	(Forssk.) Boiss.		I	
Syringodium isoetifolium	(Aschers.) Dandy		I	
CYPERACEAE				
Cyperus rotundus	L.		X	
Eleocharis dulcis	(Burm. f.) Trin. ex Hens.	kutu	I	13540
Fimbristylis cymosa	R. Br.		I	13515
Fimbristylis dichotoma	(L.) Vahl		X	13615
Fimbristylis ovata	(Burm. f.) Kern		I	13593
Kyllinga brevifolia	Rottb.		X	13548
Kyllinga nemoralis	(Forst.) Dandy ex Hutch. & Dalz.		P	
Lepironia articulata	(Retz.) Domin	kutu kofe	I	13539
Mariscus cyperinus	(Retz.) Vahl		P?	
Mariscus javanicus	(Houtt.) Merr. & Metcalfe	mahelehele	I	
Mariscus seemannianus	(Boeck.) Palla		I	
Mariscus sumatrensis	(Retz.) Raynal		P?	
Rhynchospora corymbosa	(L.) Britt.		I	13538
Scleria lithosperma	(L.) Swartz		I	13448
Scleria polycarpa	Boeck.		I	
Torulinium odoratum	(L.) S. Hooper		I	
DIOSCOREACEAE				
Dioscorea bulbifera	L.	hoi	P	
Dioscorea pentaphylla	L.	lena	P	13475
LEMNACEAE				
Lemna perpusilla	Torrey		I	
LILIACEAE				
Dianella intermedia	Endl.	afuafu	I	
ORCHIDACEAE				
Dendrobium tokai	Rchb. f.		I	
Didymoplexis micradenia	(Rchb. f.) Hemsl.		I	
Eulophia pulchra	(Thou.) Lindl.		I	13573
Geodorum densiflorum	(Lam.) Schltr.		I	

FAMILY Species	Authors	Tongan name	Status	Vouchers
Nervilia concolor	(Bl.) Schltr.		I	13590
Phaius tankervilleae	(Banks ex L'Her.) Bl.		I	
Spathoglottis plicata	Bl.		I	
Taeniophyllum fasciola	(Forst. f.) Rchb. f.		I	
Pandanus tectorius	Parkinson	fafa	I	
POACEAE				
Arundo donax	L.		X	
Brachiaria mutica	(Forssk.) Stapf		X	
Brachiaria paspaloides	(Presl) C. E. Hubb.		P	
Brachiaria reptans	(L.) Gard. & C. E. Hubb. ex Hook.		X	
Brachiaria subquadripara	(Trin.) Hitchc.		X	
Cenchrus caliculatus	Cav.	hefa	I	
Cenchrus echinatus	L.	hefa	X	
Centosteca lappacea	(L.) Desv.	mohuku 'apopoa	P	13459
Chloris barbata	(L.) Sw.		X	
Chrysopogon aciculatus	(Retz.) Trin.	mata pekepeka	P	
Coix lacryma-jobi	L.	hana	P	
Cymbopogon refractus	(R. Br.) A. Camus		I	
Cynodon dactylon	L.		X	
Cyrtococcum oxyphyllum	(Hochst. ex Steud.) Stapf		I	
Digitaria ciliaris	(Retz.) Koeler		X	13517
Digitaria radicosa	(C. Presl) Miq.		X	
Digitaria setigera	Roth ex R.& S.		I	13470, 13518
Echinochloa colonum	(L.) Link		X	13545
Eleusine indica	(L.) Gaertn.	takataka a le ala	P	
Heteropogon contortus	(L.) Beauv. ex R. & S.		I	
Melinus repens	(Willd.) G. Zizka	salapona	X	
Miscanthus floridulus	(Labill.) Warb.	kaho	I	
Oplismenus compositus	(L.) Beauv.		P	
Oplismenus hirtellus	(L.) Beauv.		X	
Panicum maximum	Jacq.		X	
Paspalum conjugatum	Berg.	vailima	X	
Paspalum dilatatum	Poir.		X	13594
Paspalum fimbriatum	Kunth		X	
Paspalum paniculatum	L.		X	13444
Paspalum scrobiculatum	L.		I	13543
Paspalum urvillei	Steud.		X	
Paspalum vaginatum	Swartz		I	
Setaria pumila	(Poir.) R. & S.		X	13491
Sorghum sudanense	(Piper) Stapf	kola	X	

FAMILY Species	Authors	Tongan name	Status	Vouchers
Sporobolus diandrus	(Retz.) P. Beauv.		X	
Sporobolus virginicus	Kunth		I	13525
Stenotaphrum micranthum	(Desv.) C. E. Hubb.		I	13524, 13586
Thuarea involuta	(Forst.) R. & S.	kefukefu	I	13463, 13510
RUPPIACEAE				
Ruppia maritima	L.		I	
TACCACEAE				
Tacca leontopetaloides	(L.) Kuntze	mahoa'a	I	
ZINGIBERACEAE				
Zingiber zerumbet	(L.) Roscoe ex Sm.	angoango	P	13602
GYMNOSPERMS				
CYCADACEAE				
Cycas seemannii	A. Braun	longolongo	I	
PODOCARPACEAE				
Podocarpus pallidus	N. E. Gray	uhiuhi	E	
FERNS				
ADIANTIACEAE				
Adiantum capillus-veneris	L.		I	13446
Adiantum hispidulum	Sw.		I	
ASPIDIACEAE				
Tectaria dissecta	(Forst. f.) Lellinger		I	
Tectaria latifolia	(Forst. f.) Copel.		I	
ASPLENIACEAE				
Asplenium nidus	L.	hakato	I	13606
Asplenium polyodon	Forst. f.		I	13497
BLECHNACEAE				
Stenochlaena palustris	(Burm.) Beddome	pasivaka	I	13544
DAVALLIACEAE				
Davallia solida	(Forst. f.) Sw.	kulutuma	I	13625
DENNSTAEDTIACEAE				
Microlepia speluncae	(L.) Moore		I	
GLEICHENIACEAE				
Dicranopteris linearis	(Burm.) Underw.		I	
HYPOLEPIDACEAE				
Hypolepis tenuifolia	(Forst. f.) Bernh.		I	
LINDSAEACEAE				
Lindsaea ensifolia	Sw.		I	
NEPHROLEPIDACEAE				
Nephrolepis hirsutula	(Forst. f.) C. Presl	hulufe	I	

FAMILY Species	Authors	Tongan name	Status	Vouchers
OPHIOGLOSSACEAE				
Ophioglossum pendulum	L.		I	
POLYPODIACEAE				
Drynaria rigidula	(Sw.) Bedd.		I	13623
Phymatosorus grossus	(Langsd. & Fisch.) Brownlie	laufale	I	13466
Pyrrosia lanceolata	(L.) Farwell		I	13447, 13598
PTERIDACEAE				
Acrostichum aureum	L.	hakato	I	
Pteris ensiformis	Burm. f.		I	13498, 13571
Pteris pacifica	Hier.		I	13495
Pteris tripartita	Swartz		I	13496
Pteris vittata	L.		I	13574
SCHIZAEACEAE				
Schizaea dichotoma	(L.) J. E. Sm.	masalu	I	
Schizaea melanesica	Selling		I	
THELYPTERIDACEAE				
Amphineuron opulentum	(Kaulf.) Holttum		I	
Christella dentata	(Forssk.) Brownsey & Jermy		I	
Christella parasitica	(L.) Lev.		I	13445, 13601
Sphaerostephanos invisus	(Forst. f.) Holttum		I	13622
Sphaerostephanos unitus	(L.) Holttum		I	
VITTARIACEAE				
Antrophyum plantagineum	(Cav.) Kaulf.		I	13604
LYCOPODIACEAE				
Lycopodium cernuum	L.	hiku 'i kuli	I	
FERN ALLIES				
PSILOTAECAE				
Psilotum complanatum	Swartz		I	
SELAGINELLACEAE				
Selaginella laxa	Spring		I	13605

Annex 3.1.

RESULTS OF THE VAVA'U REPTILE SURVEY

Sticky trap station no.	Latitude	Longitude	Island	Lau banded iguana *Brachylophus fasciatus*	Oceania gecko *Gehyra oceanica*	Mourning gecko *Lepidodactyluslugubris*	Pacific slender-toed gecko *Nactus palagicus*	Common house gecko *Hemidactylusfrenatus*	Oceanic snake-eyed skink *Cryptoblepharus poecilopleurus*	Pacific moth skink *Lipina noctua*	Undetermined skink *Emoia cyanura/ impar*	White-bellied copper-striped skink *Emoia cyanura*	Dark-bellied copper-striped skink *Emoia impar*	Tongan robust treeskink [1]*Emoia mokolahi*	Polynesian slender treeskink [2]*Emoia tongana*	Total
1A	–18.6484	–173.99867	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
1B	–18.6484	–173.99893	'Uta Vava'u	0	0	0	0	0	0	0	0	1	0	0	0	1
1C	–18.6484	–173.99922	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
1D	–18.6484	–173.99954	'Uta Vava'u	0	0	0	0	0	0	1	0	0	0	0	0	1
1E	–18.6485	–173.99982	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
2A	–18.5754	–173.9457	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
2B	–18.5755	–173.94591	'Uta Vava'u	0	0	0	0	0	0	0	0	1	4	0	0	5
2C	–18.5756	–173.9462	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
2D	–18.5757	–173.94645	'Uta Vava'u	0	0	1	0	0	0	0	0	0	0	0	1	2
2E	–18.5757	–173.94677	'Uta Vava'u	0	0	1	0	0	0	0	0	1	1	0	0	3
2F	–18.576	–173.94702	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
2G	–18.5763	–173.94698	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
2H	–18.5766	–173.94706	'Uta Vava'u	0	0	1	0	0	0	0	0	0	0	0	0	1
2I	–18.5769	–173.94698	'Uta Vava'u	0	0	0	0	0	0	1	0	0	0	0	0	1
2J	–18.5772	–173.9471	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
2K	–18.5774	–173.94714	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
2L	–18.5777	–173.94702	'Uta Vava'u	0	0	0	0	0	0	0	0	0	2	0	0	2
2M	–18.578	–173.94701	'Uta Vava'u	0	0	0	0	0	0	0	0	0	3	0	0	3
2N	–18.5784	–173.94704	'Uta Vava'u	0	0	0	0	0	0	0	0	5	1	0	1	7
3A	–18.654	–174.0528	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3B	–18.6542	–174.05256	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3C	–18.6542	–174.05225	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3D	–18.6545	–174.05214	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3E	–18.6548	–174.05214	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3F	–18.655	–174.05191	'Uta Vava'u	0	0	0	0	0	0	0	0	0	2	0	0	2

Sticky trap station no.	Latitude	Longitude	Island	Lau banded iguana	Oceania gecko	Mourning gecko	Pacific slender-toed gecko	Common house gecko	Oceanic snake-eyed skink	Pacific moth skink	Undeterminded skink	White-bellied copper-striped skink	Dark-bellied copper-striped skink	Tongan robust treeskink	Polynesian slender treeskink	Total
				Brachylophus fasciatus	*Gehyra oceanica*	*Lepidodactyluslugubris*	*Nactus palagicus*	*Hemidactylusfrenatus*	*Cryptoblepharus poecilopleurus*	*Lipina noctua*	*Emoia cyanura/ impar*	*Emoia cyanura*	*Emoia impar*	[1]*Emoia mokolahi*	[2]*Emoia tongana*	
3G	−18.6548	−174.05165	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3H	−18.6548	−174.05134	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3I	−18.6549	−174.05107	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
3J	−18.6548	−174.05078	'Uta Vava'u	0	1	0	0	0	0	0	0	0	0	0	0	1
3K	−18.6545	−174.05084	'Uta Vava'u	0	0	0	1	0	0	0	0	1	1	0	0	3
3L	−18.6542	−174.05103	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
3M	−18.654	−174.05127	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
3N	−18.6537	−174.05142	'Uta Vava'u	0	1	0	0	0	0	0	0	0	0	0	0	1
3O	−18.6536	−174.05165	'Uta Vava'u	0	1	0	0	0	0	0	0	0	0	0	0	1
3P	−18.6534	−174.05196	'Uta Vava'u	0	1	0	0	0	0	0	0	0	0	0	0	1
3Q	−18.6533	−174.05228	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
3R	−18.6534	−174.05259	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
4A	−18.6822	−173.95473	Mafana	0	1	0	0	0	0	0	0	0	0	0	0	1
4B	−18.6825	−173.95495	Mafana	0	1	0	0	0	0	0	0	0	1	0	0	2
4C	−18.6826	−173.95517	Mafana	0	0	0	0	0	0	0	0	0	0	0	0	0
4D	−18.6826	−173.95557	Mafana	0	0	0	0	0	0	0	0	0	0	0	0	0
4E	−18.6827	−173.95593	Mafana	0	0	0	0	0	0	0	0	0	0	0	0	0
4F	−18.6823	−173.95588	Mafana	0	0	0	0	0	0	0	0	0	0	0	0	0
4G	−18.6823	−173.95555	Mafana	0	0	0	0	0	0	0	0	1	0	0	0	1
4H	−18.6822	−173.95552	Mafana	0	0	0	0	0	0	0	0	0	0	0	0	0
4I	−18.6819	−173.95523	Mafana	0	0	0	0	0	0	0	0	0	0	0	0	0
4J	−18.6818	−173.95518	Mafana	0	0	0	0	0	0	0	0	0	0	0	0	0
5A	−18.6973	−173.92448	Kenutu	0	0	0	0	0	0	0	0	0	0	0	0	0
5B	−18.6976	−173.92438	Kenutu	0	0	0	0	0	0	0	0	0	2	0	0	2
5C	−18.6978	−173.92435	Kenutu	0	0	0	0	0	1	0	0	0	0	0	0	1
5D	−18.6979	−173.92405	Kenutu	0	1	0	0	0	0	0	1	3	0	0	0	5
5E	−18.6982	−173.92393	Kenutu	0	0	1	0	0	0	0	0	2	1	0	0	4

Sticky trap station no.	Latitude	Longitude	Island	Lau banded iguana *Brachylophus fasciatus*	Oceania gecko *Gehyra oceanica*	Mourning gecko *Lepidodactyluslugubris*	Pacific slender-toed gecko *Nactus palagicus*	Common house gecko *Hemidactylusfrenatus*	Oceanic snake-eyed skink *Cryptoblepharus poecilopleurus*	Pacific moth skink *Lipina noctua*	Undetermined skink *Emoia cyanura/ impar*	White-bellied copper-striped skink *Emoia cyanura*	Dark-bellied copper-striped skink *Emoia impar*	Tongan robust treeskink [1]*Emoia mokolahi*	Polynesian slender treeskink [2]*Emoia tongana*	Total
5F	−18.6984	−173.92383	Kenutu	0	0	0	0	0	0	0	1	1	0	0	0	2
5G	−18.6985	−173.92412	Kenutu	0	1	0	0	0	0	0	0	1	1	0	0	3
5H	−18.6987	−173.92437	Kenutu	0	0	0	0	0	0	0	0	1	0	0	0	1
5I	−18.6986	−173.92464	Kenutu	0	0	0	0	0	0	0	1	0	0	0	0	1
5J	−18.6986	−173.92491	Kenutu	0	0	1	0	0	0	0	1	0	2	0	0	4
5K	−18.6985	−173.92515	Kenutu	0	0	1	0	0	0	0	0	1	2	0	0	4
5L	−18.6986	−173.92543	Kenutu	0	0	1	0	0	8	0	0	2	0	0	0	11
5M	−18.6989	−173.9256	Kenutu	0	0	2	0	0	6	0	0	2	0	0	0	10
5N	−18.6991	−173.92585	Kenutu	0	0	0	0	0	0	0	0	1	0	0	0	1
5O	−18.6993	−173.92606	Kenutu	0	0	0	0	0	0	0	0	2	1	0	0	3
5P	−18.6995	−173.92592	Kenutu	0	1	1	1	0	0	0	1	2	1	0	0	7
5Q	−18.6997	−173.92611	Kenutu	0	1	1	0	0	0	0	0	2	1	0	0	5
5R	−18.6995	−173.92634	Kenutu	0	1	0	0	0	0	0	0	0	4	0	0	5
5S	−18.6994	−173.92663	Kenutu	0	0	0	1	0	0	0	0	1	3	0	0	5
5T	−18.6994	−173.92697	Kenutu	0	0	0	0	0	0	0	1	0	1	0	0	2
5U	−18.6996	−173.92718	Kenutu	0	0	0	0	0	0	0	2	1	0	0	0	3
6A	−18.6868	−173.92401	‘Umuna	0	0	1	0	0	0	0	0	0	1	0	0	2
6B	−18.6869	−173.92373	‘Umuna	0	2	0	0	0	0	0	1	1	0	0	0	4
6C	−18.6872	−173.92361	‘Umuna	0	0	1	0	0	0	0	0	0	4	0	0	5
6D	−18.6874	−173.92374	‘Umuna	0	1	0	0	0	0	0	1	2	0	0	0	4
6E	−18.6877	−173.9236	‘Umuna	0	0	0	0	0	0	0	1	0	0	0	0	1
6F	−18.6878	−173.92333	‘Umuna	0	0	0	0	0	0	0	0	0	0	0	0	0
6G	−18.6878	−173.92306	‘Umuna	0	0	0	0	0	0	0	0	0	1	0	0	1
6H	−18.6879	−173.9228	‘Umuna	0	0	0	0	0	0	0	0	0	0	0	0	0
6I	−18.688	−173.92246	‘Umuna	0	0	0	0	0	0	0	0	0	1	0	0	1
6J	−18.6877	−173.92233	‘Umuna	0	1	0	0	0	0	0	1	0	0	0	0	2
6K	−18.6875	−173.92208	‘Umuna	0	1	1	0	0	0	0	0	0	3	0	0	5

