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GLOBAL REEF EXPEDITION FINAL REPORT

Khaled bin Sultan Living Oceans Foundation

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Global Reef Expedition: Lau Province, Fiji June 2-28, 2013

Global Reef Expedition Final Report

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Andrew Bruckner, PhD

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Science Without Borders®

The Khaled bin Sultan Living Oceans Foundation (KSLOF) is a nonprofit private operating foundation dedicated to providing science-based solutions to protect and restore ocean health.

All research was completed under the research permit approved by the Ministry of Education, Natural Heritage, Culture & Arts, RA 10/13 dated 11 April 2013. The information included in this document is submitted to fulfill the requirements of the Final Report for the Global Reef Expedition: Fiji Research Mission.

The findings presented in this report were collected as part of the Global Reef Expedition through the support provided by His Royal Highness Prince Khaled bin Sultan.

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Images by Andrew Bruckner, unless noted.
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The Foundation worked closely with Wildlife Conservation Society, University of the South Pacific, Ministry of Fisheries, the Pacific Blue Foundation, Lau Provincial Council, and members of the Fiji Locally Managed Marine Area (FLMMA) Network on all aspects of this project. One of our key team members, Roko Sau, the paramount chief of Totoya, helped facilitate all communications with various chiefs, traditional leaders and community members. He also provided us with critical information on the local community traditional protocols and requirements for the scientific team throughout the islands we examined in the Lau Group. We are grateful for the collaborations with Stacy Jupiter, Laitia Raloa, Ron Vave and William Saladrau in our coral reef research and assistance they provided in our education and outreach activities.

The research missions to Fiji could never have been completed without the leadership, vision, and generosity of His Royal Highness Prince Khaled bin Sultan. We are deeply appreciative of his financial support and for the generous use of his research vessel, the M/Y Golden Shadow. His vision of Science Without Borders® was materialized in the research mission to Fiji through the partnerships and involvement by scientists from the following countries: Fiji, the USA, New Zealand, Australia, Portugal, the Philippines, and Taiwan. The Living Oceans Foundation appreciates the skill and dedication of the scientific divers that aided the Foundation in data collection, especially our international partners from NOVA Southeastern University, University of the Philippines, University of the Azores, University of Miami, NOAA, University of Wellington, Florida Aquarium, and Taiwan Museum. I am particularly grateful for the dedicated efforts of each scientist, including countless hours of time spent underwater and the tedious process of entering data. I thank each of you for your contributions, especially the detailed reports you provided which have been incorporated into the reports. I realize that many of you volunteered your precious time to participate, and gave up weekends, holidays and family time to help make each mission a success.

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As the deliverables from this massive research effort are completed, we look forward to continuing these partnerships to ensure that the information and data from this project is applied towards conservation needs and goals for the Lau Province.

Executive Summary

From 2 June 2013 – 28 June 2013, the Khaled bin Sultan Living Oceans Foundation conducted a research mission to the Lau Province, Fiji as part of the Global Reef Expedition (GRE). The research focused on coral reefs surrounding 11 islands: Cicia, Fulaga, Kabara, Mago, Matuka, Moala, Nayau, Totoya, Tuvuca, Vanua Balavu, and Vanua Vatu. The project was conducted in partnership with the Wildlife Conservation Society of Fiji, Lau Provincial Office and Fiji Department of Fisheries, with involvement of scientists from the University of the South Pacific, Department of Fisheries, Nova Southeastern University, University of the Azores, University of the Philippines, NOAA/University of Miami, National Museum of Marine Biology and Aquarium of Taiwan, Reef Environmental Education Foundation (REEF), and Victoria University. Roko Sau (Josefa Cinavilakeba, Pacific Blue Foundation) and Roko Laitia Raloa (Lau Provincial Office) provided assistance with traditional protocols, meetings and deliberations with the Chiefs, Council and elders on each island, and education activities.

The objectives of the mission were to:

1) *Identify and characterize shallow marine habitats and develop habitat and bathymetric maps;*
2) *Evaluate the composition, structure and health of coral reefs using a standardized assessment protocol;*
3) *Assess the diversity, abundance and population structure of fishes, corals and other invertebrates, and algae, including commercially valuable species;*
4) *Document impacts of broad scale disturbances and patterns of recovery with emphasis on storm damage and crown of thorns predation impacts;*
5) *Evaluate the effects of environmental stressors on coral health;*
6) *Characterize the composition of symbionts inhabiting colonies of Pocillopora, effects of environmental parameters on their composition and photosynthetic efficiency; and*
7) *Measure ocean chemistry (pH) and effects on* coral growth.

Satellite imagery, habitat maps and bathymetry were produced for Cicia, Fulaga, Kabara, Mago, Matuka, Moala, Nayau, Totoya, Tuvuca, Vanua Balavu, and Vanua Vatu. The development of these maps required acquisition of a total of 2,273 sq. km of WorldView-2 satellite imagery and collection of detailed groundtruthing data consisting of 787 videos (drop cameras) and 3,037,823 depth soundings, all collected within the shallow marine habitats off these islands over a distance of 798 km. The habitat maps and bathymetric maps extend from the shoreline to 25 m depth and include both fore reef and lagoonal habitats when present and accessible.

We identified a total of 21 shallow marine habitats within lagoonal, back reef and fore reef locations and seven intertidal, coastal and nearshore terrestrial habitats. The 21 marine habitats include four fore reef locations, the reef crest, five back reef habitats, and 11 lagoonal habitats. The total area encompassed by these marine habitats is 1060 sq km, with 95 sq km located in the fore reef, 170 sq km in the back reef, and 781 sq km of shallow lagoonal habitats. Unmapped deep lagoonal areas amounted to an additional 134 sq km and intertidal (mangrove and mudflat) and terrestrial areas included 340 sq km in total. Images and descriptions of the biology, hydrography, sedimentology, topography and depth range are provided for each habitat class.

A total of 70 reefs were surveyed in Lau Province. Surveys targeted depths of 5-30 m and included representative fore reef, back reef and lagoonal habitats in each island, when possible.

Survey	Depth (m)					TOTAL
	<8	**8-13**	**14-18**	**19-25**	**>25**	
Benthic	57	74	102	48	1	282
Coral	15	34	25	19	1	94
Photo-transects	75	124	120	106	0	425
Fish	14	161	183	1	0	359

Table 1. Total number of benthic, coral, photo-transect and fish transects completed in Lau Province.

The benthic substrates of the 70 reefs assessed during this study consisted of 52% pavement, 36% live coral cover, 7.2% rubble, 5.2% dead coral and 6.4% sand. In total, 85% of the bottom was colonized by living organisms, and the remainder was either uncolonized sand, pavement or unconsolidated rubble. Differences in the relative cover of different substrate types was minimal when data were pooled from all islands by depth. However an examination of data from individual islands illustrates considerable variation between islands. Mean live coral cover was over 45% on four islands (Cicia, Fulaga, Mago and Nayau), greater than 30% at Moala, Totoya, Tuvuca, Vanua Vatu and less than 30% at all other sites. Coral cover also varied between depths, with lowest cover at 19-25 m depth.

Coral cover pooled for all sites and depths was dominated by *Acropora* spp. (32%), *Pocillopora* (11.3%), *Porites* (9.9%), *Montipora* (8.1%) and faviids (*Goniastrea, Montastraea, Favia, Favites* and *Cyphastrea*) (13.5%), with 5.5% cover *Millepora* and the remainder made up of 34 other genera. The live cover of *Acropora* and *Pocillopora* declined with depth, while *Porites, Montipora* and the five faviid genera was greatest at 18-25 m depth.

A shallow reef off Cicia with a high cover of Acropora

Minor differences in the cover of corals were noted between islands. *Acropora* cover was highest overall at Cicia, making up over half of all coral, followed by Nayau (39%) and Tuvuca (35%), while it was lowest at Vanua Vatu (21% of the coral cover). On all other islands, Acropora made up 27-32% of the coral cover. *Pocillopora* varied from a low of 5% at Tuvuca to a maximum of 17.5% at Kabara. The cover of *Porites* was greatest overall at Vanua Vatu (22%) and lowest at Cicia (4.5%). Vanua Balavu had the most diverse coral assemblages, with over 24% of the coral composed of less common taxa.

Many deep reefs had large stands of plating and foliaceous corals such as the Turbinaria colonies seen in Totoya.

At most sites, the cover of macroalgae was low (mean=4%), with the highest cover on Vanua Balavu (8.6%). Macroalgae also increased with depth and habitat with large mats of *Caulerpa* noted on many deeper reefs and on vertical walls. Reefs also had a high cover of erect coralline algae (primarily *Halimeda*), especially at Vanua Balavu (mean=12%), Vanua Vatu (mean=10%), and Mago and Kobara (mean =8.8%). All reefs had a high cover of crustose coralline algae (mean=21.6%), with highest cover at Kabara (29.8%) and lowest at Mago (15%).

Pest species were noted on many of the reefs, especially cyanobacteria. Cyanobacteria cover on all reefs (pooled for all sites and depths) was 9.3%, with the highest cover overall at Tuvuca (14.4%). It is important to note that this represents cyanobacterial mats on pavement and dead coral. High cover of cyanobacteria was also noted in sandy areas of deeper lagoonal and fore reef sites.

Reef fish communities were fairly diverse with a total of 482 species (172 genera, 51 families) recorded within belt transects. This represents roughly 25% of the total number of reef fishes reported for Fiji. The lower number may reflect an absence of surveys in grass bed and mangrove habitats. The most diverse families seen on these reefs include the Labridae (71 species) Pomacentridae (58 species), Acanthuridae (32 species), Chaetodontidae (30 species), Scaridae (23 species), Lutjanidae (23 species), Epinephelidae (10 species), Carangidae (11 species), and Siganidae (8 species). Reef fish occurred at an average density of 218 individuals/100 m^2, with the highest density at Fulaga (297 individuals/100 m^2) and Cicia (279 individuals/100 m^2) and the lowest at Matuka (162 individuals/100 m^2). Planktivores had the highest average density (101 individuals/100 m^2) followed by herbivores (40 individuals/100 m^2) and carnivores (21 individuals/100 m^2), while piscivores and corallivores were much less dense (7 to 13 individuals/100 m^2 respectively).

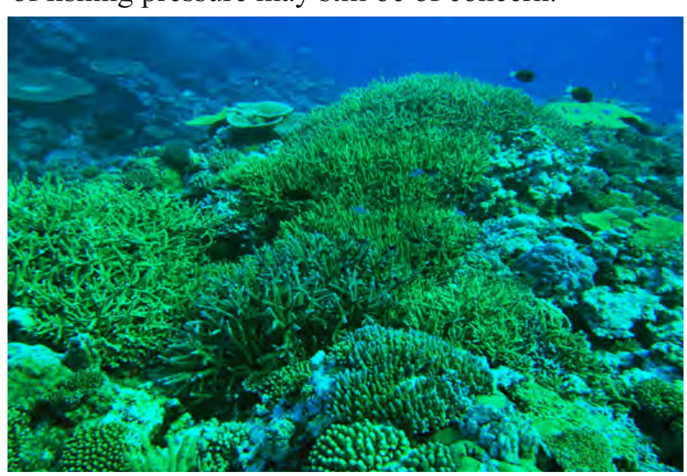
In general sharks were rare and small in size.

Reef fish assemblages were dominated by small bodied species, most less than 20 cm total length (92% of fish). The larger size classes (>40 cm) represented only 0.5% of the population and 7% of fish were between 21 and 40 cm. More than half the fish observed on Cicia, Mago and Kabara were less than 5 cm total length, while the largest fish overall were seen on Totoya and Vanua Vatu. Fish over 100 cm total length included several shark species, which were observed most frequently on Totoya.

The average biomass of reef fish at these islands was 11.27 kg/100 m^2. Biomass was greatest at Totoya and Cicia (19.4 kg/100 m^2 and 11.8 kg/100 m^2 respectively) and lowest at Matuka (8 kg/100 m^2). The biomass of piscivores (4.7 kg/100 m^2), herbivores (3.2 kg/100 m^2), and benthic carnivores (1.9 kg/100 m^2) contributed the most to the overall biomass at each island. Omnivores and corallivores contained the lowest average biomass of all feeding guilds, with just 0.3 kg/100 m^2 in each guild.

Vanua Balavu and Mago had a moderate number of larger groupers, 41-50 cm total length.

Both coral assemblages and reef fish assemblages appear to have rebounded since the early 2000s. This is primarily attributed to a recolonization of reefs by acroporid corals which died from bleaching, COTS predation and other impacts, and increases in the numbers of small bodied fishes. Size distribution was skewed towards fish that were smaller than 20 cm, which suggests the current level of fishing pressure may still be of concern.



Branching corals have largely recovered from bleaching in 2002.