Sticky trap station no.	Latitude	Longitude	Island	Lau banded iguana *Brachylophus fasciatus*	Oceania gecko *Gehyra oceanica*	Mourning gecko *Lepidodactyluslugubris*	Pacific slender-toed gecko *Nactus palagicus*	Common house gecko *Hemidactylusfrenatus*	Oceanic snake-eyed skink *Cryptoblepharus poecilopleurus*	Pacific moth skink *Lipina noctua*	Undeterminded skink *Emoia cyanura/ impar*	White-bellied copper-striped skink *Emoia cyanura*	Dark-bellied copper-striped skink *Emoia impar*	Tongan robust treeskink [1]*Emoia mokolahi*	Polynesian slender treeskink [2]*Emoia tongana*	Total
6L	–18.6872	–173.92225	‘Umuna	0	1	0	0	0	0	0	0	0	1	0	0	2
6M	–18.6869	–173.92213	‘Umuna	0	0	0	0	0	0	0	1	0	0	0	0	1
6N	–18.6866	–173.9221	‘Umuna	0	0	0	0	0	0	0	1	0	0	0	0	1
6O	–18.6865	–173.9218	‘Umuna	0	0	0	0	0	0	0	1	0	0	0	0	1
6P	–18.6866	–173.92151	‘Umuna	0	0	0	0	0	0	0	0	0	0	0	0	0
7A	–18.8453	–174.01137	Taula	0	0	0	0	0	0	0	0	0	2	0	0	2
7B	–18.8454	–174.01155	Taula	0	0	0	0	0	0	0	0	0	1	0	0	1
7C	–18.8455	–174.01175	Taula	0	0	0	0	0	0	0	0	0	2	0	0	2
7D	–18.8456	–174.01191	Taula	0	3	0	0	0	0	0	0	0	2	0	0	5
7E	–18.8457	–174.01208	Taula	0	1	0	0	0	0	0	0	0	2	0	0	3
7F	–18.8458	–174.01188	Taula	0	0	0	0	0	0	0	0	1	3	0	0	4
7G	–18.8459	–174.01171	Taula	0	1	0	0	0	0	0	0	0	0	0	0	1
7H	–18.846	–174.01148	Taula	0	1	0	0	0	0	0	0	0	1	0	0	2
7I	–18.846	–174.01125	Taula	0	0	0	0	0	0	0	0	0	0	0	0	0
8A	–18.8573	–173.99641	Maninita	0	1	0	0	0	0	0	0	0	0	0	0	1
8B	–18.8575	–173.99614	Maninita	0	1	0	0	0	0	0	0	0	2	0	0	3
8C	–18.8575	–173.99587	Maninita	0	2	0	0	0	0	0	0	0	1	0	0	3
8D	–18.8576	–173.9956	Maninita	0	0	0	0	0	0	0	0	1	0	0	0	1
8E	–18.8579	–173.99544	Maninita	0	0	0	0	0	0	0	0	0	0	0	0	0
8F	–18.8582	–173.99546	Maninita	0	0	0	0	0	0	0	0	0	0	0	0	0
8G	–18.8581	–173.99573	Maninita	0	0	0	0	0	0	0	0	0	0	0	0	0
8H	–18.8583	–173.99596	Maninita	0	0	0	0	0	0	0	0	0	0	0	0	0
8I	–18.858	–173.99612	Maninita	0	1	0	0	0	0	0	0	1	2	0	0	4
8J	–18.8579	–173.99639	Maninita	0	1	0	0	0	0	0	0	0	0	0	0	1
9A	–18.7573	–174.03684	‘Euakafa	0	0	0	0	0	0	0	0	4	0	0	0	4
9B	–18.7573	–174.03717	‘Euakafa	0	0	0	0	0	0	0	0	2	1	0	0	3
9C	–18.7575	–174.03742	‘Euakafa	0	0	0	0	0	0	0	0	0	2	0	0	2

				Lau banded iguana	Oceania gecko	Mourning gecko	Pacific slender-toed gecko	Common house gecko	Oceanic snake-eyed skink	Pacific moth skink	Undetermined skink	White-bellied copper-striped skink	Dark-bellied copper-striped skink	Tongan robust treeskink	Polynesian slender treeskink	
Sticky trap station no.	**Latitude**	**Longitude**	**Island**	***Brachylophus fasciatus***	***Gehyra oceanica***	***Lepidodactyluslugubris***	***Nactus palagicus***	***Hemidactylusfrenatus***	***Cryptoblepharus poecilopleurus***	***Lipina noctua***	***Emoia cyanura/ impar***	***Emoia cyanura***	***Emoia impar***	**[1]*Emoia mokolahi***	**[2]*Emoia tongana***	**Total**
9D	−18.7577	−174.03767	'Euakafa	0	0	0	0	0	0	0	0	0	0	0	0	0
9E	−18.7577	−174.03795	'Euakafa	0	0	0	0	0	0	0	0	0	3	0	0	3
9F	−18.7575	−174.03817	'Euakafa	0	0	0	0	0	0	0	0	0	2	0	0	2
9G	−18.7572	−174.03814	'Euakafa	0	0	0	0	0	0	0	0	0	1	0	0	1
9H	−18.7569	−174.03824	'Euakafa	0	0	0	0	0	0	0	0	0	2	0	0	2
9I	−18.7567	−174.03848	'Euakafa	0	0	0	0	0	0	0	0	0	1	0	0	1
9J	−18.7566	−174.03877	'Euakafa	0	0	0	0	0	0	0	0	0	4	0	0	4
10A	−18.7648	−174.01966	'Euaiki	0	0	0	0	0	0	0	0	0	1	0	0	1
10B	−18.765	−174.01977	'Euaiki	0	0	0	0	0	0	0	0	0	0	0	0	0
10C	−18.7653	−174.01975	'Euaiki	0	0	0	0	0	0	0	0	0	0	0	0	0
10D	−18.7656	−174.01968	'Euaiki	0	0	0	0	0	0	0	0	0	1	0	0	1
10E	−18.7659	−174.01979	'Euaiki	0	0	0	0	0	0	0	0	0	0	0	0	0
10F	−18.7661	−174.01989	'Euaiki	0	0	0	0	0	0	0	0	0	0	0	0	0
10G	−18.7664	−174.0199	'Euaiki	0	0	0	0	0	0	0	0	0	0	0	0	0
11A	−18.7182	−174.10259	Vaka'eitu	0	0	0	0	0	0	0	0	0	0	0	0	0
11B	−18.7185	−174.10275	Vaka'eitu	0	0	0	0	0	0	0	0	0	1	0	0	1
11C	−18.7187	−174.10263	Vaka'eitu	0	0	0	0	0	0	0	0	1	2	0	0	3
11D	−18.719	−174.10262	Vaka'eitu	0	0	0	0	0	0	0	0	0	2	0	0	2
11E	−18.7192	−174.10278	Vaka'eitu	0	0	0	0	0	0	0	0	0	3	0	0	3
11F	−18.7194	−174.10298	Vaka'eitu	0	0	0	0	0	0	0	0	0	0	0	0	0
11G	−18.7194	−174.10329	Vaka'eitu	0	0	0	0	0	0	0	0	1	0	0	0	1
11H	−18.7194	−174.10361	Vaka'eitu	0	0	0	0	0	0	0	0	2	0	0	0	2
11I	−18.7197	−174.10376	Vaka'eitu	0	0	0	0	0	0	0	0	1	0	0	0	1
12A	−18.5874	−174.00208	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
12B	−18.5875	−174.00186	'Uta Vava'u	0	0	0	0	0	0	0	1	0	0	0	0	1
12C	−18.5878	−174.0017	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
12D	−18.5877	−174.00144	'Uta Vava'u	0	1	0	0	0	0	0	0	0	0	0	0	1

Sticky trap station no.	Latitude	Longitude	Island	Lau banded iguana *Brachylophus fasciatus*	Oceania gecko *Gehyra oceanica*	Mourning gecko *Lepidodactyluslugubris*	Pacific slender-toed gecko *Nactus palagicus*	Common house gecko *Hemidactylusfrenatus*	Oceanic snake-eyed skink *Cryptoblepharus poecilopleurus*	Pacific moth skink *Lipina noctua*	Undeterminded skink *Emoia cyanura/impar*	White-bellied copper-striped skink *Emoia cyanura*	Dark-bellied copper-striped skink *Emoia impar*	Tongan robust treeskink [1]*Emoia mokolahi*	Polynesian slender treeskink [2]*Emoia tongana*	Total
12E	−18.588	−174.00133	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
12F	−18.588	−174.00106	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
12G	−18.588	−174.00078	'Uta Vava'u	0	1	0	0	0	0	0	0	0	0	0	0	1
12H	−18.5882	−174.00054	'Uta Vava'u	0	0	0	0	0	0	0	0	0	1	0	0	1
12I	−18.5884	−174.00029	'Uta Vava'u	0	2	0	0	0	0	1	1	3	2	0	0	9
13A	−18.5965	−173.92809	'Uta Vava'u	0	0	0	0	0	0	0	0	1	2	0	0	3
13B	−18.5967	−173.92789	'Uta Vava'u	0	0	0	0	0	0	0	0	1	2	0	0	3
13C	−18.5968	−173.92819	'Uta Vava'u	0	0	0	1	0	0	0	1	0	1	0	0	3
13D	−18.597	−173.92852	'Uta Vava'u	0	0	0	1	0	0	0	0	0	2	0	0	3
13E	−18.597	−173.92875	'Uta Vava'u	0	0	0	0	0	0	0	1	2	2	0	0	5
13F	−18.5973	−173.92885	'Uta Vava'u	0	0	0	0	0	0	0	0	5	0	0	0	5
13G	−18.5975	−173.92905	'Uta Vava'u	0	0	0	0	0	0	0	1	0	2	0	1	4
14A	−18.6252	−173.92415	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
14B	−18.6254	−173.92412	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
14C	−18.6256	−173.92406	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
14D	−18.6257	−173.92393	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
14E	−18.6259	−173.9238	'Uta Vava'u	0	0	0	0	0	0	0	0	0	0	0	0	0
15A	−18.6683	−174.0086	Pangaimotu	0	0	0	0	0	0	0	0	0	0	0	0	0
15B	−18.6684	−174.0088	Pangaimotu	0	0	0	0	0	0	0	0	2	0	0	0	2
15C	−18.6685	−174.00891	Pangaimotu	0	0	0	0	0	0	0	0	0	0	0	0	0
15D	−18.6686	−174.00919	Pangaimotu	0	0	0	0	0	0	0	0	0	0	0	0	0
15E	−18.6687	−174.00925	Pangaimotu	0	0	0	0	0	0	0	0	1	2	1	0	4
15F	−18.6689	−174.00933	Pangaimotu	0	0	0	0	0	0	0	0	1	0	0	0	1
15G	−18.669	−174.0094	Pangaimotu	0	0	0	0	0	0	0	0	0	0	0	0	0
15H	−18.6692	−174.00954	Pangaimotu	0	0	0	0	0	0	0	3	0	0	0	0	3
15I	−18.6694	−174.00969	Pangaimotu	0	0	0	0	0	0	0	0	2	0	0	0	2
Total				**0**	**33**	**14**	**5**	**0**	**15**	**3**	**23**	**67**	**112**	**1**	**3**	**276**

1 Formerly Dandy skink, ***Emoia trossula***.

2 Formerly Murphy's tree skink, ***Emoia murphyi***.

Annex 5.1.

RESULTS OF THE VAVA'U INVERTEBRATE SURVEY

Taxon	Family	Locality	Date	Notes
Moths and butterflies (Lepidoptera)				
Proterocosma triplanetis Meyr.	Agonoxenidae			Type Locality Tonga and distributed Vanuatu, Fiji and Samoa. Meyrick 1935 notes caterpillar probably a refusefeeder and almost certain artificial spread from elsewhere. May be present in as yet undetermined survey material.
Alucita candidalis Walk.	Alucitidae	Utula'aina 110 m	14-Feb-2014	2x. A many plumed moth (Meyrick 1935):Distributed Tonga, Samoa and also Vanuatu, New Guinea, Australia, Africa and India.
Cosmopterigid spp.	Cosmopterigidae	Mo'ungalafa 135 m	24-Feb-2014	Several micromoth species. Collected into preservative from a Malaise trap.~ 10 species det. J. S. Dugdale
Cosmopterigid spp.	Cosmopterigidae	Utula'aina beach 2 m	26-Feb-2014	Several micromoth species. Collected into preservative from a Malaise trap, det. J. S. Dugdale.>15 species.
Labdia hastifera Meyr.	Cosmopterigidae			Meyrick 1935 records this from Tonga, Fiji, Samoa and American Samoa. May be present in as yet undetermined survey material.
Trissodoris honorariella (Walsingham 1907)	Cosmopterigidae			Pandanus hole-cutter moth. Widely distributed in the Pacific. Larvae eat *Pandanus* species leaves which are common throughout Tonga..
Agrioglypta cf. zelimalis (Walker 1859)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x. *A. zelimalis* is known from Asia, New Caledonia and Australia. Possible new record for Tonga.
Agrioglypta eurytusalis (Walker 1859)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Distributed Southeast Asia and Australia.
Agrioglypta itysalis (Walker 1859)	Crambidae	Longamapu Road 15 m	24-Feb-2014	Distributed Southeast Asia and Australia. Said to inhabit rainforest.
Bradina chloroscia (Meyrick 1886)	Crambidae	Leimatu'a 10 m	24-Feb-2014	
Bradina chloroscia (Meyrick 1886)	Crambidae	Maninita Island 2 m	21-Feb-2014	2x
Bradina chloroscia (Meyrick 1886)	Crambidae	Mo'ungalafa 160 m	15-Feb-2014	2x
Bradina chloroscia (Meyrick 1886)	Crambidae	Mt Talau (National Park) 131 m	13-Feb-2014	
Bradina chloroscia (Meyrick 1886)	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Bradina chloroscia (Meyrick 1886)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x. A Fijian species

Taxon	Family	Locality	Date	Notes
Bradina chloroscia (Meyrick 1886)	Crambidae	Utula'aina 110 m	14-Feb-2014	2x
Bradina sp. indet.	Crambidae	Mo'ungalafa 160 m	15-Feb-2014	2x
Bradina sp. indet.	Crambidae	Mt Talau (National Park) 131 m	13-Feb-2014	3x
Bradina sp. indet.	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Bradina sp. indet.	Crambidae	Utula'aina 110 m	14-Feb-2014	6x
Cnaphalocrocis poeyalis (Boisduval 1832)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	3x
Cnaphalocrocis poeyalis (Boisduval 1832)	Crambidae	Utula'aina 110 m	14-Feb-2014	4x. Lesser rice leafroller. Larvae feed on rice and a range of grasses Poaceae. Distributed Africa, Asia and Pacific.
Cnaphalocrocis poeyalis (Boisduval 1832)	Crambidae	Vaka'eitu Island 25 m	22-Feb-2014	
Cydalima laticostalis (Guenée 1854)	Crambidae	Mo'ungalafa 160 m	15-Feb-2014	
Cydalima laticostalis (Guenée 1854)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Dracaenura sp. indet.	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Dracaenura sp. indet.	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Eurrhyparodes bracteolalis (Zeller 1852)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Apparently a new record for Tonga.
Eurrhyparodes bracteolalis (Zeller 1852)	Crambidae	Utula'aina 110 m	14-Feb-2014	4x
Glyphodes multilinealis Kenrick 1907	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Herpetogramma licarsisalis Walker 1859	Crambidae	Mo'ungalafa 160 m	15-Feb-2014	Tropical grass webworm. Caterpillars feed on grasses Poaceae, living in shelters at the base of grass clumps. Distributed Asia, Australia and New Zealand and introduced to many Pacific Islands.
Herpetogramma licarsisalis Walker 1859	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Herpetogramma licarsisalis Walker 1859	Crambidae	Neiafu 30 m	12-13/ Feb 2014	4x

Taxon	Family	Locality	Date	Notes
Herpetogramma licarsisalis Walker 1859	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Herpetogramma licarsisalis Walker 1859	Crambidae	Utula'aina 110 m	14-Feb-2014	
Herpetogramma licarsisalis Walker 1859	Crambidae	Vai'utukakau Bay 120 m	14-Feb-2014	
Herpetogramma licarsisalis Walker 1859	Crambidae	Vaka'eitu Island 25 m	22-Feb-2014	
Hydrillodes surata Meyrick 1910	Crambidae	A'a Island 20 m	18-Feb-2014	Larvae eat litter. Distributed central Pacific Islands
Hydrillodes surata Meyrick 1910	Crambidae	'Euakafa Island 5 m	21-Feb-2014	
Hydrillodes surata Meyrick 1910	Crambidae	Maninita Island 2 m	18-Feb-2014	5x, at light
Hydrillodes surata Meyrick 1910	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Hydrillodes surata Meyrick 1910	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x
Hydrillodes surata Meyrick 1910	Crambidae	Umuna Island15 m	17-Feb-2014	2x
Hydrillodes surata Meyrick 1910	Crambidae	Utula'aina 110 m	14-Feb-2014	
Hydriris ornatalis (Duponchel 1832)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	3x. Caterpillars eat Convolvulaceae species, including *Ipomoea*. Pan-tropical distribution.
Hydriris ornatalis (Duponchel 1832)	Crambidae	Utula'aina 110 m	14-Feb-2014	
Mauruca vitrata (Fabricius 1787)	Crambidae	'Umuna Island 20 m	17-Feb-2014	2x. Bean pod borer. A pan-tropical insect pest of leguminous crops.
Meroctena staintonii Lederer 1863	Crambidae	'Euakafa Island 5 m	21-Feb-2014	
Musotiminae sp. indet.	Crambidae	Utula'aina 110 m	14-Feb-2014	
Omiodes diemenalis (Guenée 1854)	Crambidae	Euaiki Island 5 m	21-Feb-2014	
Omiodes diemenalis (Guenée 1854)	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	2x
Omiodes diemenalis (Guenée 1854)	Crambidae	Ngofe Lake 1 m	24-Feb-2014	3x
Omiodes diemenalis (Guenée 1854)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	5x. Bean leafroller. Caterpillers eat a range of climbing and herbaceous Fabaceae (beans). Distributed from Idia to the western Pacific and Australia.
Omiodes diemenalis (Guenée 1854)	Crambidae	Utula'aina 110 m	14-Feb-2014	2x

Taxon	Family	Locality	Date	Notes
Omiodes diemenalis (Guenée 1854)	Crambidae	Vai'utukakau Bay 120 m	14-Feb-2014	
Omiodes leucostrepta (Meyrick 1886)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	5x
Pagyda tremula Meyrick 1932	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Piletocera ochrosema (Meyrick 1886)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	6x, Caterpillar host unknown but probably on litter. Distributed Vanuatu, Fiji and newly recorded from Vava'u, Tonga.
Piletocera ochrosema (Meyrick 1886)	Crambidae	'Umuna Island15 m	17-Feb-2014	4x
Piletocera ochrosema (Meyrick 1886)	Crambidae	Utula'aina 110 m	14-Feb-2014	1x
Piletocera ochrosema (Meyrick 1886)	Crambidae	Vaka'eitu Island 25 m	22-Feb-2014	
Piletocera signiferalis Wallengren 1860	Crambidae	A'a Island 20 m	18-Feb-2014	1xf. Caterpillar foodplant unknown but probably leaf litter. Distributed Australia, Fiji, Loyalty Islands, Samoa and recorded here from Vava'u, Tonga. Widespread and common by day among Vava'u islands and abundant on flowers of the common littoral strand shrub ngingie *Pemphis acidula* Lythraceae.
Piletocera signiferalis Wallengren 1860	Crambidae	'Euakafa Island 5 m	21-Feb-2014	6xf, 3xm
Piletocera signiferalis Wallengren 1860	Crambidae	Kenutu Island 15 m	17-Feb-2014	2xm
Piletocera signiferalis Wallengren 1860	Crambidae	Maninita Island 2 m	18-Feb-2014	6xf, 2xm
Piletocera signiferalis Wallengren 1860	Crambidae	Mo'ungalafa 160 m	15-Feb-2014	1xm
Piletocera signiferalis Wallengren 1860	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	5xf
Piletocera signiferalis Wallengren 1860	Crambidae	Neiafu 30 m	12/13-Feb 2014	2xf, 1xm
Piletocera signiferalis Wallengren 1860	Crambidae	'Oto Island 35 m	18-Feb-2014	3xf, 4xm
Piletocera signiferalis Wallengren 1860	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	1xf, 3xm
Piletocera signiferalis Wallengren 1860	Crambidae	Taula Island 2 m	26-Feb-2014	2xf, 2xm
Piletocera signiferalis Wallengren 1860	Crambidae	'Umuna Island15 m	17-Feb-2014	3xf,
Piletocera signiferalis Wallengren 1860	Crambidae	Utula'aina 110 m	14-Feb-2014	2xf, 4xm
Piletocera signiferalis Wallengren 1860	Crambidae	Vaka'eitu Island 25 m	22-Feb-2014	1xf, 1xm

Taxon	Family	Locality	Date	Notes
Piletocera sp. *?steffanyi* Tams 1935	Crambidae	'Euakafa Island 5 m	21-Feb-2014	3x
Piletocera sp. *?steffanyi* Tams 1935	Crambidae	Kenutu Island 15 m	17-Feb-2014	
Piletocera sp. *?steffanyi* Tams 1935	Crambidae	'Umuna Island 20 m	17-Feb-2014	3x. If *P. steffanyi* then known as a Samoan endemic and the record would be a Tongan range extension for this moth.
Sameodes cancellalis (Zeller 1880)	Crambidae	Euaiki Island 5 m	21-Feb-2014	3x
Sameodes cancellalis (Zeller 1880)	Crambidae	Mt Talau (National Park) 90 m	14-Feb-2014	3x
Sameodes cancellalis (Zeller 1880)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x
Sameodes cancellalis (Zeller 1880)	Crambidae	Utula'aina 110 m	14-Feb-2014	Distributed pan Asia and western Pacific to Australia.
Spoladela recurvalis (Fabricius 1782)	Crambidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Spoladela recurvalis (Fabricius 1782)	Crambidae	Utula'aina beach 2 m	14-Feb-2014	Beet webworm. A worldwide species, mainly in the tropics. Larvae eat a range of fleshy leaved annuals mostly in the plant family Amaranthaceae.
Utethesia pulchelloides marshallorum Rothschild 1910	Erebidae/ Arctiinae	'Euakafa Island 5 m	21-Feb-2014	Distributed widely around the Pacific. This striking moth is common fringing many islands in the Vava'u group. With caterpillars at times abundant on host tree *Tornefortia argentea*, tree heliotrope. Tree heliotrope elsewhere in the pacific including Samoa and main islands of Fiji is often relict in distribution but viable populations of this coastal strand tree remain common in the Vava'u archipelago.
Utethesia pulchelloides marshallorum Rothschild 1910	Erebidae/ Arctiinae	Maninita Island 2 m	21-Feb-2014	3x
Utethesia pulchelloides marshallorum Rothschild 1910	Erebidae/ Arctiinae	Taula Island 2 m	26-Feb-2014	3x
Argina cribraria Clerck	Erebidae-Arctiinae	Vai'utukakau Bay 120 m	14-Feb-2014	Larva on *Crotalaria* spp, Fabaceae. Distribution Asia-Pacific.
Nyctemera baulus Boisduval	Erebidae-Arctiinae	'Euakafa Island 5 m	21-Feb-2014	Caterpillars eat Herbs in Asteraceae *Emilia sonchifolia*, *Crassocephalum crepidiodes* and Brasicaceae *Brassica oleracea*. Distributed Southeast Asia, New Guinea, Australia and Melanesian and Polynesian areas of the Pacific east to Samoa.
Nyctemera baulus Boisduval	Erebidae-Arctiinae	Mo'ungalafa 160 m	15-Feb-2014	
Nyctemera baulus Boisduval	Erebidae-Arctiinae	Mo'ungalafa 70 m	24-Feb-2014	

Taxon	Family	Locality	Date	Notes
Nyctemera baulus Boisduval	Erebidae-Arctiinae	Mt Talau (National Park) 131 m	13-Feb-2014	
Nyctemera baulus Boisduval	Erebidae-Arctiinae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Nyctemera baulus Boisduval	Erebidae-Arctiinae	Utula'aina 110 m	14-Feb-2014	3x
?*Stoebrhinus* sp. Indet	Gelechiidae	Utula'aina beach 2 m	26-Feb-2014	A micromoth species. Collected into preservative from a Malaise trap, det. J. S. Dugdale.
Anisodes obliviaria Walker 1861	Geometridae	Utula'aina 110 m	14-Feb-2014	
Cleora samoana (Butler 1886)	Geometridae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Cleora samoana (Butler 1886)	Geometridae	Utula'aina 110 m	14-Feb-2014	Species in this genus often have caterpillars in tall shrubland or trees. Recorded from unuoi *Eugenia reinwardtiana* or *Syzygium* family Myrtaceae. Native to Samoa, Tonga and Fiji.
Comostola pyrrhogona (Walker 1866)	Geometridae	Utila'aina 110 m	14-Feb-2014	Common in forests. Distributed Asia-Pacific. Synonym *Pyrrhorachis pyrrhogona*. Holloway moths of Borneo notes "The taxon in Fiji referred to *pyrrhogona* by Robinson (1975) has male genitalia similar to those of *C. rhodoselas* Prout comb. n. from Samoa."
Gymnoscelis tylocera Prout	Geometridae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x. Larvae have been found feeding on *Glochidion* species family Phyllanthaceae (Robinson 1975). Species known from Fiji and Samoa. Newly recorded in this survey in Vava'u, Tonga.
Pasiphilodes subtrita sub sp. *aeneta* Prout 1958	Geometridae	Mt Talau (National Park) 131 m	26-Feb-2014	The subspecies is endemic to Tonga.
Perixera obliviaria Walker 1861	Geometridae	'Umuna Island 20 m	17-Feb-2014	3x. Caterpillars recorded feeding on Fabaceae *Derris* and on Rutaceae. Indo-Australian tropics east to Queensland, Fiji, excluding New Caledonia. New survey record for Tonga and Vava'u. Native. Noted as *Anisodes obliviaria* in Robinson 1975.
Scopula cf. *julietae* Robinson 1975	Geometridae	Mt Talau (National Park) 131 m	14-Feb-2014	Noted in Robinson 1975 as "an uncommon species of primary forest". Previously a Fiji endemic – newly recorded in this survey Vava'u islands Tonga.
Scopula cf. *julietae* Robinson 1975	Geometridae	'Umuna Island 20 m	17-Feb-2014	
Scopula epigypsa Meyrick 1886	Geometridae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Scopula epigypsa Meyrick 1886	Geometridae	Utula'aina 110 m	14-Feb-2014	Caterpillars recorded from *Ficus obliqua* in Fiji. Previously a Fiji endemic – newly recorded in this survey Vava'u islands Tonga.

Taxon	Family	Locality	Date	Notes
Thalassodes chloropis Meyrick 1886	Geometridae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x. In Fiji, caterpillars eat a range of small trees including *Rhus inocarpus*, *Syzygium*, *Barringtonia* and others. Robinson (1975) notes confusion between this and similar *T. pilaria* host associations.
Thalassodes pilaria Guenée 1858	Geometridae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Distributed around the Pacific – New Caledonia, Guam, Society Is., Pitcairn Is., Fiji, Samoa and newly recorded in this survey Vava'u islands, Tonga.
Thalassodes pilaria Guenée 1858	Geometridae	Utula'aina 110 m	14-Feb-2014	
?*Conopomorpha* sp.	Gracillariidae	Mo'ungalafa 135 m	24-Feb-2014	A micromoth species. Collected into preservative from a Malaise trap, det. J. S. Dugdale.
Timodora chrysochoa Meyr.	Gracillariidae			Type Locality Tonga and also found in Upolu Samoa (Meyrick 1935).
Heliozela sp. indet.	Heliozelidae	Mo'ungalafa 135 m	24-Feb-2014	A micromoth species. Collected into preservative from a Malaise trap, det. J. S. Dugdale. May be a leaf-miner on a Boraginaceae host (J. S. Dugdale personal communication).
Badamia exclamationis (Fabricius 1775)	Hesperidae	Mo'ungalafa 70 m	24-Feb-2014	
Deudorix armstrongi Hopkins 1927	Lycaenidae			
Euchrycops cnejus samoa (Herrich-Schaffer 1869)?	Lycaenidae			
Famegana alsulus lulu (Mathew 1889)	Lycaenidae			
Jamides carissima thomasi Miller & Miller1993	Lycaenidae			
Lampides boeticus (L. 1767)	Lycaenidae			
Nacaduba dyopa Herrich-Schaeffer1869	Lycaenidae			Butterfly, big-eyed blue. Adults seen in natural forest glades up to 1,100 m asl. Distributed Fiji, Tonga and Samoan islands.
Petrelaea tombugensis (Reber 1886)	Lycaenidae			
Zizina otis labradus (Godart 1824)	Lycaenidae			
Zizula hylax dampierensis (Rothschild 1915)	Lycaenidae			
Amyna axis (Guenée 1852)	Noctuidae / Erebidae	Mt Talau (National Park) 90 m	14-Feb-2014	Larvae eat range of herbs including climber *Cardiospermum halicacabum* Sapindaceae, *Parasponia andersonii* Canabaceae and spp. in Amaranthaceae. Broadly distributed in tropical regions of the world. Noted in Robinson 1975 as *A. octo*.

Taxon	Family	Locality	Date	Notes
Amyna natalis Walker 1858	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Larvae eat a range of herbs including *Amaranthus* spp., arrowleaf *Sida rhomifolia* and other Malvaceae. Distributed tropical Asia to Australia and the Pacific.
Anomis samoana Butler 1886	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Larvae probably feeding on *Hibiscus* like its sister species. Known from Fiji main islands and Samoa. New record for Tonga/Vava'u. Robinson 1975 notes "an uncommon species restricted to primary forest most often encountered in montane habitats."
Anticarsia irrorata Fabricius 1781	Noctuidae / Erebidae	Ngofe Lake 1 m	24-Feb-2014	3x. Caterpillars eatat least jackbean *Canavalia* spp. and *Vigna* spp. Fabaceae, and sugarcane *Saccharum officinarum* Poaceae. Distributed Africa, Asia and the Pacific.
Callopistria pulchrilinea Walker 1862	Noctuidae / Erebidae	Mo'ungalafa 160 m	15-Feb-2014	Larvae eat 'fern fronds'. Noted in Robinson 1975 as *C. reticulata*. Distributed Indo-Australian tropics and east to Fiji. First record for Tonga/Vava'u. Habitat preference mostly in forested localities.
Callopistria pulchrilinea Walker 1862	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	
Chrysodeixis eriosoma Doubleday 1843	Noctuidae / Erebidae	Mo'ungalafa 160 m	15-Feb-2014	3x. Green garder looper. Caterpillars eat a wide variety of plants, i.e. polyphagous. Distributed America, India, Asia, Australia and Pacific.
Chrysodeixis eriosoma Doubleday 1843	Noctuidae / Erebidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Chrysodeixis eriosoma Doubleday 1843	Noctuidae / Erebidae	Ngofe Lake 1 m	24-Feb-2014	
Chrysodeixis eriosoma Doubleday 1843	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	5x
Chrysodeixis eriosoma Doubleday 1843	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	
Chrysodeixis illuminata Robinson 1968	Noctuidae / Erebidae	'Euakafa Island 5 m	21-Feb-2014	2x. Larva on weed herbs, common, widespead. Distributed Melanesia and Polynesia.
Chrysodeixis illuminata Robinson 1968	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	3x
Condica illecta (Walker 1865)	Noctuidae / Erebidae	Mt Talau (National Park) 90 m	14-Feb-2014	2x. Illustrated in Robinson 1975 as *Platysenta illecta*. Caterpillars eat Asteraceae. Distributed India, Asia, Indonesia and Pacific.
Ericeia inangulata Guenée 1852	Noctuidae / Erebidae	Mt Talau (National Park) 90 m	14-Feb-2014	Caterpillars eat tree legumes and *Citrus* Rutaceae. Adults attracted to rotting fruit. Distributed India, Asia and Vanuatu east to Samoa. Noted in Robinson as *Ericeia levuensis* Prout.
Ericeia inangulata Guenée 1852	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	4x

Taxon	Family	Locality	Date	Notes
Ericeia inangulata Guenée 1852	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	
Hypena iconicalis Walker 1859	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Caterpillars eat *Desmodium* spp. Beggars tick and probably other semi-woody Fabaceae. Distributed India, Indonesia, New Guinea and Fiji.
Hypocala deflorata australiae Butler 1892	Noctuidae / Erebidae	'Euakafa Island 5 m	21-Feb-2014	Caterpillars eat *Diospyros* Ebinaceae and *Planchonella* Sapotaceae. Adults common and widespread during the survey. The subspecies is distributed Queensland, Vanuatu, New Caledonia, Rotuma, Fiji, Samoa, Norfolk Island and likely vagrant in New Zealand. Newly reported here from Tonga/Vava'u
Hypocala deflorata australiae Butler 1892	Noctuidae / Erebidae	Maninita Island 2 m	21-Feb-2014	2x
Hypocala deflorata australiae Butler 1892	Noctuidae / Erebidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Hypocala deflorata australiae Butler 1892	Noctuidae / Erebidae	Neiafu 30 m	12-14/ Feb 2014	5x
Hypocala deflorata australiae Butler 1892	Noctuidae / Erebidae	'Umuna Island15 m	17-Feb-2014	
Hypospila similis Tams 1935	Noctuidae / Erebidae	A'a Island 20 m	18-Feb-2014	Caterpillar food plants unknown but sister species eat herbs in Fabaceae. familyDistributed Vanuatu, New Caledonia, Fiji and Samoa. Newly reported here from Tonga/Vava'u.
Hypospila similis Tams 1935	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	5x
Lacera Noctilio Fabricius 1794	Noctuidae / Erebidae	'Umuna Island15 m	17-Feb-2014	Caterpillars eat a wide variety of plants in Fabaceae, Nyctaginaceae, Rubiaceae and Verbenaceae. Distributed Africa, Asia, Australia and the Pacific.
Maliattha ritsemae Snellen 1880	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	Larvae eat signal grass *Brachiaria* spp. Poaceae. Distributed Indonesia, Australia, Vanuatu and the Pacific.
Mocis frugalis (Fabricius 1775)	Noctuidae / Erebidae	Euaiki Island 5 m	21-Feb-2014	Sugar cane looper. Larvae eat Zingiberaceae. Distributed Orient to Australia and Pacific islands.
Mocis frugalis (Fabricius 1775)	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	
Mocis trifasciata (Stephens 1930)	Noctuidae / Erebidae	Euaiki Island 5 m	21-Feb-2014	2x. Caterpillars eat grasses Poaceae and also herbaceous Fabaceae. Distributed East Indonesia to Polynesia and Australia. Adults flushed from rank grasses and herbs.
Mocis trifasciata (Stephens 1930)	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x
Mocis trifasciata (Stephens 1930)	Noctuidae / Erebidae	'Umuna Island15 m	17-Feb-2014	4x

Taxon	Family	Locality	Date	Notes
Mocis trifasciata (Stephens 1930)	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	
Oruza cariosa Lucas 1894	Noctuidae / Erebidae	Mt Talau (National Park) 90 m	14-Feb-2014	4x. Caterpillar food plant unknown. Distributed Australia, New Guinea, Fiji Samoa and newly reported here from Tonga -Vava'u.
Oruza cariosa Lucas 1894	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	7x, at light
Oxyodes scrobiculata (Fabricius 1775)	Noctuidae / Erebidae	Mo'ungalafa 160 m	15-Feb-2014	Caterpillars feed onMeliaceae and Sapindaceae. India, New Guinea, Vanuatu, New Caledonia, Fiji, Samoa and newly reported here from Tonga/Vava'u. Tams 1935 and Robinson 1975 both discuss subspecies which are not recognised here.
Progonia micrastis Meyrick 1902	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Distributed India, Southeast Asia, Australia, Solomon Islands eastwards to Samoa.
Simplicia cornicalis (Fabricius 1794)	Noctuidae / Erebidae	Utula'aina 110 m	14-Feb-2014	The larvae feed on dead leaves, and is a pest in roofs consisting of dried palm leaves. Southeast Asia, Australia and the Pacific.
Simplicia erebina Butler 1887	Noctuidae / Erebidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Known from Queensland and Papua New Guinea.
Spodoptera mauritia Biosduval 1833	Noctuidae / Erebidae	Mt Talau (National Park) 90 m	14-Feb-2014	3x. Lawn armyworm. Almost pan-tropical, distributed North Africa to Asia and Pacific to Australia and many islands from Solomons to Hawaii. An international agricultural pest on grasses and crops with larvae on grasses.
Spodoptera mauritia Biosduval 1833	Noctuidae / Erebidae	Neiafu 30 m	13-Feb-2014	
Tamba/Throana sp. indet.	Noctuidae / Erebidae	Vaka'eitu Island 25 m	22-Feb-2014	
Thyas coronata (Fabricius 1775)	Noctuidae / Erebidae	Maninita Island 2 m	21-Feb-2014	2x. Illustrated in Robinson 1975 as *Anua coronata*. larvae feed on *Combretum*, *Terminalia*, *Nephelium* and other genera. It is considered a pest on oranges, lemons and other citrus species. Distributed Indonesia to Australia and including most of the western Pacific islands.
Trigonodes cephise Cramer 1779	Noctuidae / Erebidae	Mo'ungalafa 70 m	24-Feb-2014	Larvae feed on *Vigna* species, including *Vigna marina*. Distributed Indonesia, New Guinea, Australia/Queensland, Fiji and Samoa. New record for Tonga.
Earias ?luteolaria Hampson 1891	Nolidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	3x. If *E. luteolaria* then caterpillars have been recorded on Tiliaceae including *Hibiscus*. Distributed India, Solomon Is., Vanuatu, New Caledonia, Fiji, Samoa and Tonga.
Earias sp. indet.	Nolidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	

Taxon	Family	Locality	Date	Notes
Earias vittella (Fabricius 1794)	Nolidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Rough bollworm. Caterpillars eat cotton species *Gossypium* and probably other plants in Malvaceae and on *Hibiscus* Tiliaceae. Widely distributed India, Southeast Asia, New Guinea, Australia and the Pacific.
Giaura tetragramma (Hampson 1905)	Nolidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Distributed Solomon Is., Fiji and new in this survey from Vava'u/Tonga
Acraea andromacha polynesiaca Rebel 1910	Nymphalidae			
*Danaus plexippus*L. 1758	Nymphalidae	Neiafu 30 m	25-Feb-2014	Monarch butterfly. Local food plants *Calotropis gigantea* not common in Vava'u but adult butterflies still seen. Elsewhere globally distributed.
Doleschallia tongana tongana Hopkins 1927	Nymphalidae			Tongan leafwing butterfly. Described by Patrick and Patrick as very local and perhaps seasonal in occurrence. Subspecies is native to Vava'u, Tongatabu and Niuafoou. The host plant *Graptophyllum insularum* Acanthaceae was recorded by A. Whistler during the survey. A review of the conservation status of this plant and and leafwing butterfly associations with this and potentially other introduced Acanthaceae is recommended.
Euploea boisduvalii boisduvalii Lucas 1853	Nymphalidae			A crow butterfly. Recorded by Patrick and Patrick for the first time in Tonga in 2010. It is common around Vava'u islands.
Euploea lewinii lewinii (C & R Felder 1865)	Nymphalidae			A crow butterfly. The species was described from Tonga and this subspecies is endemic. Caterpillars feed on *Ficus* spp. Adult males often seen drifting around coastal heliotrope *Tornifortia argentia*, a coastal strand tree still common around Vava'u archipelago.
Euploea tulliolus forsteri (C & R Felder 1865)	Nymphalidae			A crow butterfly. In Tonga only known from Eua and Vava'u. Elsewhere occurs in New Caledonia, Vanuatu and Fiji.
Hypolimnas antilope lutescens (Butler 1874) *(Fig. 8)*	Nymphalidae			
Hypolimnas bolina pallescens (Butler 1874)	Nymphalidae			
Junonia villida (Fabricius 1787)	Nymphalidae			
Melanitis leda solandra (Fabricius 1775)	Nymphalidae			
Vagrans egista bowdenia (Butler 1874)	Nymphalidae			
Appias athama manaia (Hopkins 1927)	Peiridae			A white butterfly. Common around the islands of Vava'u and elsewhere native to the Samoan Islands.