Introduction

The Lau Islands form one of 14 provinces in Fiji. They are located in the South Pacific Ocean, due east of the Koro Sea and separated from the Fiji Platform by the Nanuku Channel. Lau Province covers an area of 114,000 sq km and includes a chain of about 57 islands and 43 islets at the eastern edge of Fiji on the top of the north-south running Lau-Colville Ridge. While most of the northern group of islands are high and volcanic in origin, those in the south are a mix of extinct oceanic volcanoes and low-lying carbonate islands. These include a number of atolls and near-atolls and extensive barrier reef systems that enclose a number of smaller islands. Together, they have a total land area of 487 sq km. The approximate land area, reef length and lagoonal area is shown in table 2.

Approximately 30 islands in the Lau Province are sparsely populated. The total population of Lau Province recorded in 2007 is 10,700 with residents inhabiting 13 districts and 72 villages. The population is reported to have declined substantially between 1996- 2006 (Turner et al. 2007) and it continues to decline. Best available population estimates for the 11 villages examined in this study are shown in table 2. Although human population is relatively low, a number of human stressors are still reported to have contributed to the decline of these reef systems. The most disconcerting human threats affecting these remote reef systems are unsustainable fishing pressure, destructive fishing, sedimentation and nutrients associated with runoff from agriculture and waste disposal, and removal of mangroves.

Fiji's reefs have a high biodiversity, including 219 species of scleractinian corals, over 2030 species of reef fishes, 478 species of marine molluscs and 422 species of algae. Shallow marine habitats also include mangrove forests composed of nine species and sea grass beds consisting of five different species. Fiji's reefs have an average live cover of 45%, although there has been considerable variability between sites and over time.

The most significant regional changes to Fiji's coral reefs over the last 15 years have been attributed to the 2000 coral bleaching event, with localized damage from crown of thorns starfish (COTS) and *Drupella* gastropods, cyclones, and coral disease (Wilkinson 2011). Archipelago-wide mortality from bleaching was reported to range from 40 and 80% (Lovell and Sikes 2008). The acroporids were the most severely impacted corals, with near total losses of these species noted in some locations. Fortunately, the rapid recolonization and growth of acroporid corals promoted rapid increases in coral cover with some locations reaching pre-disturbance levels by 2007.

While fewer historic data are available on the condition of coral reefs in Lau Province, these reefs have also experienced large declines in coral cover since 1998. For instance, at Totoya and Matuka, coral cover declined from 50-70% in 2000 to 20% in 2006, with a shift from a dominance of acroporids to *Pocillopora* and *Porites* (Wilson et al. 2008).

Cyclones, bleaching events and outbreaks of coral predators are thought to be the main factors responsible for the observed changes in the composition and structure of benthic communities in Lau Province (Cumming et al. 2002, Dulvy et al. 2004). Mass bleaching was reported in 2000, with localized bleaching in 2002 and 2006. Large aggregations of COTS were first reported in 1998. Interestingly, Kabara had recovered from a COTS outbreak by 2000 and coral cover increased from 1-18% by 2006 (Wilson et al. 2008). Cicia and Vanua Vatu experienced localized damage from Cyclone Ami in 2003.

Changes in fish community structure has also been reported for several islands in the Lau Province between 2000-2006. These predominantly included declines in small bodied fishes, and not the larger species that are targeted for subsistence and export fisheries. One of the primary reasons for the decline was thought to be the loss of key habitat areas associated with the demise of acroporid communities from past bleaching events and COTS

Island	Land area (km^2)	Elevation (m)	Lagoonal area (km^2)	Reef area (km^2)	Reef length (km)	No villages	Approx. Population
Cicia	34.9	?	9.2	9.3	25.8	5	1047
Fulaga	17.5	79	43.0	14.1	31.2	3	400
Kabara	31.8	?	10.4	7.0	24.8	4	700
Mago	22.0	?	11.5	8.8	22.4	1	Private island
Matuka	29.1	385	30.6	19.2	30.3	7	800
Moala	64.7	468	115.6	46.0	59.0	8	1596*
Nayau	19.2	?	6.8	5.6	20.8	3	500
Totoya	30.9	366	109.0	26.9	43.2	4	800
Tuvuca	13.3	243	14.3	8.8	20.8	1	180
Vanua Balavu	69.1	283	730.1	116.8	155.4	17	1200
Vanua Vatu	4.2	79	7.3	5.3	14.5	1	89

Table 2. Total areal extent of the major island groups, lagoons and reef, linear distance of the outer reef system, maximum elevation, number of villages and estimated population for each island/atoll examined in 2013. Land area and reef length were calculated from satellite imagery. Reef length is linear extent of reef surrounding major island group. Lagoonal area was calculated from the sum of all back reef and lagoonal habitats. Reef area was estimated by adding up the total area of all fore reef, lagoonal and back reef habitat classes, excluding rubble and soft bottom classes. Population data is from the 1996 census as reported in Dulvy et al 2004; these were updated using 2014 census data from Wikipedia when available.

outbreaks (Wilson et al. 2008, 2010). Because fishing on these islands is predominantly restricted to subsistence fishing by local residents and most areas are still managed using traditional practices, stressors are likely to be minimal. Further, a reduction in human populations and shifts to other occupations is thought to have caused a decline in fishing pressure between 1996-2006 (Turner et al. 2007).

The current study was undertaken to obtain updated information on the condition of coral reef communities off islands that were previously examined, and also to fill gaps and obtain baseline data for reef systems in unstudied areas. The surveys were designed to provide relevant information on the changes to coral reef communities that occurred since the 2000-2007 studies undertaken by Dulvy et al. (2004), Turner et al. (2007) and Wilson et al. (2008). This includes information on the patterns of recovery from bleaching events in 2000 and 2002, COTS outbreaks, and other large scale stressors, as well as the response of fish populations to these changes and to changing human pressure. Data were also collected on current stressors impacting these ecosystems. Targeted research was conducted to evaluate the health of corals, symbiont communities harbored by *Pocillopora*, ocean chemistry, and potential effects of ocean acidification on massive reef building corals. A second component of the study involved the characterization of different shallow marine habitats and mapping of their distribution and bathymetry. These datasets are designed to aid in the development of spatially-based management tools. A third component, conducted by partners from the Wildlife Conservation Society, involved an assessment of the status of invertebrate taxa targeted by fisheries, with emphasis on sea cucumber populations.

Date	Survey Location
1 June	Arrival of scientists
2 June	Depart NADI, Overnight passage
3-5 June	Totoya
6-7 June	Matuka
8-10 June	Moala
11-12 June	Fulaga
13-14 June	Kabara
15 June	Vanua Vatu
16 June	Nayau
17 June	Tuvuca
18-19 June	Cicia
20 June	Mago
21-26 June	Vanua Balavu
27 June	Mago, overnight transit
28 June	Science team disembarks

Table 3. Schedule of the Lau Province, Fiji research mission.

Fig. 1. Locations examined during the research mission to the Lau Province, Fiji.

Habitat mapping

Using multispectral WorldView-2 satellite imagery obtained from DigitalGlobe Inc., in combination with data obtained from groundtruthing (Fig. 5-7), high resolution bathymetric maps and habitat maps were created for shallow marine environments within the lagoon and fore reef. The maps extend from the shoreline to approximately 25 m depth. Groundtruthing efforts included continuous bathymetry measures, drop camera analysis, characterization of sediment and hard substrates and habitat features using two acoustic sub-bottom profiling equipment (Stratabox and Hydrobox), snorkel and dive assessments, and fine scale photo-transect surveys.

Fig. 2. Acoustic sub-bottom profiling equipment. Stratabox (left) and Hydrobox (right).

Satellite imagery

A total of 1,105 sq. km of WorldView-2 (8 band) satellite imagery was acquired for the eight islands targeted for mapping (Table 4). The satellite images had a spatial resolution of 2 m by 2 m (i.e., each pixel covers a 4 m^2 area) enabling real-time navigation in the field to locate features of interest and to avoid dangerous features (e.g., emergent reefs). In order to navigate, the team used the scenes in conjunction with a differential GPS device (dGPS). The imagery was used in conjunction with groundtruth data to create bathymetric and benthic habitat maps.

Benthic Video

An underwater video camera attached to a cable, called a drop-cam, was used to gather video on the benthic composition at each survey site. At each point, the drop-cam was held from the survey boat enabling it to 'fly' along the sea floor as it records video for 15 to 60 seconds. During this time, the laptop operator watched the video in real-time and guided the drop-camp operator to raise or lower the camera. In this manner, we were able to prevent damage to marine life. The video was recorded on a ruggedized laptop, and the geographic position, time, date, boat heading, and boat speed were burned into the video. Drop-cam deployment was limited to depths above 40 m due to the limited length of the tether cable (50 m). The acquired videos are being used to create the benthic habitat maps by providing the necessary information for the development of a habitat classification scheme and training of classification models. A minimum of 30 drop-cam videos were gathered per day (Table 4). The locations of drop camera deployments are shown in Fig. 5-7.

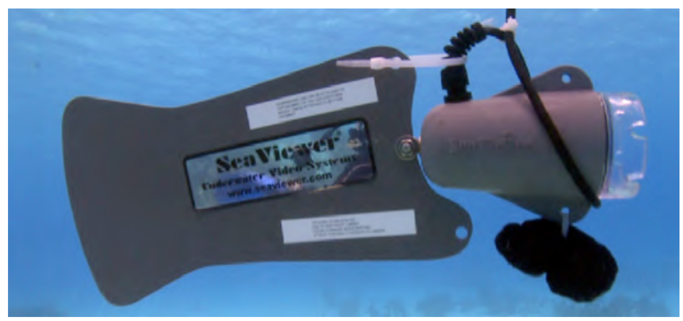


Fig. 3. SeaView Underwater Video System.

Acoustic depth soundings

Depth soundings were gathered along transects shown in Fig. 5-7 using Hydrobox, a single-beam acoustic transducer, developed by Syqwest. The instrument emits 3 pings per second. Depths were estimated based on the time the return-pulse's reaches the sounder's head. Geopositional data were simultaneously acquired by the dGPS unit. The estimated depth values and their geographic location were recorded in the ruggedized laptop, with an average of 100,000 acoustic depth soundings gathered during a full work day (Table 4). The soundings were used to train a water-depth derivation model, which is based on the spectral attenuation of light in the water column. The final topographic maps have the same spatial resolution as the satellite imagery.

Site	Imagery (sq km)	No. drop-cams	No. depth soundings	Track length (km)
Cicia	91	38	96,931	32.159
Fulaga	102	58	250,518	71.533
Kabara	76	31	156,591	40.175
Mago	57	29	102,444	25.169
Matuka	168	54	181,378	45.706
Moala	268	157	524,732	124.100
Nayau	45	24	82,152	25.427
Totoya	311	105	412,190	130.740
Tuvuca	78	53	181,574	42.533
Vanua Balavu	1,036	215	983,605	243.290
Vanua Vatu	41	23	65,708	17.392
Total	**2,273**	**787**	**3,037,823**	**798.224**

Table 4. Summary of groundtruthing data sets. The total area of satellite imagery acquired, number of deployments of the drop camera, number of depth soundings and total distance covered by the groundtruthing team are shown for the 11 islands.

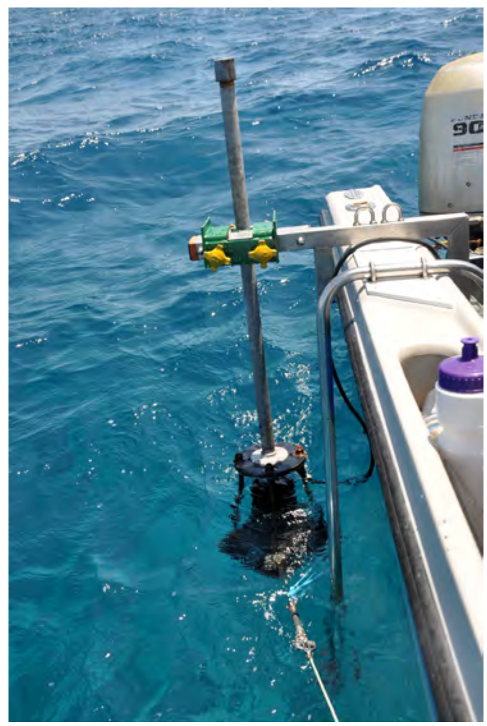


Fig. 4. The groundtruthing team deploying the drop camera (top left). The Hydrobox acoustic sounder recording water depths (top right). Recording and examining the video image collected of the benthos by the drop camera (bottom left).

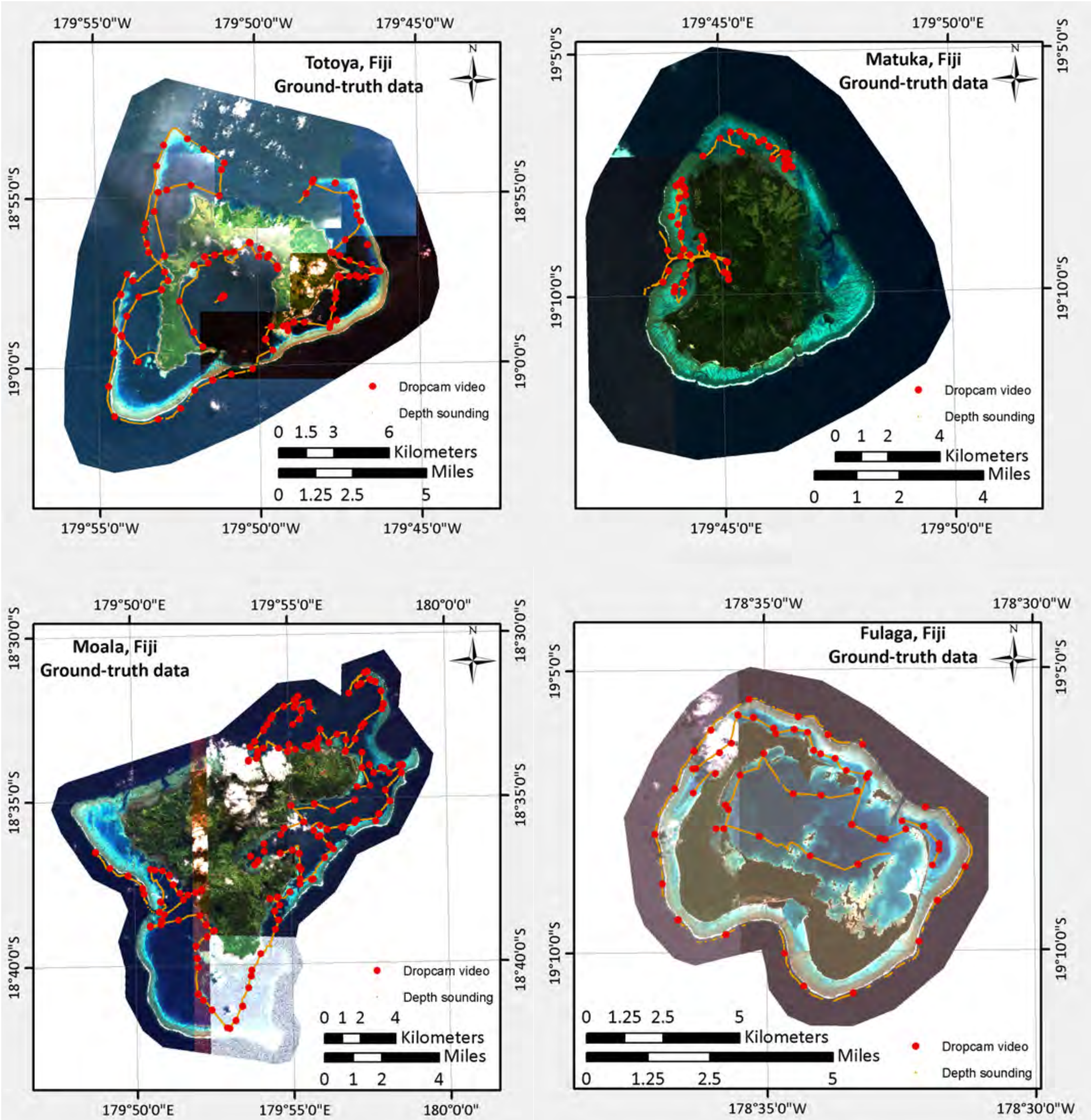


Fig. 5. Groundtruthing track (orange line) and location of drop camera videos (red dots) for Totoya, Matuka, Moala and Fulaga, Fiji.

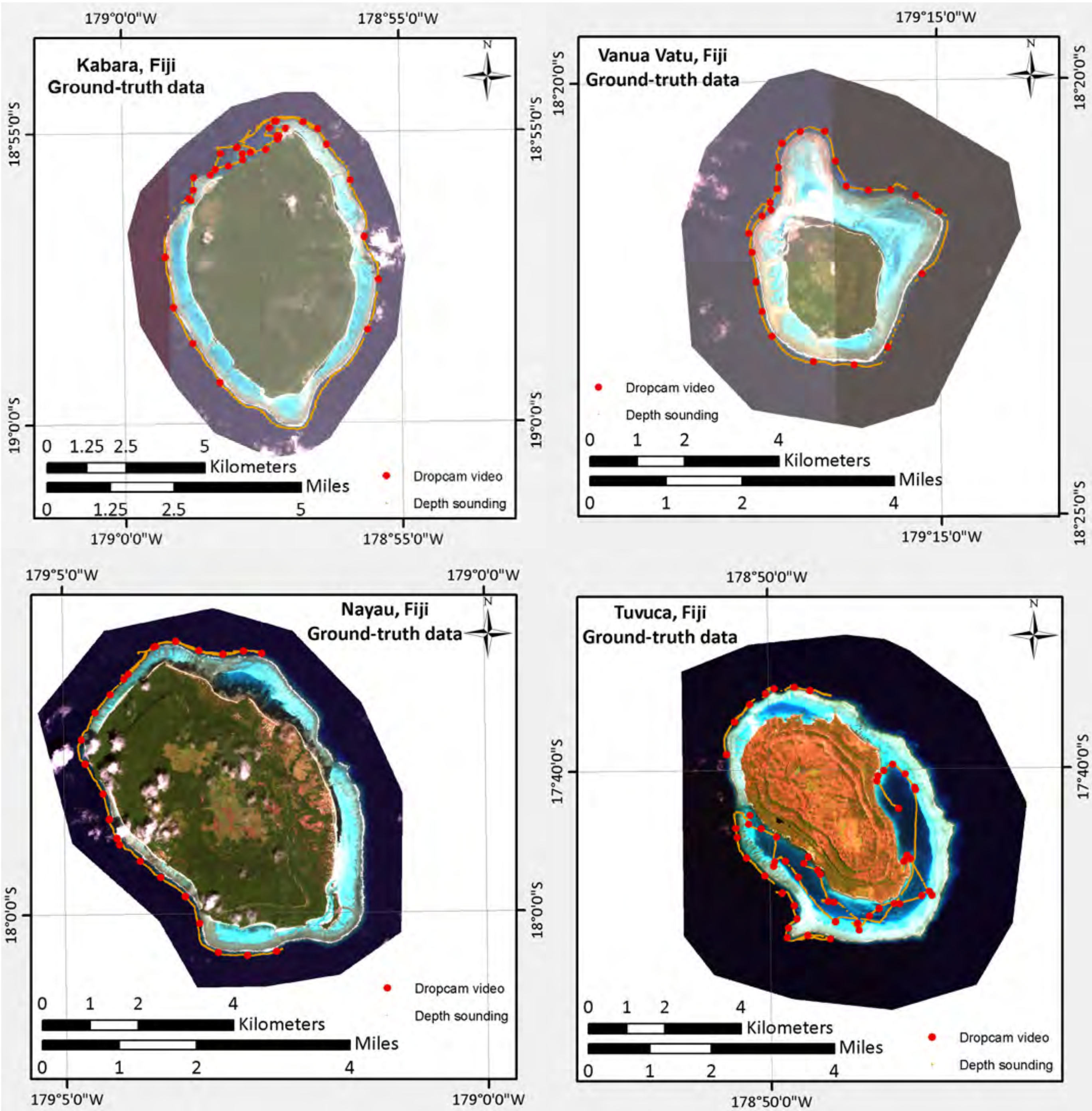


Fig.6. Groundtruthing track (orange line) and location of drop camera videos (red dots) for Kabara, Vanua Vatu, Nayau, and Tuvuca, Fiji.

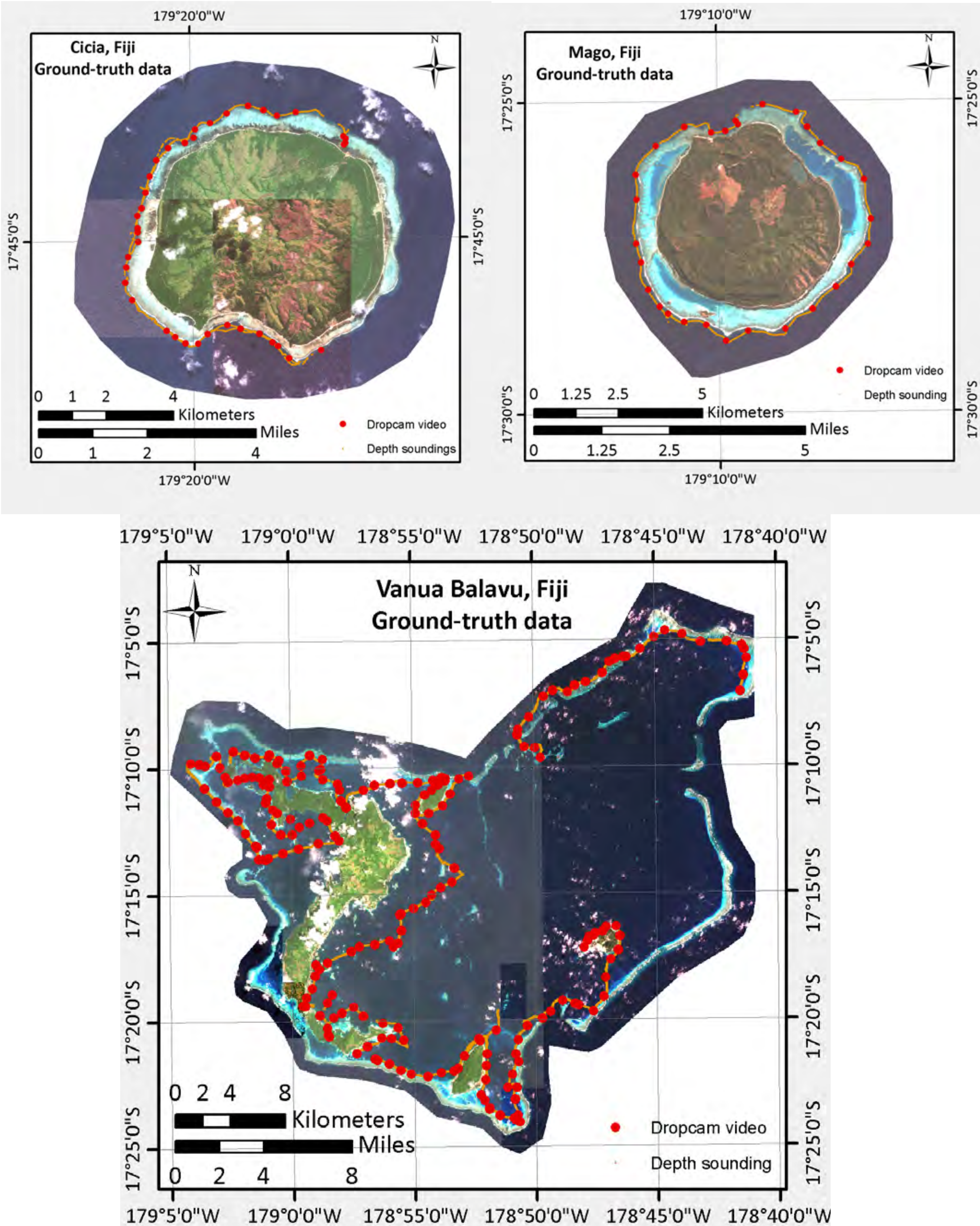


Fig. 7. Groundtruthing track (orange line) and location of drop camera videos (red dots) for Cicia, Mago and Vanua Balavu, Fiji.

Habitat Key – Lau Province, Fiji

A description of all the marine and terrestrial habitat types identified and characterized in Lau Province, Fiji are provided along with representative photographs of each of these habitats taken during the mission. A total of 21 shallow marine habitats, deep (unmapped) fore reef and lagoonal environments and four terrestrial habitats were identified. The total area encompassed by each of the habitats is shown in Table 5.

Habitat Class	Total Area (km^2)
Shallow fore reef terrace	20.9
Shallow fore reef slope	22.6
Deep fore reef slope	44.2
Fore reef sand flats	7.9
Coralline algal ridge	14.0
Back reef rubble dominated	47.8
Back reef sediment dominated	10.3
Back reef pavement	104.3
Back reef coral framework	6.7
Back reef coral bommies	1.1
Lagoonal sediment apron sediment dominated	10.7
Lagoonal floor barren	695.9
Lagoonal floor macroalgae on sediment	3.8
Lagoonal pinnacle reefs massive coral dominated	15.8
Lagoonal patch reefs	2.4
Lagoonal floor coral bommies	0.8
Lagoonal fringing reefs	35.0
Lagoonal bommie field	1.9
Dense seagrass meadows	13.3
Dense macroalgae on sediment	1.3
Deep lagoonal water	134.4
Mangroves	3.8
Mud flats	0.3
Terrestrial vegetation	308.9
Beach sand	2.6
Inland waters	0.2
Urban	0.6
Unvegetated Terrestrial	24.3
Deep ocean water	2029.7
TOTAL	3565.6

Table 5. Total area mapped for each habitat class for 11 islands/atolls within Lau Province, Fiji.