Taxon	Family	Locality	Date	Notes
Belenois java schmeltzi Hopkins 1927	Peiridae	Utula'aina beach 2 m	14-Feb-2014	Caper white butterfly. Larvae found on *Capparis cordifolia* (Capparaceae) growing on coastal rocks at Utula'aino Point. Adults widespread and also caught at sea near Fua'amotu Island in the southern part of Vava'u archipelago. A widespread tropical Pacific butterfly.
Eurema briggitta australis (Wallace 1867)	Peiridae			A smaller bright yellow species than *E. h. sulphurata*. Common on the main island of Vava'u but absent from the rest of Tonga. Elsewhere found in Fiji.
Eurema hecabe sulphurata (Butler 1875)	Peiridae			Sulphur 'white butterfly'. Widespread among Vava'u islands in disturbed areas. Elsewhere distributed broadly in the tropics.
Clania cf. ignobilis Walker 1869	Psychidae	'Umuna Island 20 m	17-Feb-2014	A bag moth species. Adult male collected at light. Bag moth caterpillar retreats – bags were common in most forest areas of Vava'u islands but a complex of species is possible.
Pterophorid sp. indet.	Pterophoridae	Utula'aina 110 m	14-Feb-2014	
Sphenarches cafferZeller 1852	Pterophoridae			Bottle gourd plume moth. May not be recorded in the present survey. Meyrick 1935: Caterpillars eat a wide variety of plants including Fabaceae and Cucuerbitaceae. Tonga Samoa Distributed Africa, India, Asia, Indonesia, New Guinea, Australia and Pacific Islands. Most likely anciently exotic in Tonga.
Endotricha mesenteralis (Walker 1859)	Pyralidae	Leimatu'a 10 m	24-Feb-2014	
Endotricha mesenteralis (Walker 1859)	Pyralidae	Mt Talau (National Park) 131 m	26-Feb-2014	
Endotricha mesenteralis (Walker 1859)	Pyralidae	Mt Talau (National Park) 90 m	14-Feb-2014	
Endotricha mesenteralis (Walker 1859)	Pyralidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	5x. Larvae feed on tropical trees including Calophyllaceae. Distributed Southeast Asia to Australia and Polynesia.
Endotricha mesenteralis (Walker 1859)	Pyralidae	'Umuna Island 20 m	17-Feb-2014	2x
Endotricha mesenteralis (Walker 1859)	Pyralidae	Utula'aina 110 m	14-Feb-2014	3x
Locastra ardua Swinhoe 1902	Pyralidae	'Euakafa Island 5 m	21-Feb-2014	Known from Fiji and newly recorded in the survey.
Locastra ardua Swinhoe 1902	Pyralidae	Maninita Island 2 m	18-Feb-2014	3x
Pyralis pictalis (Curtis 1834)	Pyralidae	'Umuna Island 20 m	17-Feb-2014	3x. Painted meal moth or poplar pyralis. Larvae eat dried vegetable foods e.g. cereals. Global distribution but likely native to Asia-Indonesia-Melanesia.
Tirathaba ?rufivena (Walker 1864)	Pyralidae	'Euakafa Island 5 m	21-Feb-2014	2x

Taxon	Family	Locality	Date	Notes
Tirathaba ?rufivena (Walker 1864)	Pyralidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x. Likely greater coconut spike moth. Larvae eat flowers and nuts of palms Arecaceae including *Cocos nucifera* coconut. DistributedSoutheast Asia, Australia and Pacific Islands. An exotic pest.
Agrius cingulata	Sphingidae	Maninita Island 2 m	~2002	Recorded on PestNet website for Maninita Island 2002. And see Houston (2002). Not a reliable record.
Cephonodes armatus Rothschild & Jordan	Sphingidae	Maninita Island 2 m	21-Feb-2014	Caterpillars eat at least *Guettarda* spp. Rubiaceae and nonu *Morinda citrifolia* Rubiaceae. Distributed Marianna Is. (subspecies), Gilbert & Ellis Is., Fiji, Samoa and Tonga.
Gnathothlibus erotus eras Boisduval	Sphingidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	2x. White-brow hawkmoth. Caterpillarseat nonu *Morinda citrifolia* Rubiaceae and vines from Convulvulaceae and Vitaceae. Distributed from India to Indonesia, New Guinea, Australia and many Pacific islands.
Hippotion velox Fabricius	Sphingidae	Maninita Island 2 m	21-Feb-2014	5x. Caterpillars have been recorded on a variety of trees includingAraceae, Convolvulaceae, Nyctaginaceae (incl. *Pisonia grandis*) and Rubiaceae species, including *Ipomoea*, *Boerhavia* and *Morinda* species. Noted on PestNet. Indo-Australian tropics east to Fiji and New Caledonia, north to Hong Kong, Taiwan and southern Japan.
Rhodoneura sericatalis Rebel 1915	Thyrididae	'Euakafa Island 5 m	21-Feb-2014	Terminalia cone maker. Distributed Indonesia to Australia, French Polynesia, Polynesia
Rhodoneura sericatalis Rebel 1915	Thyrididae	Maninita Island 2 m	18-Feb-2014	2x
Rhodoneura sericatalis Rebel 1915	Thyrididae	'Oto Island 35 m	14-Feb-2014	
Rhodoneura sericatalis Rebel 1915	Thyrididae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	
Rhodoneura sericatalis Rebel 1915	Thyrididae	'Umuna Island15 m	17-Feb-2014	3x
Rhodoneura sericatalis Rebel 1915	Thyrididae	Utula'aina beach 2 m	14-Feb-2014	
Rhodoneura sericatalis Rebel 1915	Thyrididae	Vaka'eitu Island 25 m	22-Feb-2014	2x
Striglina oecia Tams 1935	Thyrididae	'Euakafa Island 5 m	21-Feb-2014	3x
Striglina oecia Tams 1935	Thyrididae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	4x
Striglina oecia Tams 1935	Thyrididae	Utula'aina 110 m	14-Feb-2014	5x. Larvae recorded feeding on *Erythrina* Fabaceae. Previously thought endemic to Samoan Islands. Newly recorded in this survey Vava'u islands Determined as *S. inversa* in Comstock (1966).
Cyathaula maculata Meyr.	Tineidae			Type Locality Tonga and also found in Vanuatu, Fiji and Samoa (Meyrick 1935).

Taxon	Family	Locality	Date	Notes
Opogona sp. indet.	Tineidae	Mo'ungalafa 135 m	24-Feb-2014	A micromoth species. Collected into preservative from a Malaise trap, det. J. S. Dugdale.
Tineid gen. sp. indet.	Tineidae	Mo'ungalafa 135 m	24-Feb-2014	A micromoth species. Collected into preservative from a Malaise trap, det. J. S. Dugdale.
Trachycentra calamias Meyr.	Tineidae			Type Locality Tonga and also found in Fiji and Samoa (Meyrick 1935).
Duduaaprobola Meyr.	Tortricidae			Type Locality Tonga (as genus *Argyroploce*). but distributed Asia, New Guinea and Australia and probably exotic in Samoa and Tonga.
Capua endocypha Meyrick 1931	Tortricidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	A leafroller species. Caterpillars eat mangrove spp. Rhyzophoraceae. Distributed at least Singapore and Fiji. Newly recorded in the survey for Vava'u islands.
Crocidosema plebeiana Zell.	Tortricidae			Meyrick 1935 records this from Tonga, Fiji, Samoa, Hawai'i and New Zealand and suggests a South American origin. May be present in as yet undetermined survey material.
Cryptophlebia pallifimbriana Bradley 1953	Tortricidae	'Umuna Island 20 m	17-Feb-2014	A leafroller moth species. Caterpillars bore into fruits of chestnuts *Inocarpus* spp. Fabaceae. Distributed Queensland/Australia, New Guinea, Vanuatu, Austral Islands, Society Islands, Cook Islands, Fiji and this survey adds Tonga/Vava'u islands.
Epiplema cf. simmondsi Robinson 1975	Uraniidae	'Euakafa Island 5 m	21-Feb-2014	If *E. simmondsi* then a Fiji endemic, newly recorded in this survey Vava'u islands Tonga.
Epiplema instabilata Walker	Uraniidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	Distributed India, Southeast Asia New Guinea, Australia and Pacific – Melanesia, Polynesia and Fiji. Newly recorded on this survey in Vava'u/Tonga.
Ants, bees and wasps (Hymenoptera)				
Apis mellifera	Apidae	Neiafu 30 m	13-Feb-2014	Honeybee. Wild nest observed at accommodation in Neiafu. Flower visiting noted at many sites around Vava'u.
Apis mellifera	Apidae	'Umuna Island 20 m	17-Feb-2014	Wild bee hive in a coastal tree.
Bethylidae	Bethylidae	Utula'aina 110 m	26-Feb-2014	1x. A micro-wasp species.
Agathidinae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	1x. A micro-wasp species.
Agathidinae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	1x
Aphidiinae	Braconidae	'Oto Island 35 m	26-Feb-2014	1x. A micro-wasp species.
Aphidiinae	Braconidae	Utula'aina 110 m	26-Feb-2014	1x
Braconidae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	1x

Taxon	Family	Locality	Date	Notes
Braconidae	Braconidae	'Umuna Island 20 m	17-Feb-2014	1x
Cheloninae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	3x
Cheloninae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	1x
Cheloninae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	1x
Microgastrinae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	1x. A micro-wasp species.
Microgastrinae	Braconidae	Mo'ungalafa 135 m	24-Feb-2014	3x. A micro-wasp species.
Microgastrinae	Braconidae	Mt Talau (National Park) 90 m	14-Feb-2014	2x
Microgastrinae	Braconidae	Utula'aina 110 m	26-Feb-2014	7x
Chalcidoidea	Chalcidoidea	Mt Talau (National Park) 90 m	14-Feb-2014	2x. A micro-wasp species.
Chalcidoidea	Chalcidoidea	Utula'aina 110 m	26-Feb-2014	10x
Eucharitidae	Eucharitidae	Kenutu Island 15 m	17-Feb-2014	1x. A micro-wasp species.
Eupelmidae	Eupelmidae	Kulo Island 10 m	22-Feb-2014	1x. A micro-wasp species.
Eupelmidae	Eupelmidae	Mo'ungalafa 135 m	24-Feb-2014	1x
Eupelmidae	Eupelmidae	Utula'aina 110 m	26-Feb-2014	2x
Eucoilinae	Figitidae	Mo'ungalafa 135 m	24-Feb-2014	1x. A micro-wasp species.
Anoplolepis gracilipes F. Smith 1857	Formicidae	Euaiki Island 5 m	21-Feb-2014	2x. Yellow crazy ant (YCA). Wetterer (2002) notes exotic to most nations of the Pacific and pan-tropical of African origin. First noted in Vava'u group in 1956. At the time of the survey, YCA had formed a super-colony at the 'resort area' and was a considerable nuisance for any visitors there as well as a high vector risk.
Anoplolepis gracilipes F. Smith 1857	Formicidae	Kenutu Island 15 m	17-Feb-2014	4x
Anoplolepis gracilipes F. Smith 1857	Formicidae	Kulo Island 10 m	22-Feb-2014	2x
Anoplolepis gracilipes F. Smith 1857	Formicidae	Mt Talau (National Park) 90 m	13-Feb-2014	2x
Anoplolepis gracilipes F. Smith 1857	Formicidae	Neiafu 30 m	13-Feb-2014	Nest observed at our accomodation in Neiafu town .

Taxon	Family	Locality	Date	Notes
*Anoplolepis gracilipes*F. Smith 1857	Formicidae	Ngofe Lake 1 m	24-Feb-2014	1x
*Anoplolepis gracilipes*F. Smith 1857	Formicidae	Pangiamotu Is. 30 m	25-Feb-2014	2x
*Anoplolepis gracilipes*F. Smith 1857	Formicidae	Utula'aina 50 m	26-Feb-2014	3x
Camponotus maculatus group	Formicidae	Euaiki Island 5 m	21-Feb-2014	1x. New survey record for Tonga and Vava'u. African in origin and exotic to a few Pacific locations (Boulton B. 2014; Antweb).
Camponotus maculatus group	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	5x
Camponotus maculatus group	Formicidae	'Umuna Island 20 m	17-Feb-2014	1x
Camponotus maculatus group	Formicidae	Utula'aina 110 m	14-Feb-2014	3x
Camponotus maculatus group	Formicidae	Vaka'eitu Island 25 m	22-Feb-2014	1x
Cardiocondyla emeryi Forel 1881	Formicidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	6x. Wetterer (2002) notes exotic to most nations of the Pacific and pan-tropical of African origin. First noted in Vava'u group in 2002.
Monomorium floricola (Jerdon 1851)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	1x. Wetterer (2002) notes exotic to most nations of the Pacific and pan=tropical of Asian origin. First noted in Vava'u group in 1980.
Monomorium floricola (Jerdon 1851)	Formicidae	Taula Island 2 m	19-Feb-2014	1x
Nylanderia vaga (Forel 1901)	Formicidae	Euaiki Island 5 m	21-Feb-2014	1x. New survey record for Tonga and Vava'u. Likely introduced. Native to New Guinea region but distributed Australia, New Guinea, Melanesia, Fiji.
Nylanderia vaga (Forel 1901)	Formicidae	Kenutu Island 15 m	17-Feb-2014	6x
Nylanderia vaga (Forel 1901)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	5x
Nylanderia vaga (Forel 1901)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	5x
Nylanderia vaga (Forel 1901)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	2x
Nylanderia vaga (Forel 1901)	Formicidae	'Oto Island 35 m	26-Feb-2014	6x
Nylanderia vaga (Forel 1901)	Formicidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	5x
Nylanderia vaga (Forel 1901)	Formicidae	Utula'aina 110 m	26-Feb-2014	5x
Nylanderia vaga (Forel 1901)	Formicidae	Utula'aina 110 m	14-Feb-2014	1x
Nylanderia vaga(Forel 1901)	Formicidae	Vaka'eitu Island 40 m	22-Feb-2014	1x

Taxon	Family	Locality	Date	Notes
Odontomachus simillimus Smith F. 1858	Formicidae	Euaiki Island 5 m	21-Feb-2014	1x. Native and distributed Melanesia, Micronesia and much of Polynesia.
Odontomachus simillimus Smith F. 1858	Formicidae	Kenutu Island 15 m	17-Feb-2014	1x
Odontomachus simillimus Smith F. 1858	Formicidae	Maninita Island 2 m	19-Feb-2014	3x
Odontomachus simillimus Smith F. 1858	Formicidae	'Oto Island 35 m	26-Feb-2014	1x
Odontomachus simillimus Smith F. 1858	Formicidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	1x
Odontomachus simillimus Smith F. 1858	Formicidae	'Umuna Island 20 m	17-Feb-2014	2x
Odontomachus simillimus Smith F. 1858	Formicidae	Utula'aina 110 m	14-Feb-2014	1x
Pheidole megacephala (Fabricius 1793)	Formicidae	Kulo Island 10 m	22-Feb-2014	1x. Big headed ant. This was the most commonly encountered ant of the survey. Exotic to most nations of the Pacific and pan-tropical of African origin. First noted in Vava'u group in 2002. Widespread records for the archipelago during this survey.
Pheidole megacephala (Fabricius 1793)	Formicidae	Maninita Island 2 m	19-Feb-2014	4x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	30x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	>100x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	>100x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	10x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	>100x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mo'ungalafa 160 m	15-Feb-2014	4x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mt Talau (National Park) 131 m	26-Feb-2014	5x
Pheidole megacephala (Fabricius 1793)	Formicidae	Mt Talau (National Park) 131 m	26-Feb-2014	5x
Pheidole megacephala (Fabricius 1793)	Formicidae	'Oto Island 35 m	26-Feb-2014	1x
Pheidole megacephala (Fabricius 1793)	Formicidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	>100x
Pheidole megacephala (Fabricius 1793)	Formicidae	Utula'aina 110 m	14-Feb-2014	15x
Pheidole megacephala (Fabricius 1793)	Formicidae	Utula'aina beach 2 m	26-Feb-2014	>100x

Taxon	Family	Locality	Date	Notes
Pheidole megacephala (Fabricius 1793)	Formicidae	Utula'aina beach 2 m	26-Feb-2014	10x
Pheidole megacephala (Fabricius 1793)	Formicidae	Utula'aina beach 2 m	26-Feb-2014	>100x
Pheidole sp.?	Formicidae	Vaka'eitu Island 25 m	22-Feb-2014	3x. Endemic, widespread native and invasive exotic ants in this genus are known for Tonga (Wetterer, 2002).
Plagiolepis alluaudi Emery 1894	Formicidae	Euaiki Island 5 m	21-Feb-2014	2x. An exotic ant. Pan-tropical and of African origin. First recorded by Dlussky et al. 1980 cited in Wetterer, 2002. .
Plagiolepis alluaudi Emery 1894	Formicidae	Kulo Island 10 m	22-Feb-2014	1x
Plagiolepis alluaudi Emery 1894	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	3x
Plagiolepis alluaudi Emery 1894	Formicidae	Mt Talau (National Park) 90 m	14-Feb-2014	1x
Solenopsis geminata (Fabricius)	Formicidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	9x. Tropical fire ant. Introduced. Exotic to most nations of the Pacific and pan-tropical of South American origin. First noted in Vava'u group in 1956.
Strumigenys sp.	Formicidae	Mo'ungalafa 135 m	24-Feb-2014	1x. Endemic, widespread native and invasive exotic ants in this genus are known for Tonga (Wetterer, 2002).
Tapinoma melanocephalum (Fabricius 1793)	Formicidae	Kenutu Island 15 m	17-Feb-2014	2x. Introduced. Pan-tropical of Asian origin. First noted in Vava'u group in 1956.
Tapinoma sp.	Formicidae	'Oto Island 35 m	26-Feb-2014	5x. Among the potential native and exotic species, *T. minutum*, a widespread native species is known from Vava'u.
Technomyrmex sp.?	Formicidae	Kenutu Island 15 m	17-Feb-2014	4x. Among the potential native and widespread species, *T. albipes* is known from Vava'u.
Technomyrmex sp.?	Formicidae	Kulo Island 10 m	22-Feb-2014	1x
Technomyrmex sp.?	Formicidae	Mt Talau (National Park) 90 m	14-Feb-2014	1x
Technomyrmex sp.?	Formicidae	Tuita Island 10 m	19-Feb-2014	1x
Tetramorium bicarinatum (Nylander 1846)	Formicidae	Kenutu Island 15 m	17-Feb-2014	2x, Introduced to most nations of the Pacific and pan-tropical of African origin. First noted in Vava'u group in 1956.
Tetramorium bicarinatum (Nylander 1846)	Formicidae	Maninita Island 2 m	19-Feb-2014	2x
Tetramorium bicarinatum (Nylander 1846)	Formicidae	Maninita Island 2 m	19-Feb-2014	1x

Taxon	Family	Locality	Date	Notes
Tetramorium bicarinatum (Nylander 1846)	Formicidae	Ngofe Lake 1 m	24-Feb-2014	2x
Tetramorium caldarium (Roger 1857)?	Formicidae	Taula Island 2 m	19-Feb-2014	5x. New survey record for Tonga and Vava'u. Introduced. Pan-tropical of African origin. Similar in appearance to *T. simillimum*.
Tetramorium insolens (Smith 1861)	Formicidae	Mt Talau (National Park) 90 m	14-Feb-2014	1x. A wide ranging Pacific native ant. New record for Vava'u. Within Tonga, previously only recorded on 'Eua Island.
Tetramorium pacificum Mayr 1870	Formicidae	Mt Talau (National Park) 90 m	14-Feb-2014	2x. A wide ranging Pacific native ant. First recorded on Vava'u islands in 1956.
Tetramorium simillimum (Smith 1851)	Formicidae	Pangiamotu Is. west causeway 2 m	19-Feb-2014	6x. Introduced. Pan-tropical of African origin. First recorded in Vava'u in 2002.
Ichneumon promissorius Erichson 1842	Ichneumonidae	Mo'ungalafa 135 m	24-Feb-2014	1x
Playgastridae	Playgastridae	Mt Talau (National Park) 90 m	14-Feb-2014	2x. A micro-wasp species.
Playgastridae	Playgastridae	Utula'aina 110 m	26-Feb-2014	3x
Polistes olivaceus (De Geer 1773)	Vespidae	Kulo Island 10 m	22-Feb-2014	1x. Introduced common paper wa sp. At the time of the survey, this large wasp was abundant and recorded in all localities on all islands visited by the team. Members of the team were often stung. Native to India and Asia and widely introduced to Australia, New Zealand and Pacific Islands.
Polistes olivaceus (De Geer 1773)	Vespidae	Maninita Island 2 m	19-Feb-2014	1x
Polistes olivaceus (De Geer 1773)	Vespidae	Mo'ungalafa 135 m	24-Feb-2014	1x
Polistes olivaceus (De Geer 1773)	Vespidae	'Umuna Island 20 m	17-Feb-2014	2x
Dragonflies and damselflies (Odonata)				
Anax guttatus (Burmeister 1839)	Aeshnidae	Ngofe Lake 1 m	24-Feb-2014	Pale-spotted emperor or lesser green emperor dragonfly. Africa, India and Asia to Australia and the Pacific. Known from Tonga but new record for Vava'u islands.
Ischnura aurora Brauer 1865	Coenagrionidae	Ngofe Lake 1 m	24-Feb-2014	Golden dartlet damselfly. Distributed Asia to Australia and among Pacific Islands. Known from Tonga but new record for Vava'u islands.
Diplacodes bipunctata (Brauer 1865)	Libellulidae	Ngofe Lake 1 m	24-Feb-2014	Wandering percher dragonfly. Distributed Australia and southwestern Pacific.
Lathrecista asiatica Fabricius 1798	Libellulidae	Neiafu 30 m	23-Feb-2014	Asiatic blood tail dragonfly. Widely distributed from Asia to Australia. Previously noted from Tonga, not specifically noted from Vava'u till this survey.

Taxon	Family	Locality	Date	Notes
Orthetrum serapia (Watson, 1984)	Libellulidae	Ngofe Lake 1 m	24-Feb-2014	Green skimmer dragonfly. Distributed northern Australia, Fiji, Papua New Guinea and Solomon Islands. Only one of two dragonflies previously noted from Vava'u Islands.
Pantala flavescens Fabricius 1798	Libellulidae	Ngofe Lake 1 m	24-Feb-2014	Globe skimmer dragonfly. Native and also a pan-tropical dragonfly being a good disperser over oceans. Known from Tonga but new record for Vava'u islands.
Tramea limbata (Desjardins, 1832)	Libellulidae	Ngofe Lake 1 m	24-Feb-2014	Voyaging glider dragonfly. Not recorded among Vava'u islands during the durvey but previously recorded (Marinov 2012)
Tramea transmarina (Braun 1867)	Libellulidae	Ngofe Lake 1 m	24-Feb-2014	Red glider dragonfly. Distributed Southeast Asia to Australia and Pacific. Known from Tonga but new record for Vava'u islands.

Annex 6.1.
SITES SURVEYED FOR LAND SNAILS

Mo'ungalafa, limestone escarpment at southern end, broadleaved forest, 150 m elevation, 18.66547oS 174.05270oW, 24/02/2014.

Mo'ungalafa, limestone escarpment at northern end, broadleaved forest, 140 m elevation, 18.65374oS 174.05311oW, 15/02/2014.

Mo'ungalafa, plateau at northern end, broadleaved forest, 170 m elevation, 18.65426oS 174.05194oW, 15/02/2014.

Talehele, sea track on coastal cliffs northwest of Leimatu'a, coastal forest, 2–10 m elevation, 18.58684oS 174.00216oW, 20/02/2014.

Talehele, sea track on coastal cliffs northwest of Leimatu'a, broadleaved forest, 100 m elevation, 18.58764oS 174.00144oW, 20/02/2014.

Eastern end of bay east of Utula'aina Point, coastal forest on coral gravel and sand, 0.5–1.0 m elevation, 18.57539oS 173.94562oW, 24/02/2014.

Headland between Utula'aina Point and Mata'utuliki, broadleaved forest, 20 m elevation, 18.57492oS 173.94549oW, 14/02/2014.

Headland between Utula'aina Point and Mata'utuliki, broadleaved forest, 20 m elevation, 18.57423oS 173.94404oW, 14/02/2014.

Headland between Utula'aina Point and Mata'utuliki, broadleaved forest, 30 m elevation, 18.57450oS 173.94279oW, 14/02/2014.

Headland between Utula'aina Point and Mata'utuliki, broadleaved forest, 30 m elevation, 18.57462oS 173.94186oW, 14/02/2014.

Bay west of Mata'utuliki, coastal forest on sand, 3 m elevation, 18.57544oS 173.93909oW, 14/02/2014.

Vai-utu-kakau, coastal forest on coral rubble, 1–3 m elevation, 18.59464oS 173.92802oW, 18/02/2014.

Vai-utu-kakau, coastal forest on sand, 3 m elevation, 18.59595oS 173.92827oW, 17/02/2014.

Mt Talau, near top of limestone escarpment on SW side, broadleaved forest, 110 m elevation, 18.64880oS 174.00158oW, 13/02/2014.

Mt Talau, top of limestone escarpment on north side, broadleaved forest, 120 m elevation, 18.64734oS 174.00045oW, 13/02/2014.

Pangaimotu, limestone knoll on west side of 'Ahanga Passage, broadleaved scrub forest, 50 m elevation, 18.67833oS 173.98740oW, 17/02/2014.

Tuita Island, secondary broadleaved forest, 50 m elevation, 18.67696oS 174.02431oW, 20/02/2014.

Vaka'eitu Island, broadleaved forest on low limestone escarpment at back of coastal plain, 2–5 m elevation, 18.71798oS 174.10282oW, 22/02/2014.

Kulo Island, broadleaved–*Pandanus*–*Casuarina* scrub forest on limestone, 10 m elevation, 18.71753oS 174.09777oW, 22/02/2014.

'Euakafa Island, broadleaved forest on limestone escarpment, 40 m elevation, 18.75708oS 174.03763oW, 21/02/2014.

'Euaiki Island, broadleaved forest at foot of limestone escarpment, back of coastal plain, 3–5 m elevation, 18.76600oS 174.02065oW, 21/02/2014.

Taula Island, coastal forest on sand, 1–3 m elevation, 18.84716oS 174.01113oW, 19/02/2014.

Maninita Island, coastal forest on fine coral gravel, 1–3 m elevation, 18.85716oS 173.99550oW, 19/02/2014.

Annex 6.2.

DISTRIBUTIONS OF LAND SNAIL SPECIES AT THE SITES SURVEYED ON VAVA'U IN FEBRUARY 2014

Extra-Pacific species are listed in bold type.

Species	Site
Family HYDROCENIDAE	
Georissa sp. 1	1–21
Georissa sp.	4, 13
Family HELICINIDAE	
Sturanya culminans (Mousson, 1871)	4–6, 12, 13, 19, 21
Sturanya musiva (Gould, 1847)	2–6, 8–10, 12, 13
Sturanya multicolor (Gould, 1847)	1–21
Sturanya sp. 1	1–11, 13–17
Family ASSIMINEIDAE	
Omphalotropis vallata (Gould, 1847)	1–3, 5, 9, 12, 13, 19
Family TRUNCATELLIDAE	
Truncatella guerinii Villa & Villa, 1841	6, 12
Family VERONICELLIDAE	
Laevicaulis alte (Férussac, 1821)	1–3, 5–10, 13–17, 20
Family ELLOBIIDAE	
Melampus adamsianus Pfeiffer, 1855	4
Melampus fasciatus (Deshayes, 1830)	4, 6, 12
Melampus luteus (Quoy & Gaimard, 1832)	4, 6, 12
Melampus tongaensis Mousson, 1871	4, 6, 12
Melampus sp. 1	4, 6, 12
Pythia scarabaeus (Linnaeus, 1758)	4, 6, 7, 12, 13
Family ACHATINELLIDAE	
Elasmias apertum (Pease, 1864)	2, 5, 14, 15, 17, 20
Lamellidea pusilla (Gould, 1847)	12, 13, 19, 22, 23
Pacificella variabilis Odhner, 1922	21
Family VERTIGINIDAE	
Gastrocopta pediculus (Shuttleworth, 1852)	1, 4, 6, 11, 13, 15–17, 19–23
Gastrocopta servilis (Gould, 1843)	4, 14, 16, 19
Nesopupa armata (Pease, 1871)	2, 4, 12, 14, 16–21
Nesopupa sp. 1	1, 2, 13–16, 19–21
Ptychopatula orcula (Benson, 1850)	17, 19, 20

Species	Site
Family SUBULINIDAE	
Allopeas clavulinum (Potiez & Michaud, 1838)	2, 13
Allopeas gracile (Hutton, 1834)	18, 19, 21–23
Allopeas micra (d'Orbigny, 1835)	2, 5, 6, 8, 9, 11, 13, 16, 17, 21
Opeas hannense (Rang, 1831)	2, 4, 5, 11, 13, 16, 17, 19, 21–23
Paropeas achatinaceum (Pfeiffer, 1846)	1–11, 13–20
Subulina octona (Bruguière, 1792)	1–11, 13–17, 20, 21
Family STREPTAXIDAE	
Gulella bicolor (Hutton, 1834)	16
Family RHYTIDIDAE	
Delos gradata (Gould, 1848)	2–5, 9, 10, 12, 13
Family CHAROPIDAE	
Discocharopa aperta (Mollendorff, 1888)	4, 8, 14, 17, 19
Sinployea paucicosta Solem, 1983	1–5, 8–10, 12, 13, 18
Sinployea vicaria (Mousson, 1871)	
Family EUCONULIDAE	
Coneuplecta microconus (Mousson, 1865)	1, 3, 14–17
Diastole tongana (Quoy & Gaimard, 1832)	1–6, 13–15, 17, 20
Lamprocystis excrescens (Mousson, 1870)	4, 5
Liardetia samoensis (Mousson, 1865)	1–6, 8–17, 19–21
'Microcystina' gerritsi Benthem Jutting, 1964	1, 2, 4, 11, 13, 16–18, 20
Family SUCCINEIDAE	
Quickia concisa (Morelet, 1848)	16
Family BRADYBAENIDAE	
Bradybaena similaris (Rang, 1831)	1, 5, 14

Annex 7.1.

CORAL SPECIES RECORDED IN VAVA'U, TONGA, DURING THE BIORAP SURVEY

Coral species recorded by site with relative abundances indicated on the DAFOR scale, with R = rare, U = uncommon, C = common, A = abundant, and D = dominant. Site numbers without a letter indicatetheseare species identified from photographs and abundance was not assessed.'S1' indicates a shallow snorkel site. New records are indicated where the species had not previously been reported from Tonga by Lovell and McLardy (2008) or Holthus (1996). Range extensions are where the present records for the species are outside the ranges indicated in Veron (2000), Wallace (1999), Hoeksema (1989), Randall and Cheng (1984), and Razak and Hoeksema (2003). New records and range extensions are numbered consecutively.

	Species	Sites and abundance	Record	Range extension
Family Astrocoeniidae				
1.	*Stylocoenniella guntheri*	2R, 12R, 16R, 21R, 22R, 26R, 27R	1	
Family Pocilloporidae				
2.	*Pocillopora* cf. *ankeli*	10R	2	1
3.	*Pocillopora damicornis*	1U, 2C, 3U, S1C, 14U, 15, 16R, 17R, 19R, 20U, 22U, 23U, 24C, 25R, 27U		
4.	*Pocillopora danae*	22R	3	2
5.	*Pocillopora eydouxi*	4U, 5U, 8D, 9A, 10C, S1U, 14R, 15R, 16U, 17U, 18R, 19R, 22R, 23U, 24R, 25R, 26U, 27R		
6.	*Pocillopora meandrina*	4R, 19R, 21R, 22, 24R, 27R		3
7.	*Pocillopora* cf. *setichelli*	22	4	
8.	*Pocillopora verrucosa*	1R, 4R, 5R, 8A, 9C, 10, 12U, 13U, 15R, 16R, 17U, 18R, 19R, 26R, 27R		
9.	*Stylophora pistillata*	9U, 10U, 11U, 12C, 13U, 15C, 16U, 18U, 19U, 20R, 22, 25R, 27U		
10.	*Stylophora* cf. *subseriata*	1C, 2C, 3C, S1, 23U, 24R, 25, 26U	5	4
Family Acroporidae				
11.	*Montipora caliculata*	27R	6	
12.	*Montipora capitata*	2U, 3R, 4R, 5R, 10R, 12R, 14R, 16R, 17R, 18R, 19R, 20R, 21R, 22U, 25U, 27U	7	5
13.	*Montipora cebuensis*	25R	8	6
14.	*Montipora foveolata*	10R, 11, , S1R, 12U, 13U, 14U, 15C, 16R, 17R, 18U, 19U, 22U, 25R, 26R		
15.	*Montipora foveolata-like*	5R	9	
16.	*Montipora grisea*	8U		
17.	*Montipora hispida*	3C		
18.	*Montipora* cf. *informis*	2R		
19.	*Montipora palawanensis*	1U, 2U, 3R, 23	10	7
20.	*Montipora tuberculosa*	4R, 15, 18R, 19R, 22R, 24U, 27C		
21.	*Montipora turgescens*	1U, 2R, 3U, 12U, 14U, 15, 22C, 23, 24C, 25C, 26, 27C		
22.	*Montipora venosa*	11R		
23.	*Montipora verrucosa*	24, 25R, 27R		
24	*Isopora crateriformis*	8, 12, 13	11	8
25.	*Isopora cuneata*	8C, 9U, 10R, 11R, 12C, 13U, 15C, 16U, 18U, 19U, 20U, 22U, 23R, 24R, 25U, 26C, 27C		9
26.	*Isopora palifera*	13R, 14R, 23U, 26R, 27R		10
27.	*Acropora acuminata*	23R		
28.	*Acropora austera*	10R, S1R, 13R, 14R, 15R, 16U, 17U, 18U, 22U, 24U, 25, 26U		

	Species	Sites and abundance	Record	Range extension
29.	*Acropora carduus*	3U, 9R, 22, 23C, 24R, 25R, 26R, 27R		
30.	*Acropora carolineana*	27R	12	
31.	*Acropora cerealis*	15, 17R, 22R, 23, 24R, 25R		
32.	*Acropora chesterfieldensis*	9, 14, 15, 16R, 17R, 23R	13	
33.	*Acropora clathrata*	9R, 14R, 15R, 16U, 18R, 19R, 23R, 26U, 27R	14	
34.	*Acropora cytherea*	S1, 14R, 16R, 22R, 23C		
35.	*Acropora* cf. *dendrum*	24		11
36.	*Acropora digitifera*	S1C, 22R, 23C, 24U, 25A		
37.	*Acropora florida*	2, 3U, 14U, 16R, 22C, 24C, 25C, 27U		12
38.	*Acropora gemmifera*	S1U, 17U, 25R		
39.	*Acropora globiceps*	5R, 8C, 9A, 10C, 11U, 12C, 13U, 14, 15C, 16C, 17U, 18U, 19U, 21R, 22U, 26U	15	
40.	*Acropora* cf. *grandis*	12		
41.	*Acropora granulosa*	1C, 2C, 3C, 22R, 24, 25A, 27U		
42.	*Acropora hyacinthus*	8R, 9, S1U, 12U, 14R, 15U, 16U, 17U, 22R, 24C, 27C		
43.	*Acropora* cf. *jacquelineae*	16R, 25R	16	13
44.	*Acropora lutkeni*	8R, 14, 15, 16R, 17R		
45.	*Acropora millepora*	1U, 2U, 3C, 23R, 24R, 25R, 27R		14
46.	*Acropora monticulosa*	9R, 12R, 14R, 15R, 16R, 17R, 19R, 22U, 23		
47.	*Acropora muricata*	1U, 2R, 18, 23U	17	
48.	*Acropora nasuta*	25R		
49.	*Acropora intermedia* (=*nobilis*)	13U, 16U, 17U, 18, 22U, 23C, 24U		
50.	*Acropora palmerae*	17R, 18R, 23	18	
51.	*Acropora paniculata*	12, 17R, 18, 19, 20U, 22U, 23U, 24C, 25C, 26R, 27U	19	
52.	*Acropora* cf. *rambleri*	3C	20	
53.	*Acropora retusa*	5, 9R, 10R, 12U, 14R, 15C, 16C, 17C, 18U, 19U, 22U, 25U, 26R	21	
54.	*Acropora robusta*	1, S1U, 12R, 16U, 22C, 23, 24R, 27R		
55.	*Acropora rosaria*	16R, 17U, 18U, 19U, 23U	22	15
56.	*Acropora solitaryensis*	12R, 14U, 22, 25U, 27U	23	16
57.	*Acropora surculosa*	8R, 9C, 10U, 12R, 14R, 15R, 16R, 18, 22U, 26R	24	
58.	*Acropora tenuis*	9C, 10U, 12, 14R, 15R, 16U, 18U, 19U, 22R, 23, 24R, 25R, 26R	25	
59.	*Acropora valenciennesi*	17R		
60.	*Acropora* cf. *valida*	16, 17, 18, 22, 26U, 27U		
61.	*Acropora verweyi*	5R, 8, 9U, 10R, S1, 11R, 12R, 13R, 14U, 15R, 16U, 17U, 18U, 19U, 26U, 27R		
62.	*Acropora* cf. *yongei*	23C		17
63.	*Acropora* sp. 1	9U, 10U, 12U, 13U, 14C, 18U, 19U, 26R	26	
64.	*Acropora* sp. 2	8U, 9R	27	
65.	*Acropora* sp. 3	3C, 14C, 23, 24C, 27U	28	
66.	*Acropora* sp. 4	8U, 9C, 14R, 15U, 16C, 17C, 18U, 19R, 26R	29	
67.	*Acropora* sp. 5	10, 12, 13, 15, 16, 17A, 18C, 19C, 22, 26R, 27R	30	
68.	*Astreopora cucullata*	5R, 9U, 10R, 11R, 12R, 14R, 16R, 17R, 18R, 19R, 22, 24R, 27R	31	