Terrestrial Habitats

For terrestrial (coastal/nearshore) habitats the following habitats classes were discriminated: Terrestrial-Vegetated, Terrestrial - Unvegetated, Beach Sand and Urban (human-made structures),

Fig. 8. Examples of coastal habitats. Terrestrial-vegetated, Mago (top left). Terrestrial-Unvegetated, Cicia (top right). A mix of Terrestrial -Unvegetated and Vegetated habitats at Fulaga (center left). A hillside with dense vegetation, Moala (center right). Beach Sand, Nayau (lower left). Urban, Vanua Balavu (lower right).

Shallow Fore Reef Terrace

BIOLOGY: Benthic community structure varies due to the local disturbance regime and resilience. Spur tops may host a complex community of short, stout branched acroporids and pocilloporids, small encrusting and submassive faviids; on the deeper ends, *Montipora, Astreopora* and other corals take on a plating morphology. Live coral cover in these cases may be very high (60% to 80%). In other cases, the spur top is a scoured hardground with isolated scleractinians and abundant calcareous coralline algae (CCA). Coral density on spur walls ranges from sparse to a dense assemblage of plating and encrusting colonies. Similarly, grooves may be uncolonized coral rock, host CCA accumulations, or support dense coral assemblages.

HYDROGRAPHY: Oceanic and wind-driven waves strongly influence this habitat. Large waves begin to break over spurs, and may generate currents off the reef as water circulation is channeled down the grooves.

SEDIMENTOLOGY: Little sediment accumulates on spurs. Coral rubble and sand accumulates in the grooves. Fine grained sediments are exported by wave generated water motion and currents.

TOPOGRAPHY: Spur tops and grooves have low rugosity. Grooves are highly variable in width and height with some examples being narrow (<1 m) and deep (>2 m) and others being wide (>2 m) and shallow (<50 cm). Grooves may be shallow or deep near the reef crest and similarly shallow or deep near their termination on the reef slope.

DEPTH RANGE: Emergent to 8 m

Fig. 9. Shallow fore reef terrace communities. Coral community is dominated by digitate and tabular acroporids, Kabara, 3 m depth (top right). Large Diploastrea colony with table acroporids, foliose Turbinaria and other species,Cicia, 8 m depth (center). Shallow fore reef terrace at Vanua Balavu, 5 m depth.

Shallow Fore Reef Slope

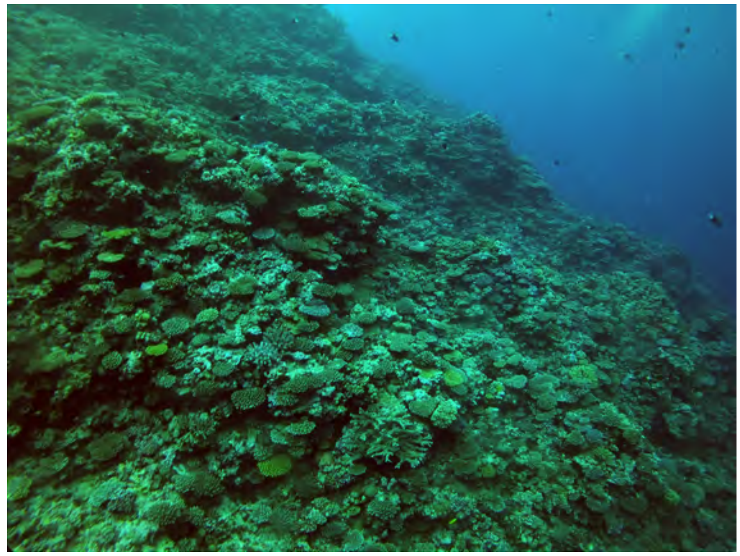
BIOLOGY: The benthic community is highly diverse and coral-dominated often with a substantial macroalgae component. Environment and disturbance regime govern benthic community structure. Scleractinian diversity is very high and often dominated by acroporids, pocilloporids, poritids, and faviids. The edge of the shallow slope is often dominated by large *Pocillopora eydouxi* colonies, thick-branched and elkhorn-like *Acropora* (e.g. *A. cuneata, A. palifera*), and unusually large *Favia stelligera* and/or *Pavona clavus* stands. Common macroalgae include the genera *Halimeda, Turbinaria*, and *Sargassum*.

HYDROGRAPHY: Water motion is driven by wind and oceanic waves and alongshore currents. Wave influence on the zone abates as depth increases.

SEDIMENTOLOGY: Coral dominated. When present, calcareous macroalgae contribute substantial amounts of sediment. Terraces on the reef slope may capture patches of sand and coral rubble.

TOPOGRAPHY: Gently sloping with some scattered mounds and spurs of coral framework running perpendicular to the reef crest. At the transition from this zone to the "Fore reef deep slope" (near 15 m), a build-up of corals often forming a ridge or mound perforated by shore-perpendicular channels often occurs and runs parallel to the reef crest.

DEPTH RANGE: 8 m to 15 m



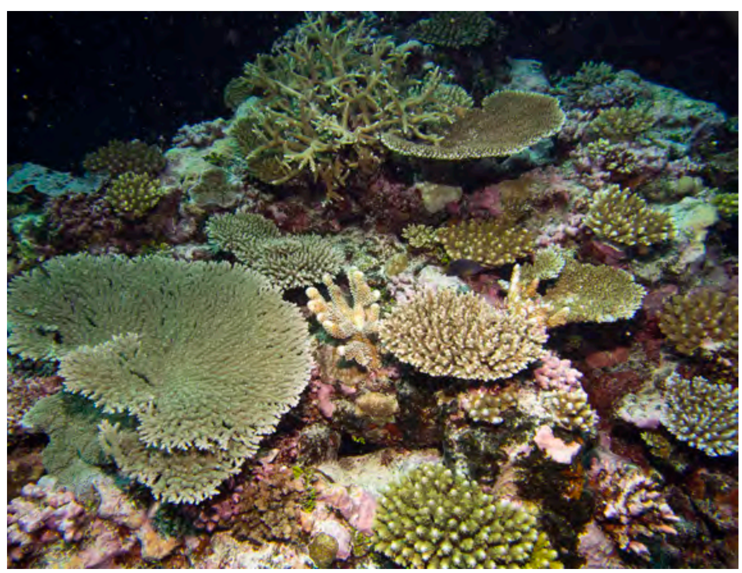


Fig. 10. Shallow fore reef slope at 8-12 m depth, Reefs often had high cover of small pocilloporids, acroporids, Montipora and faviids such as that seen at Kabara (top right), Cicia (center), and Nayau (bottom right). In most cases the branching corals were fairly small (>1 m) and generally less than 10 years old which suggests they have recruited and regrown since the 2002 bleaching event.

Deep Fore Reef Slope

BIOLOGY: A diverse benthic community with the dominant scleractinian community differing by location. Shallower areas may be dominated by branching acroporids and (sub)massive poritids with encrusting and plating corals also present. Small mounds of hosting diverse mixed coral assemblages may be present. At greater depths, colonies take on plating morphologies and may form a series of shingle-like structures. Large monospecific stands of foliaceous and plating *Pachyseris, Leptoseris, Montipora* and *Merulina* occur on more gradual slopes while encrusting and laminar morphologies become more common when the slope becomes close to vertical. Prominent macroalgae include *Halimeda, Caulerpa,* and *Dictyota*.

HYDROGRAPHY: Deep fore reef slope lies below the fair-weather wave base but is episodically exposed to high energy during severe storm events and tsunamis. Alongshore currents may be present. Differences in storms, surge, wind and wave exposure influence the benthic community.

SEDIMENTOLOGY: Coral dominated, however *Halimeda* algae may also contribute substantial volumes of sediment. Terraces on the reef slope may capture patches of sand and coral rubble. Water motion tends to be lower that the shallow reef slope resulting in greater rates of deposition.

TOPOGRAPHY: This zone occurs where the shallow fore reef slope begins to steepen (typically 12 – 15 m) and continues into the ocean depths.

DEPTH RANGE: 15 m to 40 m

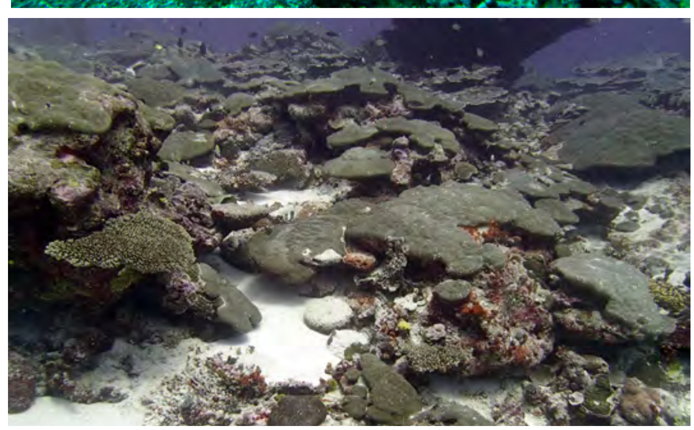
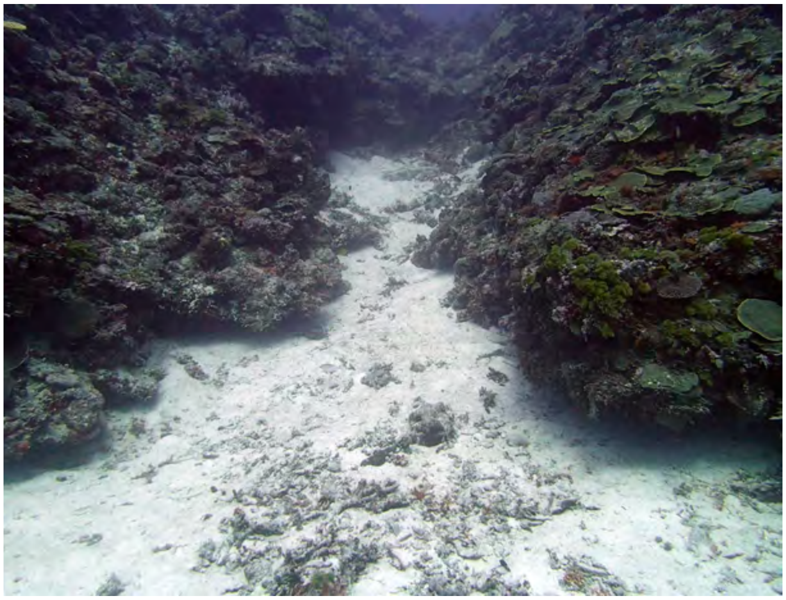


Fig. 11. Deeper fore reef off slope off Vanua vatu (top right) and Vanua Balavu (bottom right). The deeper fore reef often had small pinnacles surrounded by sand and rubble such as that seen in Vanua Balavu (above). Porites lobata colonies exhibited a plating morphology on the deeper fore reef environments such as that seen here from Totoya (bottom left).

Fore Reef Sand Flats



BIOLOGY: Interstitial fauna account for the majority of biomass. Benthic cover is usually very low because the substrate is mobile and largely unconsolidated thus inhibiting colonization by benthic organisms. In some cases, large *Porites lobata* colonies and tabular acroporids occur within the sand flats, especially in deeper areas (30-50 m). Macroalgae become more common with depth due to the abatement of wave energy with increasing depth.

HYDROGRAPHY: Water motion is driven by wind and oceanic waves and alongshore currents. Wave influence on the zone abates as depth increases.

SEDIMENTOLOGY: Coral dominated. When present, calcareous macroalgae contributes.

TOPOGRAPHY: Generally low relief. Large areas may have higher relief as they follow the antecedent topography's slope into deeper waters.

DEPTH RANGE: 10 m to 40 m

Fig. 12. The deeper fore reef habitats at the base of the reef were generally low relief sand flats, mostly uncolonized. Often there was a sparse assemblages of cyanobacteria and small patches of macroalgae, along with isolated larger corals. Examples of deeper sand flats from Vanua Balavu are shown in the top right and center. A coral trout, Plectropomus leopardus is swimming across the sand flat (top right). Closer to the reef system, sandy areas typically had more rubble such as that shown in the lower right.

Coralline Algal Ridge (reef crest)

BIOLOGY: Crustose coralline algae (CCA) accounts for the majority of biotic cover. Coral growth is limited due to wave action and episodic aerial exposure and is limited to species tolerant of the chronic disturbances.

HYDROGRAPHY: A high energy environment exposed to large (often > 1 m) waves on a regular basis. The reef crest may be aerially exposed during low tides. The continuity of the algal ridge is broken at irregular intervals by shore-perpendicular grooves cut by waves and currents. These channels provide paths of tidal water exchange between the open ocean and the lagoon or back reef.

SEDIMENTOLOGY: The reef crest is an important source of carbonate detritus. Continuous wave energy generates and transports sediment, shoreward, or down-slope.