	Species	Sites and abundance	Record	Range extension
69.	*Astreopora eliptica*	10R		18
70.	*Astreopora expansa*	18C	32	19
71.	*Astreopora gracilis*	2R, 22	33	20
72.	*Astreopora listeri*	1U		
73.	*Astreopora myriophthalma*	5R, 9R, 10R, 11R, 12R, 15U, 16R, 17R, 22, 24R, 25R, 26U, 27R		
Family Euphyllidae				
74.	*Euphyllia cristata*	9U, 12U, 14, 18R, 23, 24R, 25R	34	21
75.	*Plerogyra sinuosa*	2R, 3R, 21R, 24R		
Family Oculinidae				
76.	*Galaxea astreata*	1R, 2R, 3R, 8R, 10R, 11R, 13R, 16R, 19R		
77.	*Galaxea fascicularis*	8R, 16R, 17R, 19R, 20R, 22R, 25R, 26U		
78.	*Galaxea horrescens*	1C, 2R, 3R, 14R, 24U, 25U, 26R		
79.	*Galaxea paucisepta*	1R, 2R, 22, 25R	35	22
Family Siderastreidae				
80.	*Psammocora contigua*	1U, 3R, 25		
81.	*Psammocora haimeana*	2R, 3R, 8R, 11R		
82.	*Psammocora nierstraszi*	1R, 9R, 11R, 12R, 15R, 17R, 18R, 19R, 20U, 25R, 27R	36	
83.	*Psammocora profundacella*	2R, 9R, 10R, 15R, 17R, 18R, 19R, 21R, 22, 24R, 26A	37	
84.	*Psammocora* sp. 1	5R, 9R, 10R, 12R, 13R, 14, 15U, 16R, 17R, 20R, 26U		23
85.	*Coscinaraea collumna*	3R, 5R, 8R, 9U, 10R, 11C, 12U, 13R, 15U, 16U, 17U, 18U, 19U, 20U, 22R, 23, 24R, 25R, 26U, 27U		
86.	*Coscinaraea monile*	1R, 2	38	24
Family Agaricidae				
87.	*Pavona bipartita*	20C, 25U	39	
88.	*Pavona cactus*	3U		
89.	*Pavona chiriquensis*	1U, 2U, 5R, 8R, 9U, 10R, 11R, 12R, 13R, 15R, 16R, 17R, 18R, 19R, 20R, 22R, 24R, 25R, 26R, 27R	40	
90.	*Pavona clavus*	1R, 2R, 3U, 27U		
91.	*Pavona* cf. *diffluens*	16, 18, 20R, 25	41	
92.	*Pavona duerdeni*	8U, 9R, 10R, 11R, 12U, 13R, 15R, 16R, 25R, 26R, 27R	42	
93.	*Pavona explanulata*	4U, 5R, 9R	43	
94.	*Pavona gigantea*	17R	44	25
95.	*Pavona maldivensis*	9R, 10U, 11R, 12R, 16, 18R, 21R, 24R, 25R, 26R, 27R	45	
96.	*Pavona minuta*	2R, 10R, 20C		
97.	*Pavona varians*	1R, 2U, 3R, 9R, 16R, 17R, 20R, 23R, 25R, 26R		
98.	*Leptoseris foliosa*	1R, 2U, 3R	46	26
99.	*Leptoseris incrustans*	2R, 9R, 10U, 11R, 20U, 24R	47	
100.	*Leptoseris mycetoseroides*	1R, 2R, 10R, 12R, 13R, 18R, 19R, 24R, 25R, 26R, 27R	48	
101.	*Leptoseris scabra*	1U, 19R, 25R	49	
102.	*Leptoseris yabei*	26U	50	27
103.	*Gardineroseris planulata*	9, 13R, 20, 26R, 27R		
104.	*Pachyseris foliosa*	1U, 25U	51	28

	Species	Sites and abundance	Record	Range extension
105.	*Pachyseris gemmae*	2R, 9R, 21R, 22R, 24R, 25U, 26U, 27R	52	
106.	*Pachyseris rugosa*	1C, 2U, 3U, 20R, 21R, 23C, 25R, 27U		29
107.	*Pachyseris speciosa*	1C, 3R, 10U, 14U, 16U, 17R, 20U, 21R, 22U, 23R, 25U, 26U		
Family Fungiidae				
108.	*Cycloseris cyclolites*	1R	53	30
109.	*Cycloseris tenuis*	18R, 20R, 26R		
110.	*Fungia concinna*	2R, 9U, 11U, 12U, 13U, 15R, 16U, 18U, 19U, 21R, 22U, 24R, 26U		
111.	*Fungia fungites*	13R, 23, 25R		
112.	*Fungia granulosa*	1R, 13R, 16R, 18R, 19R, 22R, 23R	54	
113.	*Fungia gravis*	13R	55	
114.	*Fungia horrida*	3R, 9R, 12R, 13R, 15R, 16R, 17R, 18R, 23, 24, 25R, 26R		
115.	*Fungia molokensis*	1R, 5R	56	
116.	*Fungia paumotensis*	9U, 10R, 11R, 13U, 15U, 16U, 18R, 19R, 21R, 23R, 24U, 25R, 26R		
117.	*Fungia scruposa*	1R, 23R, 24U, 25R, 26R, 27R	57	
118.	*Fungia scutaria*	9U, 11U, 13R, 14R, 15U, 16U, 17U, 18U, 19U, 21R, 22R, 25R, 26U		
119.	*Ctenactis crassa*	1R, 2R, 3R, 16R, 17, 19R, 22U, 23U, 25R, 27R	58	
120.	*Herpolitha limax*	1R, 5, 9R, 10R, 13U, 14, 15R, 16U, 17U, 18R, 19R, 21R, 22R, 23R, 24R, 25U, 26U, 27U		
121.	*Herpolitha weberi*	1R, 2R, 3R, 9R, 11R, 15R, 20R, 21R, 22R	59	31
121.	*Sandalolitha dentata*	2R, 13R, 17R, 18R	60	
122.	*Sandalolitha robusta*	5R, 8, 9U, 10R, 11R, 12R, 13R, 14R, 15U, 16U, 17R, 18R, 19R, 22, 24R, 26U		
124.	*Lithophyllon mokai*	1U, 2U, 4R	61	32
125.	*Podabacia motuporensis*	3U, 9U, 10R, 14R, 20R, 22R, 25R, 26R	62	33
Family Mussidae				
126.	*Acanthastrea brevis*	9R, 11R, 12R, 13U, 15R, 16R, 17R, 18R, 19U, 26R	63	34
127.	*Acanthastrea echinata*	10R, 13R, 14R, 15R, 16R, 18R, 24R, 26, 27R		
128.	*Acanthastrea hemprichii*	10R, 13, 16R, 17R, 18, 19R		35
129.	*Acanthastrea ishigakiensis*	10R, 11U, 12U, 13U, 15R, 18U, 26R	64	
130.	*Acanthastera subechinata*	4R, 15R, 24R, 26R	65	36
131.	*Lobophyllia hataii*	1, 21, 25, 27R	66	37
132.	*Lobophyllia hemprichii*	1C, 2U, 3U, 9R, 11R, 12R, 14R, 15R, 16U, 17R, 18U, 19U, 21R, 22R, 24U, 26R		
133.	*Symphyllia agaricia*	8R, 10R, 15R, 16R, 17R, 19R		38
134.	*Symphyllia* cf. *hassi*	2U, 3U, 11R, 20R, 23	67	39
135.	*Symphyllia radians*	12R, 13R, 14R, 19R, 20R, 23R		40
Family Faviidae				
136.	*Caulastrea furcata*	18R		
137.	*Favia matthai*	13R, 15R, 18R, 19R, 21R, 26R, 27R		
138.	*Favia pallida*	4R, 5U, 10U, 12U, 13U, 15U, 16U, 17U, 18U, 19U, 20R, 25R, 26R		
139.	*Favia rotundata*	9U, 14U, 16R		41
140.	*Favia stelligera*	8U, 9U, 10U, 11U, 12U, 13U, 14U, 15U, 16U, 17U, 18U, 19U, 20U, 22R, 24R, 25R, 26C		

	Species	Sites and abundance	Record	Range extension
141.	*Favia* cf. *truncatus*	S1R	68	42
142.	*Favites abdita*	23, 24R, 25R, 26R		
143.	*Favites* sp.	13R, 14, 15, 16R, 17, 18, 26		
144.	*Goniastrea australiensis*	12, 13, 15R		
145.	*Goniastrea edwardsi*	1R, 2R, 9R, 10R, 18R, 21R		
146.	*Goniastrea favulus*	26		
147.	*Goniastrea minuta*	10R, 11R, S1R, 12U, 13U, 14R, 16R, 17R, 22U, 23R, 24U, 25R, 26R, 27U	69	43
148.	*Goniastrea pectinata*	1U, 2R, 8R, 10U, 11U, 12C, 13U, 14C, 15C, 16U, 17U, 18U, 19U, 20U, 21C, 22C, 24U, 25U, 26C, 27C		
149.	*Goniastrea retiformis*	15C		
150.	*Goniastrea* sp. [1]	10R, S1, 11R, 12A, 14C, 17U, 20R, 22, 24U, 26C, 27U	70	
151.	*Platygyra contorta*	19R	71	44
152.	*Platygyra daedalea*	2R, 3R, 4R, S1U, 12R, 13R, 14R, 16R, 18R, 23R, 26U		
153.	*Platygyra pini*	1U, 12R, 13, 16R, 21R		
154.	*Platygyra verweyi*	4R	72	45
155.	*Oulophyllia crispa*	5R, 9R, 10R, 11R, 12U, 13R, 14R, 15R, 16U, 17R, 18U, 19U, 20U, 22U, 24R, 25R, 26U, 27U		
156.	*Leptoria phrygia*	5R, 9U, 11U, S1U, 12U, 13C, 15C, 16C, 17U, 18U, 19U, 20U, 21U, 22U, 23R, 24R, 25R, 26U, 27U		
157.	*Montastrea annuligera*	5R, 8U, 9R, 10R, 11R, 12U, 13R, 14R, 15R, 16R, 17R, 18R, 19R, 26R		46
158.	*Montastrea curta*	5U, 8U, 9U, 10R, 11U, S1R, 12R, 14U, 15U, 16U, 17U, 18U, 19U, 20U, 22U, 24U, 25R, 26U		
159.	*Plesiastrea versipora*	4C, 12R, 22R	73	
160.	*Diploastrea heliopora*	1R, 25, 27U		
161.	*Leptastrea bewickensis*	4C, 14R, 15R	74	47
162.	*Leptastrea pruinosa*	4U, 5U, 10R, 15R, 22R, 24R, 27		48
163.	*Leptastrea purpurea*	1R, 2U, 3U, 5U, 8U, 19R, 21R, 25R, 26R, 27R	75	
164.	*Leptastrea transversa*	5R, 8R, 9U, 10R, 11R, 12R, 15R, 16R, 18R, 20R, 22, 23R, 25R, 26R	76	
165.	*Cyphastrea decadea*	1R	77	49
166.	*Echinopora* cf. *gemmacea*	13		
167.	*Echinopora hirsutissima*	9U, 10R, 11R, 12R, 13R, 15U, 16U, 17U, 18R, 20R, 23R, 26U	78	50
168.	*Echinopora lamellosa*	1R, 13R, 16R, 17U, 20R		
Family Poritidae				
169.	*Porites annae*	21R		51
170.	*Porites arnaudi*	10R	79	
171.	*Porites cylindrica*	1D, 3U, 21U, 24C, 25C, 27R		
172.	*Porites horizontallata*	1A, 2U, 3U	80	
173.	*Porites evermanni*	10R, 13R, 16R, 18, 24R, 25	81	52
174.	*Porites lichen*	12U, 14U, 15U, 16	82	
175.	*Porites* massive	1C, 2, 3, 4, 5, 13		
176.	*Porites monticulosa*	21U	83	53
177.	*Porites rus*	1D, 2C, 3C, 9R, 13R, 20C, 21A, 24R, 26R		
178.	*Porites vaughani*	1U, 2U, 9R, 10R, 11R, 12R, 13R, 15U, 17R, 18R, 19R, 20U, 21, 22R, 24R, 25R, 26C		

	Species	Sites and abundance	Record	Range extension
179.	*Porites* sp. 1	9U, 14R	84	
180.	*Goniopora* cf. *collumna*	21U	85	54
181.	*Goniopora* sp. 1	12R		
182.	*Alveopora excelsa*	2	86	55
183.	*Alveopora viridis*	1U, 3R, 23,	87	56
Familiy Pectinidae				
184.	*Echinophyllia aspera*	10R, 11R, 13R, 15		
185.	*Echinomorpha nishihirai*	2R, 12U, 14R, 15, 16R, 17U, 18U, 19U, 20R, 21R, 22U, 24U, 25U, 27R	88	57
186.	*Oxypora crassispinosa*	2R, 25R, 26U	89	58
187.	*Oxypora lacera*	9U, 10U, 12U, 13R, 15U, 16R, 18R, 19R, 26U		
188.	*Mycedium elephantotus*	9U, 10U, 11R, 12U, 13R, 14U, 15U, 16C, 17U, 18C, 22U, 24U, 25U, 26, 27U		
189.	*Pectinia paeonia*	1U, 2R		59
Family Merulinidae				
190.	*Hydnophora exesa*	9U, 10U, 11R, 13R, 14R, 15R, 16U, 17U, 18R, 19R, 22		
191.	*Hydnophora microconos*	9U, 10U, S1R, 12U, 13U, 14U, 15U, 16U, 17U, 18U, 19U, 23R, 25R, 27R		
192.	*Hydnophora rigida*	13U, 26R		60
193.	*Merulina ampliata*	10U, 12R, 13R, 14R, 15R, 16R, 18R, 19R, 24, 25R, 26U		
194.	*Merulina scabricula*	13U, 14U, 15U, 20R, 22R, 26U	90	61
195.	*Scapophyllia cylindrica*	9U, 10R, 11R, 17R, 18R, 27R	91	62
Family Dendrophyllidae				
196.	*Turbinaria mesenteria*	9R, 12R, 15R, 17R, 19R		
197.	*Turbinaria peltata*	5R, 16, 17R, 21R, 25, 26R	92	
198.	*Turbinaria reniformis*	1U, 9U, 10R, 11R, 13U, 16R, 17R, 22, 26R		
199.	*Turbinaria stellulata*	4U, 9R, 10R, 12R, 13R, 14R, 15R, 16U, 17R, 18U, 19U, 21R, 22R, 25R, 26R		63
Octocorallia				
200.	*Tubipora musica*	24R		64
Hydrozoa				
201.	*Millepora dichotoma*	5R, 8C, 23		65
202.	*Millepora exaesa*	12, 17R, 18, 22R, 25R		66
203.	*Millepora intricata*	1U, 2C, 3C, 22R, 23C, 27R	93	67
204.	*Millepora* cf. *platyphylla*	4C, 5U, 8C, 9R, 10R, 11R, 12U, 13U, 14R, 15R, 16R, 18U, 19C, 22R, 23R, 25R, 26R		
205.	*Stylaster* sp.	20U	94	
206.	*Distichopora violacea*	8U, 11R, 19R, 20C	95	

Annex 8.1.

LIST OF MACROINVERTEBRATE SPECIES OBSERVED IN VAVA'U, TONGA, DURING BIORAP SURVEY

Family	Species	Sites present
Acanthasteridae	*Acanthasterplanci*	2, 25
Actiniidae	*Entacmaea quadricolor*	3, 18, 25
Aglaopheniidae	*Macrorhynchia* sp.	10, 25
Alcyoniidae	*Cladiella sp.*	5, 11, 13, 14, 16, 18, 19, 22, 27
	Lobophytum sp.	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27
	Sarcophyton sp.	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27
	Sinularia sp.	6, 7, 8, 10, 11, 12, 13, 14, 15, 18, 21, 22, 26
Alpheidae	*Alpheus djiboutensis*	23
	Alpheus ochrostriatus	22, 27
Antipathidae	*Cirrihipathes* sp.	2, 19, 20, 24, 25, 27
Briareidae	*Briareum* sp.	8
Bursidae	*Tutufa bufo*	3
	Tutufa rubeta	10, 18, 22
Calappidae	*Calappa* sp.	10
Callyspongiidae	*Callyspongia* sp.	2, 3, 13, 20, 22
Cardiidae	*Tridacna crocea*	6, 23, 26
	Tridacna derasa	1, 7
	Tridacna maxima	5, 6, 7, 8, 13, 14
	Tridacna squamosa	6, 7, 8, 12, 14, 15, 17, 22
Cassidae	*Semicassis bisulcata*	12
Cerithiidae	*Cerithium* sp.	12
Chalinidae	*Haliclona* sp. [1]	
	Haliclona sp. [2]	
	Haliclona sp. [3]	

Family	Species	Sites present
Chamidae	*Chama lazarus (macerophylla)*	1, 18
Chromodorididae	*Chromodoris lochi*	17
	Chromodoris sp.	5
	Chromodoris sp.	8
	Chromodoris sp.	23
	Chromodoris sp.	22
	Glossodoris cincta	3
Clavelinidae	*Clavelina* sp.	5, 15
Clavulariidae	*Clavularia* sp.	24
	Carijoa sp.	11
Colobometridae	*Cenometra bella*	10, 19
	Cenometra perspinosa	9, 18, 26
	Oligometra serripinna	18
Comasteridae	*Comanthus briareus*	4, 9, 13, 20, 23, 26, 27
	Comanthusparvicirrus	9, 16, 20, 21
	Comaster audax	18, 20, 21
	Comaster multifidus	11, 17, 19
	Oxycomanthus benneti	7, 25
	Phanogenia gracilis	4, 7, 13, 14, 15, 19, 20, 21, 24, 25, 27
Conidae	*Conus achatinus*	22
	Conus eburneus	9, 25
	Conus floccatus	9
	Conus litteratus	6
	Conus marmoreus	5
	Conus miles	21
	Conus miliaris	6
	Conus muriculatus	19
	Conus striatus	4, 7, 23
	Conus suturatus	21
	Conus sp.	7
	Conus sp.	26
Cypraeidae	*Cypraea chinensis*	19
	Cypraea limacine	13
	Cypraea mappa	27

Family	Species	Sites present
	Cypraea scurra	8
	Cypraea talpa	8
	Cypraea tigris	2
Diadematidae	*Diadema savignyi*	1, 3, 22, 24, 25, 27
	Diadema setosum	19, 20
	Echinothrix calamaris	9, 17, 25
	Echinothrix sp.	7
Dictyonellidae	*Stylissa massa*	19
	Stylissa sp.	18, 25
	Stylissa sp.	24, 26, 27
Didemnidae	*Didemnum* sp.	14, 26
	Lissoclinum patella	21
	Lissoclinum sp. [1]	8, 12
Diogenidae	*Calcinus gaimardii*	3, 6
	Calcinus minutus	3, 4, 7, 13
	Ciliopagurus strigatus	12
	Dardanus guttatus	6, 11, 16
	Dardanus lagopodes	19
	Dardanus megistos	16
	Dardanus sp.	8
Discosomatidae	*Discosoma* sp. [1]	9, 19
	Discosoma sp. [2]	17, 23
	Rhodactis sp. [1]	14, 24, 25
	Rhodactis sp. [1]	16, 20
Dysideidae	*Dysidea* sp. [1]	13
	Dysidea sp. [2]	2, 16
Echinometridae	*Echinometra mathaei*	7, 10, 21
	Echinostrephus molaris	6, 7, 8, 13, 20, 22, 26, 27
	Echinostrephus sp. [1]	6
	Heterocentrotus mamillatus	12
Ellisellidae	*Ellisella* sp.	16, 21, 24
Flabellinidae	*Flabellina* sp.	5
Goniasteridae	*Fromia milleporella*	16
	Neoferdina sp.	5
Gryphaeidae	*Hyotissa hyotis*	20, 24
	Hyotissa sp. [1]	1, 21
Halichondriidae	*Halichondria* sp. [1]	12
	Hymeniacidon sp. [1]	1, 12

Family	Species	Sites present
Harpidae	*Harpa harpa*	14
Hippolytidae	*Thor amboinensis*	8
Hipponicidae	*Sabia* sp. [1]	12
Holothuriidae	*Actinopyga echintes*	20
	Actinopyga mauritiana	5, 13
	Actinopyga miliaris	16, 21, 22
	Bohadschia argus	1, 2, 3, 14, 15, 16, 17, 21
	Bohadschia vitiensis	15, 18, 21, 23, 24, 27
	Holothuria atra	14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24
	Holothuria coluber	3, 23
	Holothuria edulis	1, 2, 3, 12, 17, 22, 23, 26
	Holothuria fuscogilva	12, 13, 17, 19
	Holothuria fuscopunctata	1, 2, 3, 12, 13, 14, 17, 18, 21, 23, 24, 25
	Holothuria whitmaei	6, 7, 9, 12, 17
Inachidae	*Achaeus* sp. [1]	4, 8
	Camposcia retusa	7
Leucettidae	*Leucetta* sp. [1]	7, 15
	Leucetta sp. [2]	14, 16, 26
Loliginidae	*Sepioteuthis lessoniana*	21
Malleidae	*Malleus malleus*	20
Mariametridae	*Lamprometra palmata*	5, 15
	Lamprometra regalis	11, 13, 17
Megabalaninae	*Megabalanus* sp. [1]	23
Melithaeidae	*Melithaea* sp. [1]	14, 20, 24, 25
Microcionidae	*Clathria* sp. [1]	7, 25
	Clathria sp. [2]	12, 23
Mitridae	*Mitra papalis*	2
	Mitra sp. [1]	19
Muricidae	*Chicoreus* sp. [1]	3
	Chicoreus sp. [2]	15, 23
	Coralliophila violacea	15
	Coralliophila radula	18
	Coralliophila sp. [1]	22
	Drupella cornus	2, 4
	Drupella robusta	2, 7, 13

Family	Species	Sites present
	Drupella sp. [1]	5, 6, 11, 16
	Mancinella armigera	18
Mytilidae	*Lithophaga zitteliana*	20
	Modiolus sp. [1]	17
Nassariidae	*Nassarius* sp. [1]	10, 14
Nembrothinae	*Nembrotha lineolata*	13
Nephtheidae	*Dendronephthya* sp.[1]	8, 9
	Stereonephthya sp. [1]	9, 13
Neritidae	*Nerita albicilla*	10
Nidaliidae	*Siphonogorgia* sp.[1]	25
Octopodidae	*Octopus cyanea*	6, 23, 24
Olividae	*Olvia reticulate*	6, 9
Ophidiasteridae	*Linckia laevigata*	1, 2, 3, 22, 24, 25, 27
	Linckia multifora	26
	Ophioplocus imbricatus	9, 10, 19
	Ophioplocus sp. [1]	6
	Ophioplocus sp. [2]	23
Ophiotrichidae	*Ophiothela danae*	6, 26
	Ophiothrix sp. [1]	7, 9, 11
	Ophiothrix sp. [2]	13, 21, 22
	Ophiothrix sp. [3]	16, 26
	Ophiothrix sp. [4]	17, 23
Oreasteridae	*Choriaster granulatus*	1, 2, 3, 20, 21, 22, 23, 24, 25, 27
	Culcita novaeguineae	1, 2, 3, 15, 17, 18, 22, 23, 24
Ovulidae	*Ovula costellata*	10
	Ovula ovum	18
	Calpurnus verrucosus	7
Paguridae	*Paguritta gracilipes*	20
Palaemonidae	*Periclimenes amboinensis*	11
	Periclimenes holthuisi	10
	Periclimenes sp. [1]	1
Palinuridae	*Panulirus versicolor*	15, 18
	Paracis sp. [1]	10
Pectinidae	*Chlamys (Gloripallium) pallium*	23
	Pedum spondyloideum	19, 22, 25
Phyllidiidae	*Phyllidia carlsonhoffi*	9

Family	Species	Sites present
	Phyllidia cf. *ocellata*	3
	Phyllidia elegans	7
	Phyllidia nobilis	4
	Phyllidia ocellata	11
	Phyllidia varicosa	21
	Phyllidia sp.1	4
	Phyllidia sp.2	11
	Phyllidiella cooraburrama	4
	Phyllidiella pustulosa	5, 9
Plakinidae	*Plakortis nigra*	18
	Plakortis sp. [1]	20
Plexauridae	*Rumphella* sp. [1]	10, 11, 12, 19, 25, 26
Polycitoridae	*Eudistoma* sp. [1]	11, 19
	Eudistoma sp. [2]	12, 14
	Exostoma sp. [1]	8
Pseudoceratinidae	*Pseudoceratina* sp. [1]	13, 14
Pteriidae	*Pinctada margaritifera*	1, 2, 3, 5, 20, 22, 25
	Pteria penguin	21
	Pteria sp. [1]	2, 22
	Reticulidia halgerda	16
Ranellidae	*Charonia tritonis*	21, 26
	Cymatium sp. [1]	16
Rhynchocinetidae	*Rhynchocinetes striatus*	26
	Rhynchocinetes uritai	1
Ricordeidae	*Ricordea* sp. [1]	12
	Ricordea sp.2	15, 22
Sabellidae	*Sabellastarte* sp. [1]	5, 18, 21
Serpulidae	*Spirobranchus giganteus*	7, 8, 10, 11, 15, 18
Solanderiidae	*Solanderia* sp. [1]	1, 16
	Solanderia sp. [2]	11
Sphenopidae	*Palythoa tuberculosa*	12, 13, 15, 26
	Palythoa sp. [1]	12
Spondylidae	*Spondylus varius*	2, 3, 21
	Spondylus sp. [1]	1
Spongiidae	*Hippospongia* sp. [1]	1
	Hippospongia sp. [2]	3
	Hippospongia sp. [3]	2

Family	Species	Sites present
	Coscinoderma sp. [1]	13
Stichodactylidae	*Heteractis aurora*	11, 12, 26
	Heteractis crispa	1, 6, 21
	Heteractis magnifica	2, 6, 8, 9, 18, 22, 23
	Stichodactyla haddoni	18
	Stichodactyla mertensii	13
Stichopodidae	Stichopus chloronotus	22, 23, 27
	Thelenota anax	12, 14, 17, 18, 20, 21, 22, 23, 24, 25, 27
	Thelenota ananas	7, 12, 21
Strombidae	*Lambis scorpius*	6
	Lambis truncate	6, 7, 23, 25
Styelidae	*Polycarpa* sp. [1]	8, 14, 21
	Polycarpa sp. [2]	9, 19, 24
Stylasteridae	*Distichopora* sp. [1]	8, 9
	Distichopora sp. [2]	19
Tegulidae	*Tectus nilotocus*	8, 9, 10, 11, 12, 13, 14, 16, 17, 21, 22, 23, 24

Family	Species	Sites present
	Tectus sp. [1]	6, 7, 9, 27
Tethyidae	*Tethya* sp. [1]	1
Thorectidae	*Hyrtios* sp. [1]	1
	Phyllospongia sp. [1]	9, 23
	Phyllospongia sp. [2]	22
	Phyllospongia sp. [3]	26
Toxopneustidae	*Toxopneustes pileolus*	19
	Tripneustes gratilla	15, 16
Trapeziidae	*Trapezia tigrina*	6
	Trapezia sp. [1]	8
Triphoridae	*Euthymella* sp. [1]	5
Trochidae	*Calliostoma laugieri*	10, 14, 19
Turbinidae	*Turbo chrystomas*	10
	Turbo petholatus	5, 21
	Turbo sp. [1]	9, 22
Vermetidae	*Dendropoma maximum*	7, 10, 20
Xanthidae	*Zosimus aeneus*	6
Xeniidae	*Cespitularia* sp. [1]	25, 26
	Heteroxenia sp. [1]	7, 9, 10, 11, 12, 13, 15, 16, 21, 22, 26

Annex 9.1.

COMPLETE LIST OF REEF-ASSOCIATED FISH SPECIES RECORDED DURING THE BIORAP SURVEY OF THE VAVA'U ARCHIPELAGO

Family	Species
Acanthuridae	*Acanthurus achilles*
	Acanthurus albipectoralis
	Acanthurus blochii
	Acanthurus dussumieri
	Acanthurus guttatus
	Acanthurus lineatus
	Acanthurus nigricans
	Acanthurus nigricauda
	Acanthurus nigrofuscus
	Acanthurus nigros
	Acanthurus olivaceus
	Acanthurus pyroferus
	Acanthurus thompsoni
	Acanthurus triostegus
	Acanthurus xanthopterus
	Ctenochaetus cyanocheilus
	Ctenochaetus striatus
	Ctenochaetus tominiensis
	Naso brachycentron
	Naso brevirostris
	Naso caesius
	Naso hexacanthus
	Naso lituratus
	Naso lopezi
	Naso thynnoides
	Naso tonganus
	Naso unicornis
	Naso vlamingii
	Paracanthurus hepatus
	Zebrasoma scopas
	Zebrasoma veliferum
Apogonidae	*Cheiloddipterus macrodon*
	Cheiloddipterus quinquelineatus
	Ostorhinchus aureus
	Ostorhinchus cyanosoma
	Pristiapogon fraenatus

Family	Species
Aulostomidae	*Aulostomus chinensis*
Balistidae	*Balistapus undulatus*
	Balistoides conspicIlum
	Balistoides viridescens
	Melichthys vidua
	Odonus niger
	Pseudobalistes flavimarginatus
	Pseudobalistes fuscus
	Rhinecanthus aculeatus
	Rhinecanthus rectangulus
	Sufflamen bursa
	Sufflamen chrysopterum
	Sufflamen fraenatum
	Xanthichthys auromarginatus
Blennidae	*Aspidontus dussumieri*
	Aspidontus taeniatus
	Atrosalarias fuscus holomelas
	Bleniella chrysospilos
	Cirripectes castaneus
	Cirripectes variolosus
	Escenius bicolor
	Exallias brevis
	Meiacanthus procne
	Meiacanthus tongaensis
	Plagiotremus flavus
Bothidae	*Bothus pantherinus*
Caesionidae	*Caesio caerulaurea*
	Caesio lunaris
	Caesio sp.
	Pterocaesio digramma
	Pterocaesio marri
	Pterocaesio tile
	Pterocaesio trilineata
Callionymidae	*Synchiropus ocellatus*
Caracanthidae	*Caracanthus maculatus*

Family	Species
Carangidae	*Caranx ignobilis*
	Caranx lugubris
	Caranx melampygus
	Caranx sexfasciatus
	Elagatis bipinnulata
	Gnathanodon speciosus
	Scomberoides lysan
	Trachinotus blochii

Family	Species
Carcharhinidae	*Carcharhinus amblyrhynchos*
	Carcharhinus melanopterus
	Triaenodon obesus
Chaetodontidae	*Chaetodon auriga*
	Chaetodon baronessa
	Chaetodon benetti

Annex 9.2.

NUMBER OF REEF FISH SPECIES OBSERVED PER FAMILY DURING THE BIORAP SURVEY OF THE VAVA'U ARCHIPELAGO

Data shown shaded in grey are the six dominant reef fish families used to calculate the Coral Fish Diversity Index (Allen 1998).

FAMILY	SITE NO.																											
Family	All	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Acanthuridae	31	9	11	11	11	15	16	22	27	11	10	14	13	13	12	10	14	9	12	9	18	12	16	15	12	19	13	7
Chaetodontidae	31	15	12	14	8	11	11	12	19	12	15	16	14	20	15	18	13	7	14	13	17	14	15	15	14	11	13	9
Labridae	52	18	10	10	12	11	9	13	31	19	15	23	17	20	26	27	30	26	28	27	28	23	27	32	19	16	5	8
Pomacanthidae	8	3	3	3	1	2	4	5	7	3	1	3	1	3	4	4	3	1	6	6	6	5	4	4	2	2	3	2
Pomacentridae	57	20	23	20	9	13	13	14	20	11	10	17	17	21	23	17	18	9	17	8	19	20	25	24	24	23	18	8
Scaridae	22	7	6	7	1	3	2	4	6	12	8	7	11	8	7	10	8	6	10	9	9	10	13	10	6	8	13	11
Apogonidae	5	1	1	1											2						1		1	2	2	1		
Aulostomidae	1	1	1	1				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Balistidae	13	4	4	3	5	8	9	12	12	4	5	5	3	4	2	4	4	3	5	6	1	4	4	4	1	3	1	2
Blennidae	11	3	2	2	1	1	1	2	4	2	2	3	1	3	2	4	6	4	2	2	2	2	3	3	3	2	2	2
Bothidae	1														1													
Caesionidae	7	1		1		2		3	3	1	1	1		4	1	1			1		3	4	1	2			2	
Callionymidae	1					2																						
Caracanthidae	1	2		2			1	1			1	1																
Carangidae	8				4	4	1	3	6	2				1	1								1		1			1
Carcharhinidae	3				1	1	1	1	2	2			1	2			1				1				1			
Cirrhitidae	4	2	2	2	2	2	3	4	4	3	3	3	3	3	3	3	3	2	3	3	4	4	4	4	3	3	1	1
Dasyatidae	1	1									2																	
Diodontidae	1							1																				
Echeneidae	1								1																			
Ephippidae	1													1														1
Fistulariidae	1		1						2					1														1
Gerreidae	1			1																								
Gobiidae	12	2	2	1		1	1	1	1		2	1	2	3	2	1	1	1	2	3		1	2	1	7	2	2	1
Haemulidae	2		1	1					1					1	1									2				
Holocentridae	17	5	4	2		1	3	5	7	5	3	3	3	6	6	3	2	3	8	4	2	2	7	7	5	4		1
Kyphosidae	3					2			1													1				2		
Lethrinidae	9	2	1	2		1		3	4	2	5	4	4	2	3	2	2		2	2	1	1	2	3	2	4	2	1
Lutjanidae	10	2		1	3	4		4	8	6	5	5	5	8	6	7	7	1	8		5	3	4	9	1	2	3	4
Malacanthidae	3					1	2	1	1		1	1					1		1									1
Microdesmidae	1														1													
Monacanthidae	9	3	1				1	2	1	1	1	1	2		1	3	4		2	1	1	1	2					
Mugilidae	1																				2							
Mullidae	10	6	4	4	2	2	2	1	5	4	3	3	6	6	6	2	4	3	5	3	6	5	4	9	8	6	3	4
Muraenidae	3						1					1	1		2								1					1
Myliobatidae	1								1														1					

FAMILY	SITE NO.																											
Family	All	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Nemipteridae	3	2	1	2					1	1	1	2			3	1			1	1	2	1	1	1	1	1		2
Ophichthidae	1																									1		
Ostraciidae	2						1	2	1		1		2	2			1			1	1	1						
Pempheridae	2					1					1				1				1		1	1						
Pinguipedidae	2	2	2	2					2	2		1	1	1	2	1	2	1	1	2	1	1	2	1	2	1	1	1
Plotosidae	1																										1	
Priacanthidae	1	1		1						1	1			1	1				1	1	1	1	1	1	1	1		
Microdesmidae	5						1	2	3	2	2	2	1	2	1	2	3	1	3	3	2	1		2	1	2		
Scombridae	1					1			1											1								
Scorpaenidae	1						1																1					
Serranidae	24	2	2	2	8	6	9	5	12	7	4	4	5	8	4	4	3	4	2	5	5	4	4	7	6	6	1	1
Siganidae	5	1	2	2		1			1		1	1			3		2	2	1	1	2	2	2	2	1	1		1
Sphyraenidae	3			1		1	1		1					2					1									
Syngnathidae	3	1																1							1	1		
Synodontidae	2	2	2	2	1	1	1	1	2	1	1	2	1	2	2	1	2	2	2	2	2	2	1		1			
Tetraodontidae	6		2			1	2									1		2	1	3	3	1		1	1			
Zanclidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total	406	119	101	102	70	100	98	126	200	116	107	126	117	150	146	128	136	90	142	118	148	129	151	163	128	124	86	72

Annex10.1.