TOPOGRAPHY: The reef crest's ocean-face is a cement-like barrier with irregularly spaced ridges and grooves. Ridges are exposed at low-tide and between waves, and grooves allow for seaward transport of water.

DEPTH RANGE: +2 m to -1 m

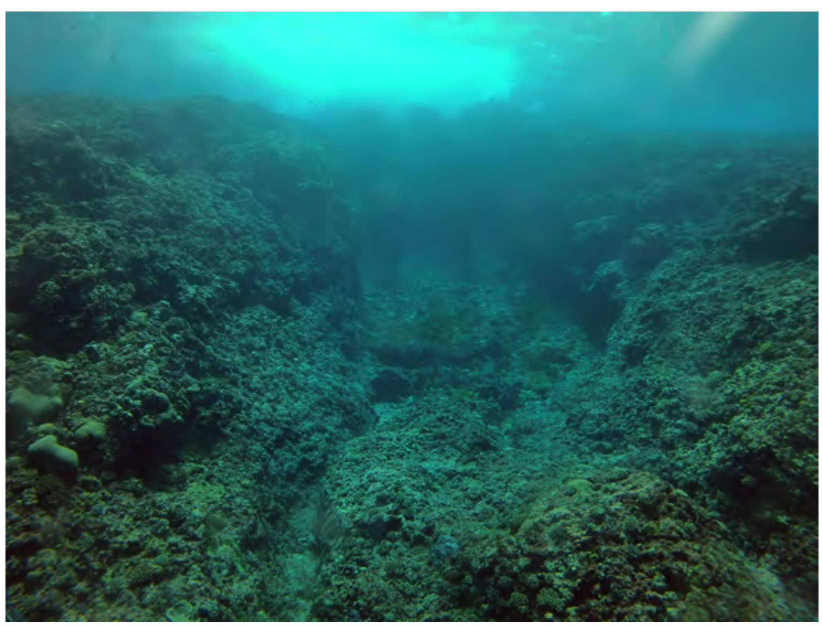
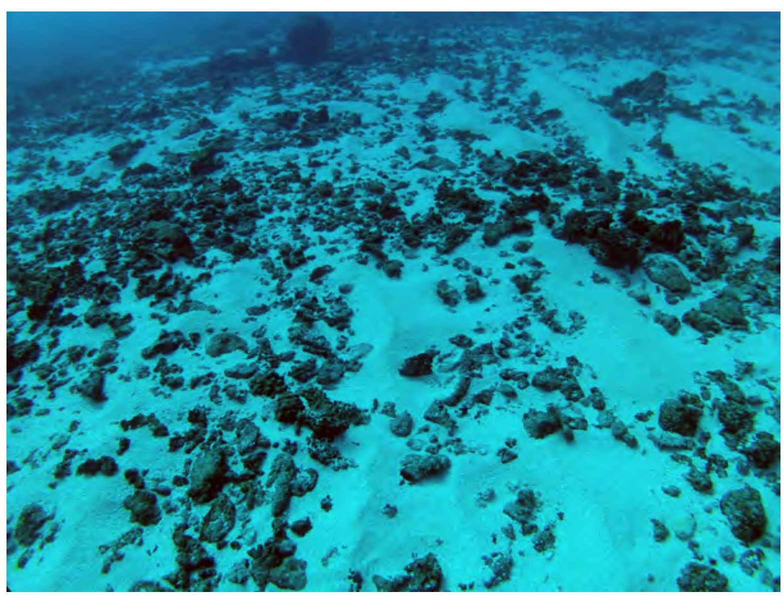


Fig. 13. Reef crest habitats in Lau Province. The reef crest at Fulaga had small encrusting corals and coralline algae (top right). Above water view of the emergent reef crest off the west side of Vanua Balavu at low tide (center). Windward reef crest off Vanua Vatu. There are prominent channels that transport sediments to the fore reef.

Back Reef – Rubble Dominated



BIOLOGY: Biotic cover is low in this zone because the substrate is mobile and largely unconsolidated. Algae dominate, and isolated coral colonies are present, but at low density and of a small size. Calcareous red algae and turf algae are prominent, and rhodoliths may accumulate. Coral colonies are typically encrusting, submassive and free living (e.g. *Psammocora* and fungiids) and hardier than those found in other zones.

HYDROGRAPHY: Water motion in this zone is driven by waves, tides, and wind. Breaking waves transport water and sediment over the reef crest into this zone. Tidal pools form during low tide when water is trapped in topographic lows.

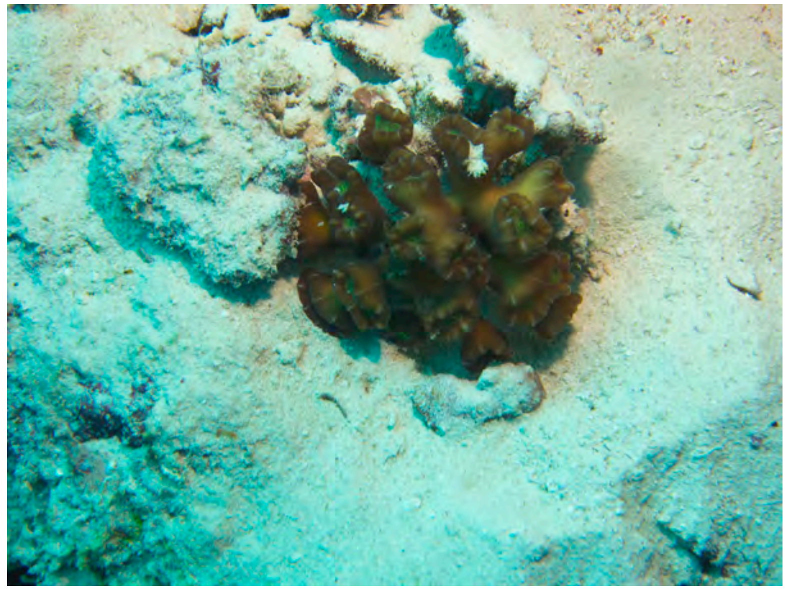
SEDIMENTOLOGY: Sediment is composed primarily of accumulated dead coral fragments ("rubble") of varying sizes. Biotic and chemical processes cement the rubble in place over time. The degree of cementation varies.

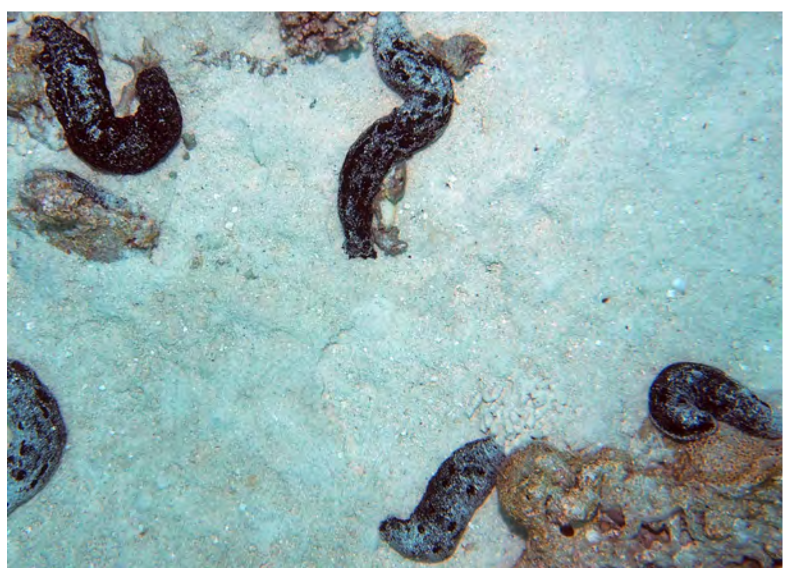
TOPOGRAPHY: The back reef is the shoreward extension of the reef crest. It is fully aggraded to sea level and has low-relief. Large boulders of reef rock moved up over the reef crest by severe storms and tsunamis may be present and mix with outcrops of stranded fossil reef deposited during geological periods of higher sea level.

DEPTH RANGE: Emergent to 1 m

Fig. 14. Shallow back reef environments with accumulations of rubble. These habitats generally have very few live corals. Unconsolidated, poorly sorted rubble at Matuka (top right). Back reef environment in Vanua Balavu (center). Shallow back reef rubble field in Totoya (bottom right).

Back Reef – Sediment Dominated





BIOLOGY: Biotic cover is low due to high disturbance rates. Sparse turf and macroalgae may stabilize the accumulated sediments.

HYDROGRAPHY: Water motion in this zone is driven by waves, tides, and wind. Breaking waves transport water and sediment over the reef crest into this zone. Tidal pools form during low tide when water is trapped in topographic lows.

SEDIMENTOLOGY: Where wave action is more moderate, the back reef tends to be less rugose and composed of compacted carbonate sands deposited periodically by large storm waves.

TOPOGRAPHY: The back reef is the shoreward extension of the reef crest. It is fully aggraded to sea level and has low-relief. Large boulders of reef rock moved up over the reef crest by severe storms and tsunamis may be present and mix with outcrops of stranded fossil reef deposited during geological periods of higher sea level.

DEPTH RANGE: 0 m to 1 m

Fig. 15. Sediment-dominated shallow back reef environments were relatively uncommon except at Totoya, Tuvuca, Cicia and Vanua Balavu. These soft bottom communities had sparse cover of benthic organisms, consisting of small free living corals and occasional patches of macroalgae, cyanobacteria or turf algae. Algae were more common in calm, protected areas. Caulastrea colonies were found in sandy areas in the back reef at Tuvuca (top right). Small Porites lobata colonies were found close to the reef crest. Some shallow back reef environments had high numbers of Holothuria edulis sea cucumbers.

Back Reef – Pavement

BIOLOGY: A planation hardground colonized by turf algae and isolated coral colonies (<1% live cover). Scleractinians found in this habitat include stout branched *Pocillopora, Stylophora*, and submassive *Platygyra, Favites*, and *Favia*.

HYDROGRAPHY: Water motion in this zone is driven by waves, tides, and wind. Breaking waves transport water and sediment over the reef crest into this zone. Tidal pools form during low tide when water is trapped in topographic lows.

SEDIMENTOLOGY: Very little sediment, except in depressions between pavement. In protected areas the surface of the pavement may have a fine layer of sediment or turf with sediment.

TOPOGRAPHY: The back reef is the shoreward extension of the reef crest. It is fully aggraded to sea level and has low-relief. Large boulders of reef rock moved up over the reef crest by severe storms and tsunamis may be present and mix with outcrops of stranded fossil reef deposited during geological periods of higher sea level.

DEPTH RANGE: 0 m to 1 m

Fig. 16. The shallow Back Reef - Pavement community at Vanua Balavu had turf algae and small corals, with scattered sand channels (top right). At Kabara, the extensive Back Reef - Pavement habitat was colonized by turf algae (center). In some areas off Matuka, crustose coralline algae and turf were common colonizers and sea urchins had bioeroded small holes into the pavement (bottom right).

Back Reef-Coral Framework

BIOLOGY: Coral framework with variable benthic community composition. The coral community may be composed of dense acroporid thickets or massive poritids and agariciids forming microatolls whose tops are colonized by submassive, branching, and foliose coral colonies.

HYDROGRAPHY: The back reef is a low energy environment as wave energy dissipates across the reef crest and back reef. Tides and wind are the dominant drivers of water motion.

SEDIMENTOLOGY: The back-reef has little sedimentation. Topographic depressions serve as collection points for coarse carbonate sands, *Halimeda* plates, and coral rubble.

TOPOGRAPHY: The back reef lies shoreward of the back reef and displays varying degrees of reef framework aggradation depending on the width of the back reef and hydrodynamics.

DEPTH: 0 m to 2 m.

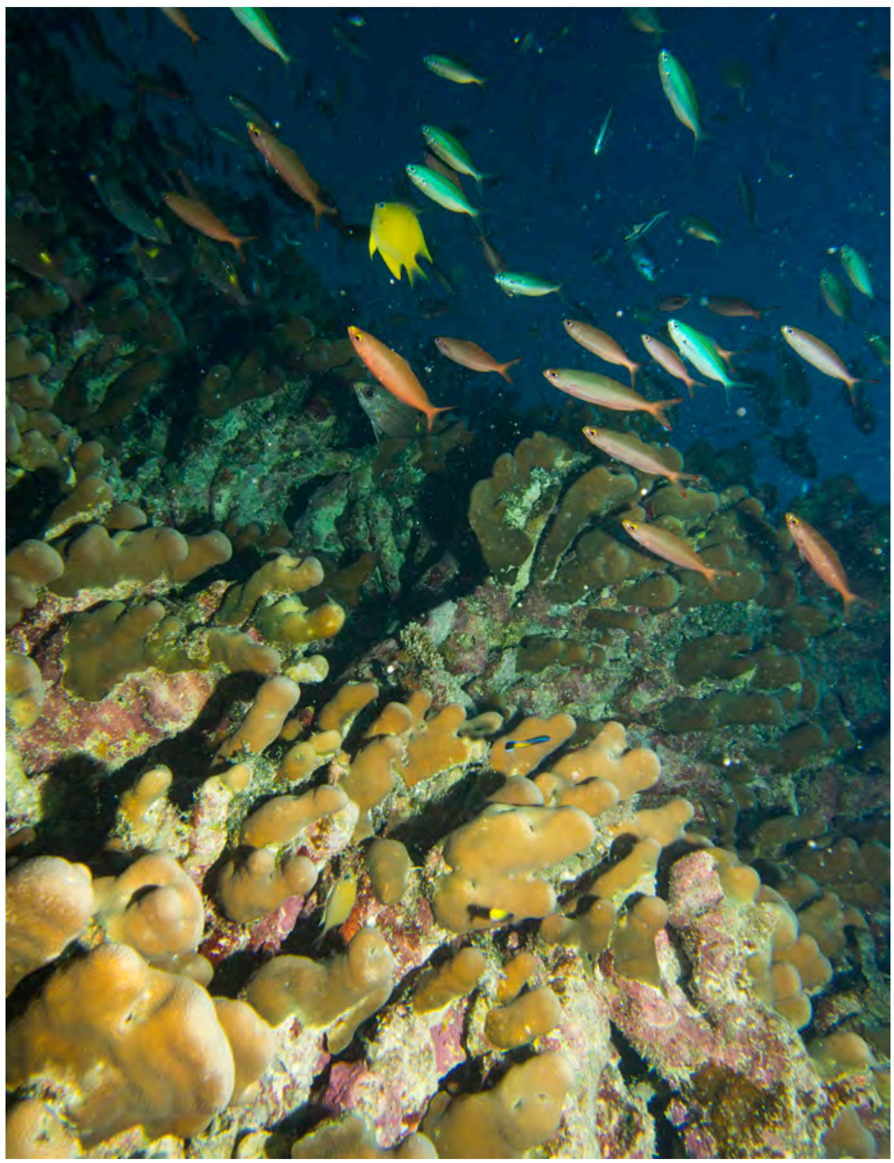


Fig. 17. The shallow back reef community often had high cover of small massive corals including Porites, faviids, digitate acroporids and other species in exposed areas (top right). More sediment tolerant corals such as Pavona clavus were seen in protected environments (bottom right).

Back Reef - Coral Bommies

BIOLOGY: Isolated or composite coral heads with a plan-form area <200 sq. m growing to near sea level. The coral community may be composed of dense acroporid thickets or massive poritids and agariciids forming microatolls whose tops are colonized by submassive, branching, and foliose coral colonies.

HYDROGRAPHY: The back reef is a low energy environment as wave energy dissipates across the reef crest and back reef. Tides and wind are the dominant drivers of water motion.

SEDIMENTOLOGY: The back-reef has little sedimentation. Topographic depressions serve as collection points for coarse carbonate sands, *Halimeda* plates, and coral rubble.

TOPOGRAPHY: The back reef lies shoreward of the back reef and displays varying degrees of reef framework aggradation depending on the width of the back reef and hydrodynamics.

DEPTH RANGE: 1 m to 2 m

Fig. 18. Examples of Back Reef-Coral Bommies. Shallow back reef environments in sandy areas often had small coral heads scattered over the substrate. These typically consisted of small clumps of staghorn corals and table acroporids (top right), colonies of Porites lobata (center) and various faviid corals (bottom right).

Dense Seagrass Meadows

BIOLOGY: An expanse of dense seagrass in sediment.

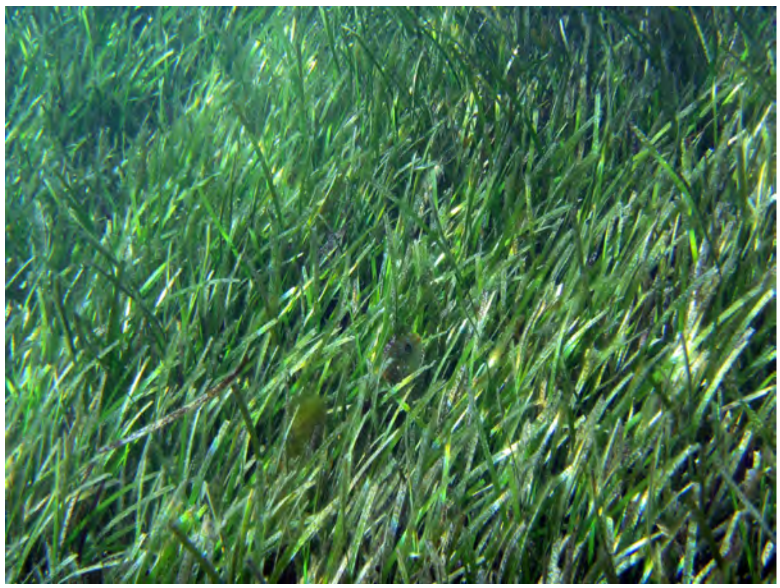
HYDROGRAPHY: Restricted water motion with little influence from waves due to sheltering by reefs and islands. Water restriction leads to long resident times for water masses, and the suspension of detritus creates moderate turbidity.

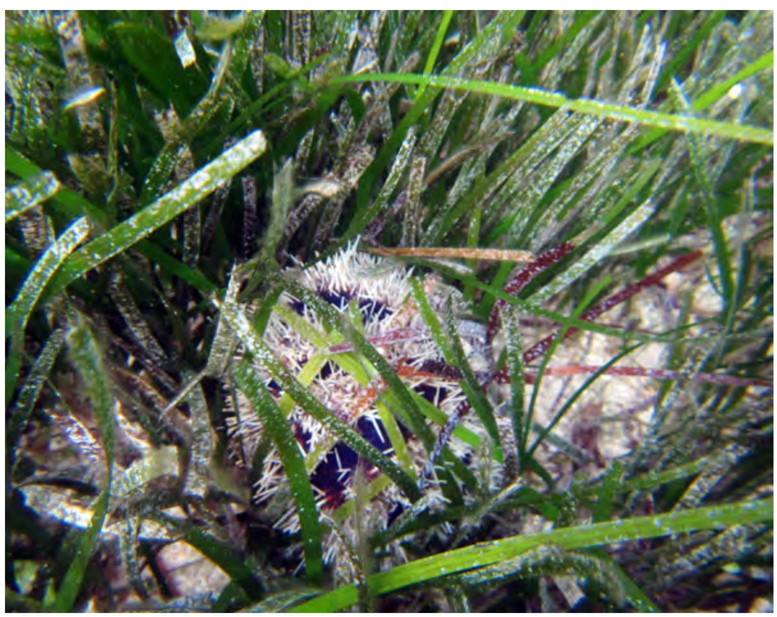
SEDIMENTOLOGY: Predominantly fine-grained sediments trapped by the seagrasses. Most sediments are biogenic, resulting from the breakdown of the marine vegetation and associated calcareous epibionts.

TOPOGRAPHY: Low relief.

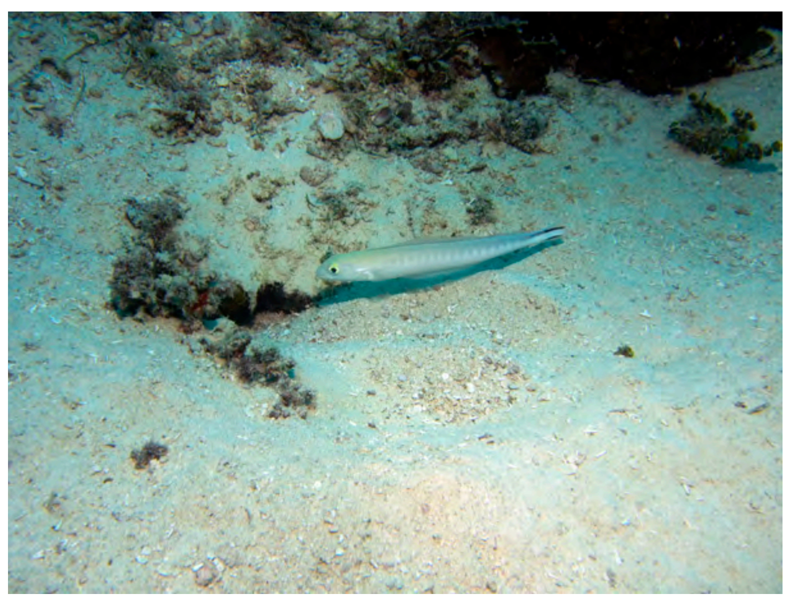
DEPTH RANGE: From 1 m to 15 m

Fig. 19. Dense seagrass beds were seen in intertidal and shallow subtidal lagoonal habitats off Matuka, Tuvuca, Kabara and Cicia, with sparse seagrass coverage in deeper habitats. There are five species and one subspecies reported from Fiji. Syringodium isoetifolium was found from 1-6 m depth (top right). Thalassia hemprichii was the most common species (center right). Shallow areas also had a high abundance of Halophila ovalis and Halodule uninervis, but beds were not as dense as Thalassia beds. Seagrass beds are extremely productive, efficient recyclers of nutrients, critical nursery areas, and they support a high biomass of consumers including sea urchins (bottom right). Halophila teneded to occur in deeper lagoonal areas, rarely forming dense assemblages (bottom left).





Lagoon - Sediment Apron



BIOLOGY: The lagoonal sediment apron supports a shallow and narrow terrace of unconsolidated sand, lagoonward of the back reef that spans a range of depths from the intertidal and shallow subtidal to 5 m depth.

HYDROGRAPHY: A low energy environment dominated by tides and wind-driven waves. Oceanic influence is minimal because long-swell waves break on the reef crest, and their energy is greatly attenuated before reaching this zone.

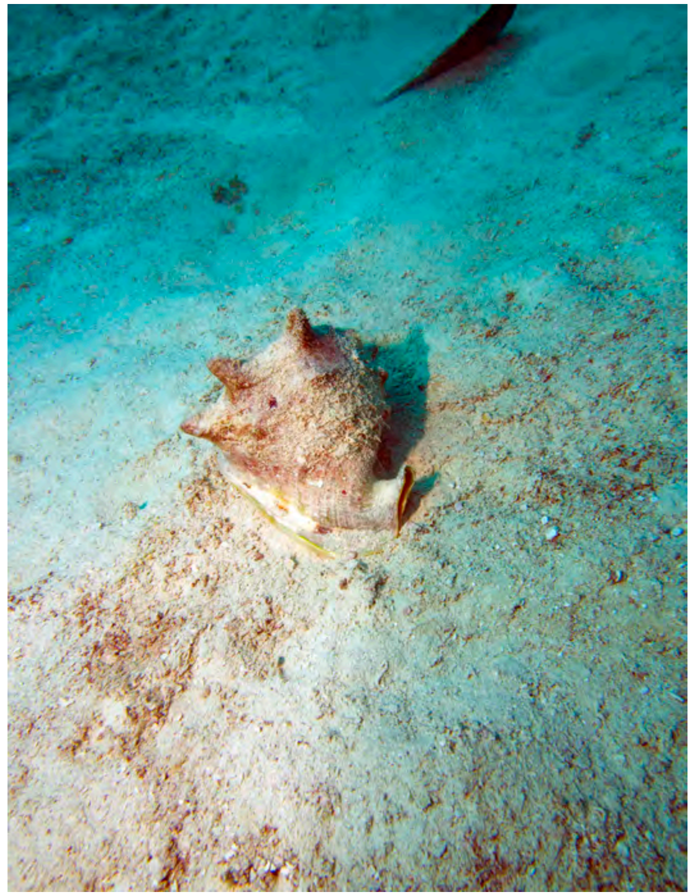
SEDIMENTOLOGY: The active face of lagoon in-filling by an accumulation of well-sorted sand-sized carbonate detritus. Most sediments in this zone are transported from the reef crest and fore reef during storms and their size distribution is largely the result of differential transport by high bottom-water velocities during those events. Sandy islands or shingle banks may develop in between the back reef and deep lagoon.

TOPOGRAPHY: Generally low relief.

DEPTH RANGE: 1 m to 5 m

Fig. 20. Unconsolidated sand and fine silt was common in shallow lagoonal areas adjacent to the shoreline (top right). In areas with higher wave action, sand waves and small pieces of rubble were observed (center). Sandy lagoonal environments often contained erect coralline algae such as Halimeda and supported a number of small burrowing fish such as the tile fish Malacanthus brevirostris (bottom right).

Lagoonal Floor - Barren



BIOLOGY: Few benthic organisms with exception of motile invertebrates. Isolated colonies of sediment-tolerant and low-light adapted *Acropora* colonies. Sparse community of fleshy macroalgae may grow in the sediment.

HYDROGRAPHY: Restricted water motion with little influence from waves due to sheltering by the reef. Oceanic wave energy dissipates before reaching this zone, and the orbitals of wind generated waves attenuate before reaching the seafloor. Tidal cycles flush the lagoon, however restricted flow leads to long resident times for water masses and high turbidity.