NUMBER OF INDIVIDUALS, MEAN DENSITY, MEAN BIOMASS, AND MEAN AND MAXIMUM FORK LENGTH FOR ALL FISH SPECIES RECORDED IN THE 2014 VAVA'U BIORAP

The maturity length (Database IRD, Nouméa –M. Kulbicki, personal communication) and maximum size (Kulbicki 2005; FishBase 2013) are presented for comparison. The symbol – means that no data or value was available. In the 'Mean/max. fork length' column, numbers highlighted in orange represent species with mean fork length lower than or equal to the minimum maturity length. Numbers highlighted in red represent species with maximum fork length lower than the minimum maturity length.

Family/Species	No. of individuals	Total mean density (fish/m²)	Total mean biomass (ton/km²)	Mean/max. fork length (cm)	Maturity length/max. size (reference)
Acanthuridae	3,192	0.236	48.71	16.9/56	–
Acanthurus achilles	Out of transect			–	–/24
Acanthurus albipectoralis	190	0.014	3.64	21.2/31	–/33
Acanthurus blochii	20	0.001	0.66	26/30	–/45
Acanthurus dussumieri	69	0.005	8.53	39.3/50	25/54
Acanthurus guttatus	8	0.001	0.03	21/24	–/26
Acanthurus lineatus	40	0.003	0.46	17.5/20	18/38
Acanthurus nigricans	95	0.007	0.61	11.4/23	–/21.3
Acanthurus nigricauda	125	0.009	3.16	19.3/36	–/40
Acanthurus nigrofuscus	639	0.047	1.75	9.5/17	11.5/21
Acanthurus olivaceus	68	0.005	0.70	17.2/24	–/35
Acanthurus pyroferus	41	0.003	0.02	15.4/18	–/25
Acanthurus thompsoni	10	0.001	0.10	20/26	–/27
Acanthurus triostegus	112	0.008	0.29	11/12	7.5/27
Ctenochaetus cyanocheilus	128	0.009	0.25	9.2/13	–/16
Ctenochaetus striatus	674	0.050	4.61	15/20	12/26
Naso brachycentron	Out of transect			–	–/90
Naso brevirostris	72	0.005	0.87	21.8/28	–/60
Naso caesius	131	0.010	5.39	30.8/56	–/45.6
Naso hexacanthus	144	0.011	4.75	28.1/40	45/75
Naso lituratus	170	0.013	2.65	17.3/26	–/46
Naso lopezi	12	0.001	0.39	28/30	–/60
Naso tonganus	37	0.003	7.53	43.5/52	–/60
Naso unicornis	44	0.003	1.32	22.4/43	–/70
Naso vlamingii	4	0.0003	0.13	25/28	–/60
Paracanthurus hepatus	70	0.005	0.19	12/16	–/31
Zebrasoma scopas	258	0.019	0.37	8.6/12	8/15
Zebrasoma veliferum	31	0.002	0.32	15.6/24	–/40
Aulostomidae	17	0.001	0.07	30.5/48	–
Aulostomus chinensis	17	0.001	0.07	30.5/48	42/80
Balistidae	496	0.037	3.40	18.2/48	–
Balistapus undulatus	67	0.005	0.59	15.9/28	–/30

Family/Species	No. of individuals	Total mean density (fish/m²)	Total mean biomass (ton/km²)	Mean/max. fork length (cm)	Maturity length/max. size (reference)
Balistoides conspicillum	9	0.001	0.29	25.4/28	41/50
Balistoides viridescens	2	0.0001	0.36	45/48	47/75
Melichthys vidua	86	0.006	0.90	17.5/27	–/40
Odonus niger	232	0.017	0.63	20.5/32	–/50
Pseudobalistes fuscus	3	0.0002	0.20	29.7/35	37/55
Rhinecanthus rectangulus	Out of transect			–	-/30
Sufflamen bursa	33	0.002	0.13	12.7/18	–/25
Sufflamen chrysopterum	62	0.005	0.23	14.2/18	–/30
Sufflamen fraenatum	2	0.0001	0.07	26/26	19/38
Caesionidae	1,069	0.079	12.62	18.3/22	–
Caesio caerulaurea	682	0.051	3.93	16.3/20	–/35
Caesio lunaris	43	0.003	0.21	15.5/16	–/40
Caesio sp.	6	0.0004	0.02	14/14	–
Pterocaesio digramma	40	0.003	0.54	21/22	20.2/30
Pterocaesio tile	271	0.020	0.83	15.7/20	–/30
Pterocaesio trilineata	27	0.002	7.09	37.5/16	–/20
Carangidae	15	0.001	1.93	43/90	–
Caranx ignobilis	1	0.0001	1.15	90/90	58/170
Caranx lugubris	Out of transect			–	36.5/100
Caranx melampygus	11	0.001	0.57	34.7/50	35/117
Caranx sexfasciatus	Out of transect			–	42/120
Elagatis bipinnulata	3	0.0002	0.21	46/46	–/180
Gnathanodon speciosus	Out of transect			–	61/120
Scomberoides lysan	Out of transect			–	-/110
Trachinotus blochii	Out of transect			–	58/110
Carcharhinidae	3	0.0002	1.95	100/100	–
Carcharhinus amblyrhynchos	Out of transect			–	124.6/255
Carcharhinus melanopterus	Out of transect			–	94.5/200
Triaenodon obesus	3	0.0002	1.95	100/100	106.5/213
Chaetodontidae	705	0.052	1.27	9.5/27	–
Chaetodon auriga	39	0.003	0.11	10.8/15	10/23
Chaetodon baronessa	3	0.0002	0.00	9/10	–/16
Chaetodon bennetti	2	0.0001	0.00	10/10	–/20
Chaetodon citrinellus	36	0.003	0.02	7.5/10	–/13
Chaetodon ephippium	36	0.003	0.09	10.5/14	–/30
Chaetodon flavirostris	Out of transect			–	–/20
Chaetodon kleinii	17	0.001	0.02	9/12	7/15
Chaetodon lineolatus	8	0.001	0.01	10.5/13	12/30
Chaetodon lunula	19	0.001	0.04	9.8/13	–/20

Family/Species	No. of individuals	Total mean density (fish/m²)	Total mean biomass (ton/km²)	Mean/max. fork length (cm)	Maturity length/max. size (reference)
Chaetodon lunulatus	19	0.001	0.04	9.5/12	10/14
Chaetodon melannotus	8	0.001	0.01	8.3/9	–/18
Chaetodon mertensii	73	0.005	0.05	7.4/10	10/12.5
Chaetodon ornatissimus	1	0.0001	0.00	12/12	–/20
Chaetodon pelewensis	134	0.010	0.05	6.3/9	9/12.5
Chaetodon plebeius	5	0.0004	0.01	8.5/9	–/15
Chaetodon rafflesii	16	0.001	0.03	9.4/11	–/18
Chaetodon reticulatus	38	0.003	0.06	9/17	–/18
Chaetodon semeion	Out of transect			–	–/26
Chaetodon trifascialis	10	0.001	0.01	8.5/12	12/18
Chaetodon ulietensis	41	0.003	0.08	10.5/12	–/15
Chaetodon unimaculatus	17	0.001	0.05	9.8/12	–/20
Chaetodon vagabundus	52	0.004	0.13	10.8/22	12/23
Forcipiger flavissimus	40	0.003	0.02	8.3/10	–/22
Hemitaurichthys polylepis	61	0.005	0.15	9.3/11	–/18
Heniochus acuminatus	1	0.0001	0.01	13/13	15/25
Heniochus chrysostomus	17	0.001	0.10	13.7/18	–/18
Heniochus monoceros	7	0.001	0.11	19.8/27	–/24
Heniochus singularius	2	0.0001	0.05	22/23	–/30
Heniochus varius	3	0.0002	0.00	13/13	–/19
Ephippidae	1	0.0001	0.06	28/28	–
Platax orbicularis	1	0.0001	0.06	28/28	50/50
Fistulariidae	2	0.0001	0.00	25/25	–
Fistularia commersonii	2	0.0001	0.00	25/25	–/160
Haemulidae				58/58	–
Plectorhinchus chaetodonoides	Out of transect			58/58	40/72
Plectorhinchus picus	Out of transect			–	52/84
Holocentridae	330	0.024	3.12	17.3/26	–
Myripristis adusta	4	0.0003	0.06	18.5/18	–/35
Myripristis berndti	36	0.003	0.76	19.8/26	12/30
Myripristis kuntee	44	0.003	0.40	15/22	12/26
Myripristis murdjan	17	0.001	0.16	15/16	17.5/30
Myripristis sp.	2	0.0001	0.02	15.5/16	–
Myripristis violacea	16	0.001	0.18	17/17	14/35
Myripristis vittata	6	0.0004	0.14	20/20	–/25
Neoniphon opercularis	3	0.0002	0.01	16.3/18	–/35
Neoniphon sammara	69	0.005	0.32	14.5/17	15/32
Sargocentron caudimaculatum	96	0.007	0.41	15.1/18	–/25
Sargocentron ittodai	2	0.0001	0.01	13.5/14	–/20

Family/Species	No. of individuals	Total mean density (fish/m²)	Total mean biomass (ton/km²)	Mean/max. fork length (cm)	Maturity length/max. size (reference)
Sargocentron punctatissimum	Out of transect			–	–/23
Sargocentron spiniferum	31	0.002	0.62	20.8/26	–/51
Sargocentron tiere	3	0.0002	0.02	18/19	–/33
Sargocentron violaceum	1	0.0001	0.01	21/21	–/45
Kyphosidae	2	0.0001	0.17	37/37	–
Kyphosus cinerascens	Out of transect			–	–/50
Kyphosus sp.	Out of transect			–	–
Kyphosus vaigiensis	2	0.0001	0.17	37/37	39/70
Labridae	183	0.014	8.54	24.4/100	–
Bodianus axillaris	1	0.0001	0.00	15/15	–/20
Bodianus loxozonus	13	0.001	0.34	26/31	–/47
Cheilinus fasciatus	34	0.003	0.17	18/25	–/40
Cheilinus trilobatus	26	0.002	0.40	20.9/33	26/45
Cheilinus undulatus	7	0.001	6.23	67.8/100	64.4/229
Coris aygula	9	0.001	0.13	23.8/32	45/120
Coris gaimard	1	0.0001	0.02	27/27	–/40
Epibulus insidiator	15	0.001	0.18	19/26	35/54
Hemigymnus fasciatus	20	0.001	0.21	18.5/32	–/80
Hemigymnus melapterus	18	0.001	0.48	25/42	–/90
Oxycheilinus digramma	2	0.0001	0.01	15/15	–/40
Oxycheilinus unifasciatus	37	0.003	0.37	17.4/27	–/46
Lethrinidae	135	0.010	4.46	24.8/53	–
Gnathodentex aureolineatus	46	0.003	0.47	17/21	–/30
Gymnocranius euanus	Out of transect			–	31/45
Gymnocranius sp.	Out of transect			–	–
Lethrinus harak	Out of transect			–	22/50
Lethrinus obsoletus	7	0.001	0.12	21.8/24	25/60
Lethrinus olivaceus	7	0.001	0.99	47.5/53	34.6/100
Lethrinus sp.	1	0.0001	0.04	29/29	–
Monotaxis grandoculis	74	0.005	2.84	23.6/47	–/60
Lutjanidae	969	0.072	29.75	29.7/70	–
Aphareus furca	25	0.002	0.65	25/39	–/70
Aprion virescens	10	0.001	1.30	50/60	44.5/112
Lutjanus bohar	56	0.004	6.04	30.1/70	45/90
Lutjanus fulviflamma	Out of transect			–	13/35
Lutjanus fulvus	27	0.002	0.35	22.4/26	19/40
Lutjanus gibbus	314	0.023	10.40	28.1/40	22/50
Lutjanus kasmira	476	0.035	7.69	21/27	17/40
Lutjanus monostigma	6	0.0004	0.19	29.7/32	26/60
Macolor macularis	35	0.003	1.65	30/45	–/60

Family/Species	No. of individuals	Total mean density (fish/m²)	Total mean biomass (ton/km²)	Mean/max. fork length (cm)	Maturity length/max. size (reference)
Macolor niger	20	0.001	1.48	41/45	–/75
Monacanthidae	1	0.0001	0.01	37/37	–
Aluterus scriptus	1	0.0001	0.01	37/37	–/110
Mugilidae	Out Of Transect			–	–
Liza vaigiensis	Out of transect			–	32/63
Mullidae	323	0.024	2.14	16.9/36	–
Mulloidichthys flavolineatus	27	0.002	0.16	18/20	11/43
Mulloidichthys vanicolensis	43	0.003	0.12	15/18	20/38
Parupeneus barberinoides	14	0.001	0.06	15.3/17	11/30
Parupeneus barberinus	31	0.002	0.40	19.1/31	19/60
Parupeneus ciliatus	23	0.002	0.24	19/20	–/38
Parupeneus crassilabris	15	0.001	0.17	18/26	–/35
Parupeneus cyclostomus	34	0.003	0.21	20/36	–/50
Parupeneus indicus	6	0.0004	0.05	18/19	19/45
Parupeneus multifasciatus	122	0.009	0.72	14.2/27	15.8/35
Parupeneus pleurostigma	2	0.0001	0.01	16/16	12/33
Muraenidae	2	0.0001	0.04	50/60	–
Gymnothorax flavimarginatus	Out of transect			-	65/240
Gymnothorax meleagris	2	0.0001	0.04	50/60	–/120
Nemipteridae	76	0.005	0.40	14.7/20	–
Scolopsis bilineata	73	0.005	0.39	14.8/20	–/23
Scolopsis trilineata	3	0.000	0.01	14/14	–/20
Pempheridae	Out of transect			–	–
Pempheris sp.	Out of transect			–	–
Priacanthidae	18	0.001	0.37	25/32	–
Priacanthus hamrur	18	0.001	0.37	25/32	25/45
Scaridae	1481	0.110	38.02	25.5/52	–
Calotomus carolinus	3	0.0002	0.08	26/28	–/54
Cetoscarus bicolor	16	0.001	0.56	34.7/46	30/90
Chlorurus bleekeri	55	0.004	2.05	28/36	–/49
Chlorurus microrhinos	79	0.006	3.13	28.6/45	–/70
Chlorurus sordidus	251	0.019	4.99	21.8/32	15/40
Hipposcarus longiceps	26	0.002	2.19	41/52	–/60
Scarus altipinnis	6	0.0004	0.56	39/43	42/60
Scarus chameleon	59	0.004	1.53	25.7/32	–/31
Scarus dimidiatus	13	0.001	0.24	23.3/26	–/40
Scarus forsteni	28	0.002	0.72	26.1/35	–/55
Scarus frenatus	14	0.001	0.75	27/32	17/47
Scarus ghobban	22	0.002	0.31	21.3/30	41/90

Family/Species	No. of individuals	Total mean density (fish/m²)	Total mean biomass (ton/km²)	Mean/max. fork length (cm)	Maturity length/max. size (reference)
Scarus globiceps	56	0.004	1.39	27.4/34	18/27
Scarus longipinnis	60	0.004	1.25	24.9/36	–/40
Scarus niger	59	0.004	1.78	25.2/45	–/40
Scarus oviceps	27	0.002	0.47	25/32	–/35
Scarus psittacus	197	0.015	5.11	23.8/32	10.5/30
Scarus rivulatus	21	0.002	0.22	20.8/30	–/40
Scarus rubroviolaceus	28	0.002	2.11	38.3/50	–/70
Scarus schlegeli	275	0.020	7.31	23.6/35	–/40
Scarus sp.	178	0.013	1.01	15.4/21	–
Scarus spinus	8	0.001	0.27	27.3/33	–/30
Scombridae	Out Of Transect			90/90	–
Gymnosarda unicolor	Out of transect			90/90	–/248
Serranidae	301	0.022	4.62	27.5/53	–
Cephalopholis argus	13	0.001	0.53	31.4/40	31/60
Cephalopholis miniata	Out of transect			–	23/45
Cephalopholis sexmaculata	2	0.0001	0.10	33/36	–/50
Cephalopholis sonnerati	Out of transect			–	29/57
Cephalopholis urodeta	94	0.007	0.69	17.6/31	17/28
Epinephelus fasciatus	161	0.012	1.85	23/33	19.2/40
Epinephelus fuscoguttatus	1	0.0001	0.14	48/50	50/120
Epinephelus hexagonatus	Out of transect			–	19/27.5
Epinephelus maculatus	Out of transect			–	26/60.5
Epinephelus merra	5	0.0004	0.06	22.3/26	11/31
Epinephelus polyphekadion	1	0.0001	0.08	42/42	41/90
Epinephelus spilotoceps	1	0.0001	0.02	28/28	19/35
Plectropomus laevis	5	0.0004	0.44	41/53	60/125
Plectropomus leopardus	1	0.0001	0.06	38/38	30/120
Variola louti	17	0.001	0.66	33/50	40/83
Siganidae	103	0.008	1.05	18.5/32	–
Siganus argenteus	36	0.003	0.25	17.2/20	20/40
Siganus doliatus	47	0.003	0.23	15.3/20	–/25
Siganus punctatus	13	0.001	0.50	28/32	24/40
Siganus sp.	7	0.001	0.07	20.3/21	–
Siganus spinus	Out of transect			–	-/28
Sphyraenidae	52	0.004	10.70	64/90	–
Sphyraena barracuda	2	0.0001	0.17	56/60	58/200
Sphyraena qenie	50	0.004	10.53	80/90	–/170
Zanclidae	111	0.008	0.43	11.4/15	–
Zanclus cornutus	111	0.008	0.43	11.4/15	–/23

Annex 13.1.

OVERVIEW OF CORAL REEF SITES SURVEYED AND ASSOCIATED SPECIES RICHNESS, REEF HEALTH AND FISH BIOMASS

An 'x' highlights the sites where values were observed to be among the highest.

Site name	Site no.		Parameter			
		Invertebrate species richness	Coral species richness	Reef health	Reef fish species richness	Fish biomass
Lotuma Island	1		x		x	
LotumaIsland channel	2					
Mount Talau, Vava'u Lahi	3					
Fonualei Island, north	4	x				x
Fonualei Island, south	5	x				x
Toku Island, south	6	x				x
Toku Island, north	7	x		x		x
Toku Island, Joe's Spit	8	x		x	x	x
Mata'utuiliki, Vava'u Lahi	9					
'Onetale Bay, Vava'u Lahi	10					
'Umana Island	11					
Maninita Island, inside	12			x	x	x
Maninita Island, outside	13				x	x
Taula Island, inside	14			x	x	x
Taula Island, outside	15		x		x	x
Fonua'one'one Island, south	16		x	x		x
Fonua'one'one Island, north	17		x			x
Fangasito Island, south	18		x	x	x	x
Fangasito Island, north	19				x	x
A'a Island	20				x	
'Oto Island	21					
'EuakafaIsland, south	22			x	x	x
'EuakafaIsland, north	23			x	x	x
'Euaiki Island, east	24			x	x	x
'Euaiki Island, west	25		x		x	x
Vaka'eitu Island	26		x			
Langito'o Island	27					

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