SEDIMENTOLOGY: Sediment entirely skeletal in origin and tends to have a very poorly sorted, coral gravel-rich base which grades up into poorly sorted muddy sands with infaunal molluscan gravel. Intense bioturbation by callianassid shrimps.

TOPOGRAPHY: Generally has low relief. Local highs created by coral colonies.

DEPTH RANGE: 15 m to 35 m

Fig. 21. Deeper lagoonal environments were dominated by sand with small pieces of rubble and scattered, sediment tolerant corals. Often the sediment was colonized by cyanobacteria and motile invertebrates were seen, such as the helmet snail (top right) and sea cucumber (bottom left). Branching acroporids were common in many areas (bottom right).

Lagoonal Floor – Macroalgae on Sediment

BIOLOGY: An expanse of dense macroalgae in which thalli are interspersed by unconsolidated sediment.

HYDROGRAPHY: Restricted water motion with little influence from waves due to sheltering by the reef. Oceanic wave energy dissipates before reaching this zone, and the orbitals of wind generated waves attenuate before reaching the seafloor. Tidal cycles flush the lagoon, however restricted flow leads to long resident times for water masses and high turbidity.

SEDIMENTOLOGY: Predominantly fine-grained carbonate sediments trapped by the macroalgae thalli.

TOPOGRAPHY: Low relief.

DEPTH RANGE: 2 m to 30 m

Fig. 22. Soft bottom habitats in the lagoon often had dense assemblages of macroalgae, including a number of taxa of erect coralline algae. Common taxa included Halimeda (top right). Turf algae was also found in lagoonal soft bottom areas, especially in areas where the sand was mixed with coral rubble (center). In some areas the sediment was stabilized by the rhizomes of Caulerpa (bottom right).

Lagoonal Pinnacle Reefs – Massive Coral Dominated

BIOLOGY: Coral framework with a plan-form area >400 sq. m aggraded from the lagoon floor to the water surface with steep, sediment dominated flanks. Coral community composition is determined by the development stage of each patch. In the early stage, the coral community is dominated by massive species (e.g., *Porites* sp.) which build to form a pinnacle. Accommodation space becomes limited as the pinnacle aggrades to sea level, leading to the formation of microatolls from the massive colonies. Branching, submassive, and encrusting coral species colonize the tops of the microatolls. Over time, skeletal debris and sediment collect in the center of the microatoll leading to the formation of cays. A relative sea level drop may expose the top of the pinnacle to form a lagoonal island, which, with time, can then be colonized by vegetation. Simultaneously, the coral community may back-step to form a Lagoonal Island Fringing Reef.

HYDROGRAPHY: Tides and wind-driven waves affect the benthic community and spatial distribution of sediments. Water motion in the lagoon is restricted which can lead to highly turbid waters. Water in the center of the patches is restricted further causing water masses to warm from solar radiation.

SEDIMENTOLOGY: The tops of the pinnacles are coral-dominated and characterized by reef derived debris in the sand and rubble size fractions. Sediments become muddier with increasing depth.

TOPOGRAPHY: Isolated coral pinnacles rise from the lagoon-floor into the zone of maximum carbonate production. Pinnacles are usually circular in shape, but may elongate along hydrodynamic gradients. Pinnacle-tops flatten as they near sea level

DEPTH RANGE: 1 m to 30 m

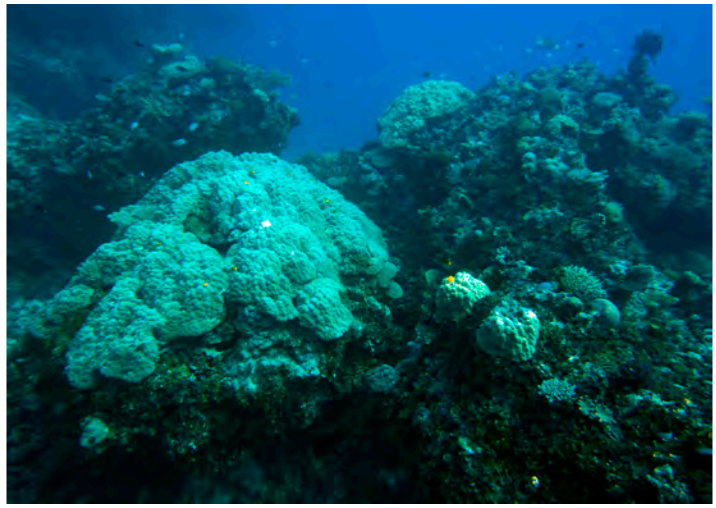
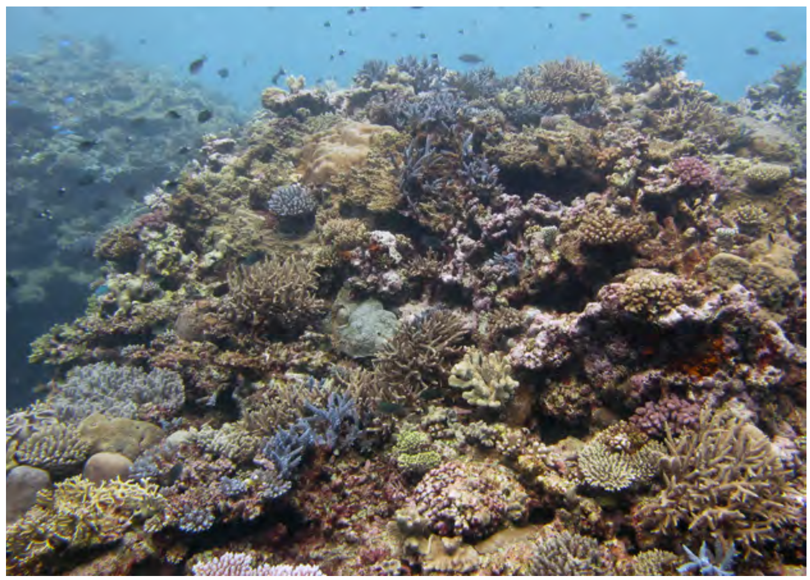


Fig. 23. Lagoonal pinnacle reef in Vanua Balavu, 15 m depth (top right). Large Diploastrea colonies often colonized the sides and tops of the pinnacle reefs (center). Many of the lagoonal pinnacle reefs had flourishing acroporid communities on their top surfaces, especially in shallow water (bottom right).

Lagoonal Patch Reefs



BIOLOGY: Coral framework with a plan-form area >100 sq. m and <400 sq. m aggraded from the lagoon floor to sea level. Coral community composition is determined by the framework's development stage. The coral community may be composed of dense acroporid thickets, massive poritids and agariciids forming microatolls whose tops are colonized by submassive, branching, and foliose coral colonies, or a mixture of the two.

HYDROGRAPHY: Tides and wind-driven waves affect the benthic community and spatial distribution of sediments. Water motion in the lagoon is restricted which can lead to highly turbid waters. Water in the center of the patches is restricted further causing water masses to warm from solar radiation.

SEDIMENTOLOGY: Upper reaches of the patches are coral dominated and characterized by reef derived debris in the sand and rubble size fractions.

TOPOGRAPHY: Coral framework rises from the lagoon floor. Patches are usually circular in shape, but may elongate along hydrodynamic gradients, and their tops flatten as they near sea level.

DEPTH RANGE: 2 m to 15 m

Fig. 24. Vanua Balavu had an extensive lagoonal habitat with numerous patch reefs such as this reef (top right). The top and sides of a large patch reef at Totoya colonized primarily by staghorn and digitate acroporids and small massive corals. An unusual field of branching Galaxea at the eastern end of Vanua Balavu lagoon.

Lagoonal Floor – Coral Bommies

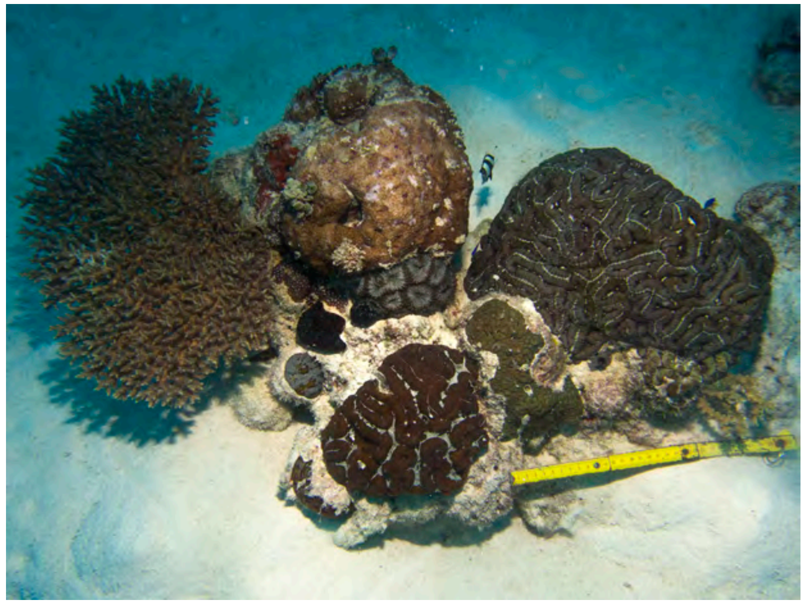
BIOLOGY: Isolated or composite coral heads with a plan-form area <100 sq. m growing up from the lagoon floor to near sea level. The coral community may be composed of dense acroporid thickets or massive poritids and agariciids forming microatolls whose tops are colonized by submassive, branching, and foliose coral colonies.

HYDROGRAPHY: Restricted water motion with little influence from waves due to sheltering by the reef. Oceanic wave energy dissipates before reaching this zone, and the orbitals of wind generated waves attenuate before reaching the seafloor. Tidal cycles flush the lagoon, however restricted flow leads to long resident times for water masses and high turbidity.

SEDIMENTOLOGY: Sediment entirely skeletal in origin and tends to have a very poorly sorted, coral gravel-rich base which grades up into poorly sorted muddy sands with infaunal molluscan gravel. Intense bioturbation by callianassid shrimps.

TOPOGRAPHY: Generally has low relief. Local highs created by coral colonies.

DEPTH RANGE: 2 m to 10 m



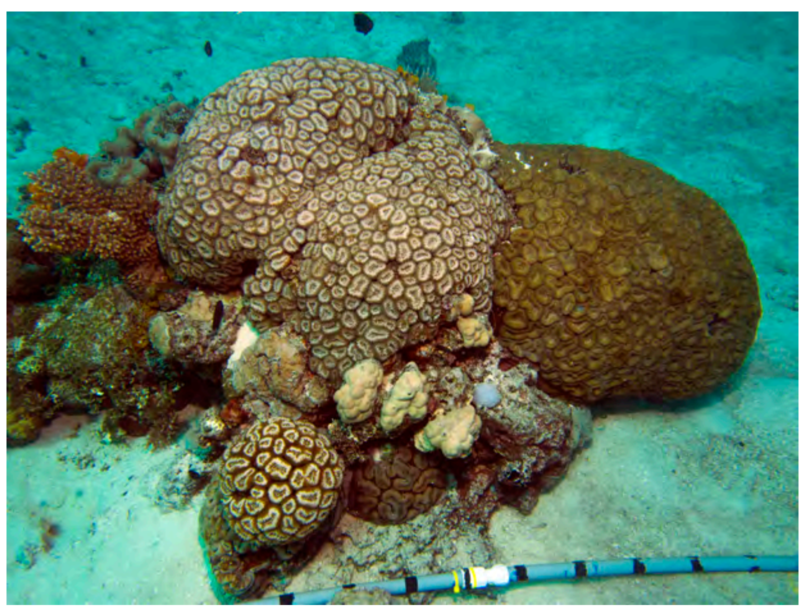
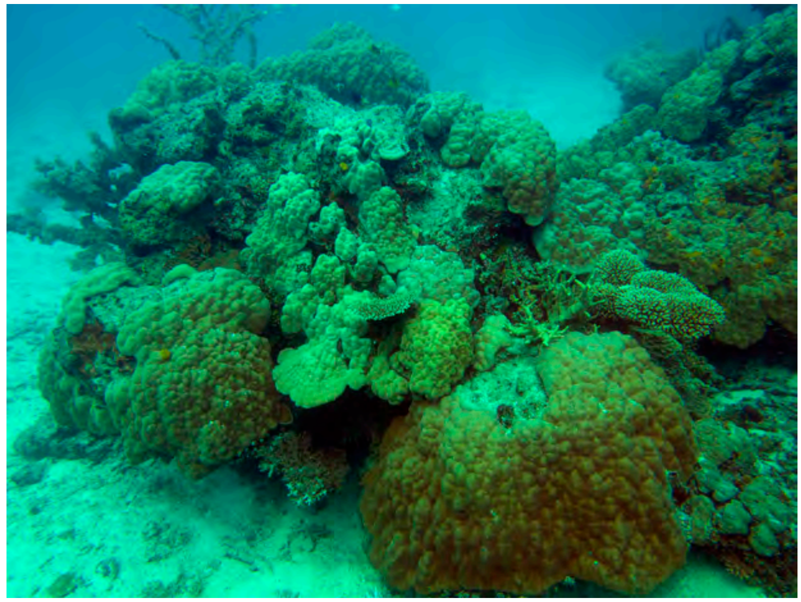
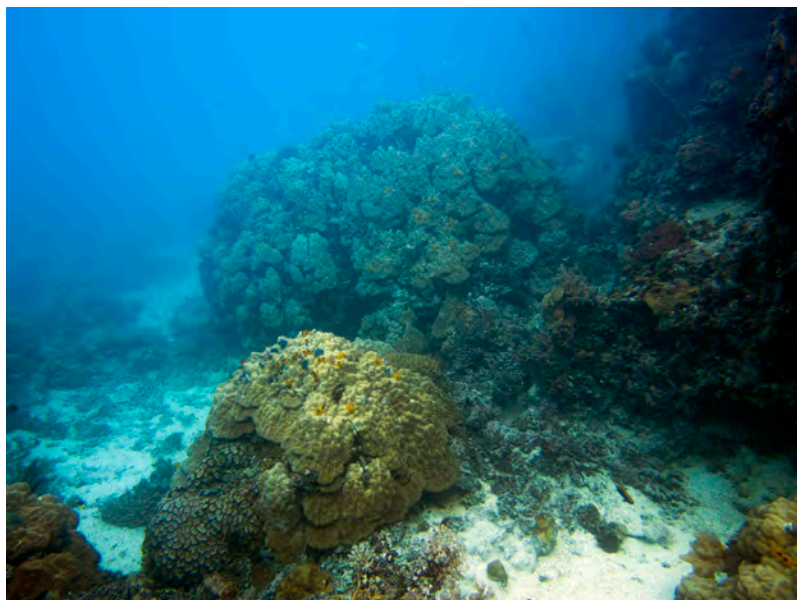


Fig. 25. Scattered coral bommies were seen throughout lagoonal environments in shallow water. These included mixed species assemblages with Porites, Favia, Lobophyllia, Acropora dominating. In most cases they were only a few meters diameter. A small coral bommie with Acropora, Lobophyllia and Porites at Vanua Balavu, 3 m depth (top right). Coral bommies constructed of large massive Porites lobata colonies off Kabara at 12 m depth (center). Larger colonies of Lobophyllia in the lagoon off Totoya at 5 m depth (bottom right).

Lagoonal Floor – Bommie Field

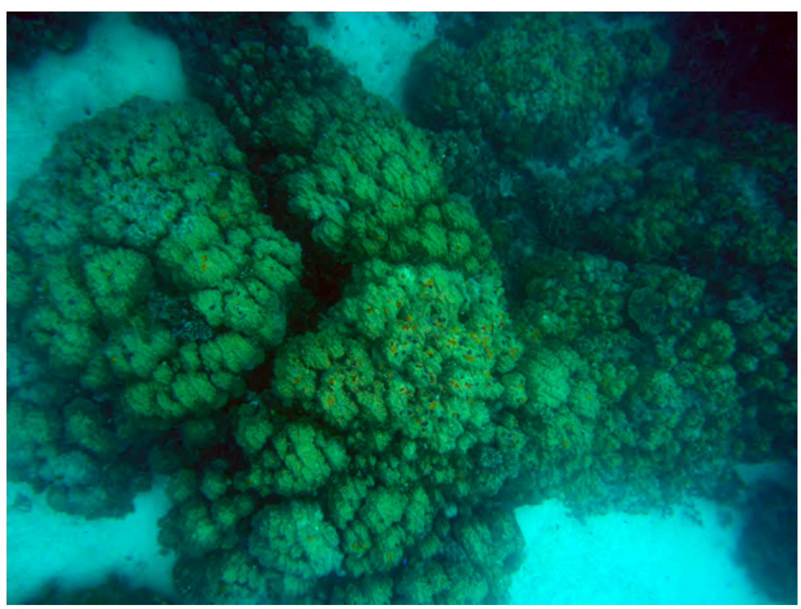


BIOLOGY: A high density of small patch reefs, so called “bommies,” grouped together, and regularly spaced on the lagoon floor. These reefs, tend to be circular with plan-form areas always <100 sq. m, but typically <10 sq. m and do not reach sea level. While the individual bommies are constructed from massive corals, such as poritids and agariciids, portions of the tops may be inhabited by dense acroporid thickets.



HYDROGRAPHY: Tides and wind-driven waves affect the benthic community and spatial distribution of sediments. Water motion in the lagoon is restricted which can lead to highly turbid waters. Water in the center of the patches is restricted further causing water masses to warm from solar radiation.

SEDIMENTOLOGY: The tops of the pinnacles are coral-dominated and characterized by reef derived debris in the sand and rubble size fractions. Sediments become muddier with increasing depth.



TOPOGRAPHY: The bommies rise a few meters from the lagoon floor and are spaced less than 10 m from one another with channels of sand or fine grained lagoon floor mud, located between them as described in “Lagoon floor - barren”.

DEPTH RANGE: 5 m to 35 m

Fig. 26. Examples of bommie fields within lagoonal habitats constructed primarily of Porites lobata colonies. Porites bommies at 5 m depth in Vanua Balavu (top right). Coral bommies at Moala. A deeper lagoon floor coral bommie field dominated by very large colonies of Porites at Vanua Balavu, 20 m depth (bottom right).

Lagoonal Fringing Reefs

BIOLOGY: Coral reef frameworks fringing islands. Benthic community composition is similar to that of lagoonal patch reefs.

HYDROGRAPHY: Tides and wind-driven waves affect the benthic community and spatial distribution of sediments. Water motion in the lagoon is restricted which can lead to highly turbid waters. Water in the center of the patches is restricted further causing water masses to warm from solar radiation.

SEDIMENTOLOGY: Similar to that of lagoonal pinnacle reefs. Lagoonal islands may be circular to elongate in shape and develop through two mechanisms. Lagoonal pinnacle reefs may fill the accommodation space, or the islands may be remnants of fossil reef stranded from episodes of higher-than-present sea level. The most mature lagoonal islands possess a water table and are heavily vegetated.

TOPOGRAPHY: Moderate to steeply sloping reef framework rising from the lagoon-floor into the zone of maximum carbonate production. Usually elongate and narrow, extending along the coastline. The reef top flattens as it approaches sea level.

DEPTH RANGE: 1 m to 30 m

Fig. 27. Fringing reefs were seen along several of the islands examined in Lau Province. A shallow lagoonal fringing reef in Vanua Balavu exposed at low tide. Image by Stacy Jupiter (top right). Close-up of the coral community of Vanua Balavu exposed at low tide (center). A shallow submerged fringing reef in Totoya (bottom right).

Dense Macroalgae on Sediment

BIOLOGY: An expanse of dense macroalgae in which thalli are interspersed by unconsolidated sediment.

HYDROGRAPHY: Restricted water motion with little influence from waves due to sheltering by reefs and islands. Moderate turbidity results from the typically restricted hydrodynamic conditions and the suspension of detritus.

SEDIMENTOLOGY: Predominantly fine-grained carbonate sediments trapped by the macroalgae thalli.

TOPOGRAPHY: Low relief.

DEPTH RANGE: 1 m to 15 m

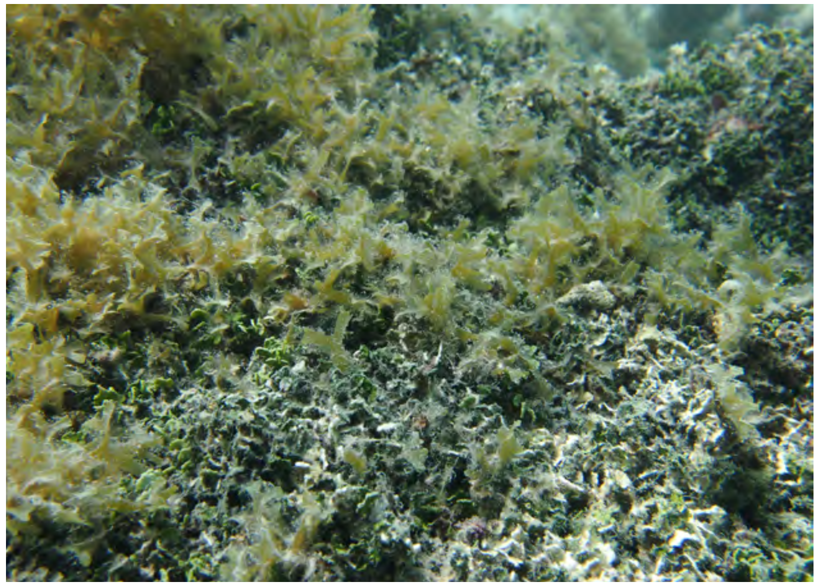
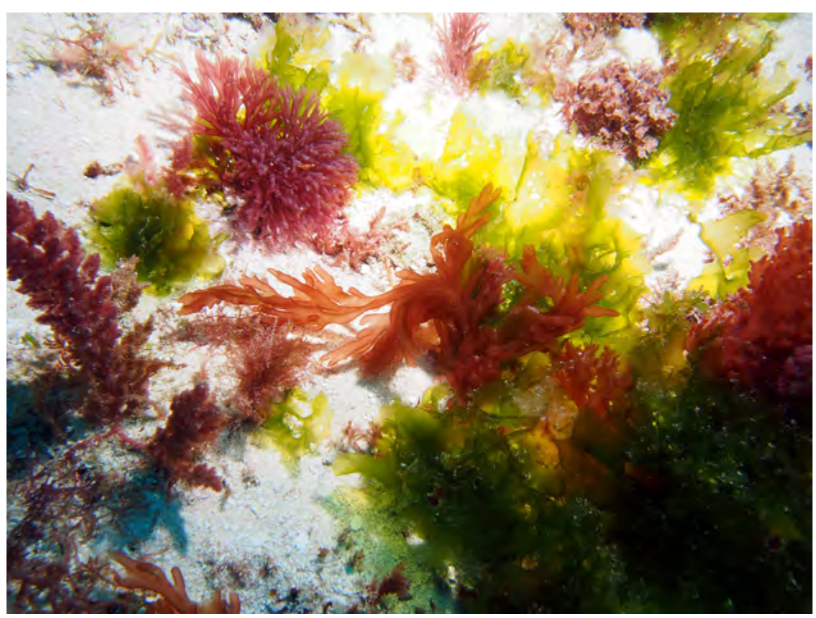


Fig. 28. Soft bottom habitats occasionally had dense assemblages of Halimeda and Dictyota (top right). In some area a variety of red and brown macroalgae were common including Padina (center). A variety of green algae also occurred with erect red coralline algae and red macroalgae (bottom right). Large stands of Caulerpa were seen in many locations. Some species primarily occurred on vertical surfaces and at the base of the reef on rubble and dead coral such as Caulerpa racemosa (bottom left), while others carpeted sandy areas.



Mud flats

BIOLOGY: Benthic community is primarily microbial. Benthic invertebrates are isolated or absent due to aerial exposure during low tides. Interstitial fauna are common. Sparse seagrass (e.g. *Halodule*) may be present.

HYDROGRAPHY: Restricted water motion with little influence from waves due to sheltering by reefs and islands. Tidal cycles flush the area. The water column has high turbidity due to suspension of detritus.

SEDIMENTOLOGY: Predominantly fine-grained sediments trapped by mangrove prop roots and seagrasses. Sediments are biogenic, resulting from the breakdown of the marine vegetation.

TOPOGRAPHY: Low relief. Seaward from shore, the substrate may slope to the base of the lagoon, with accumulations of debris (leaf litter, macroalgae) and scattered patches of rubble.

DEPTH RANGE: 0 to 2 m

Fig. 29. Fine grained sediments and silt in a protected nearshore lagoonal habitat in Mago. Adjacent to the mud flat is a well developed mangrove community (top right). An intertidal mudflat exposed at low tide. The flat is colonized by sparse seagrass (center). Submerged mudflat adjacent to a mangrove community at Vanua Balavu (bottom right).

Mangroves

BIOLOGY: Coastal area dominated by mangroves. Diverse filter-feeding invertebrate communities including sponges, tunicates, bryozoans and certain cnidarians may occur among prop roots

HYDROGRAPHY: Restricted water motion with little influence from waves due to sheltering by reefs and islands. Tidal cycles flush the area. The water column has high turbidity due to suspension of detritus.

SEDIMENTOLOGY: Predominantly fine-grained sediments trapped by mangrove prop roots and seagrasses. Sediments are biogenic, resulting from the breakdown of the marine vegetation.

TOPOGRAPHY: Mud flats around the roots are low relief. Root system provides relief, substrate for invertebrate colonization, and habitat for fishes.

DEPTH RANGE: Dependent on tidal range. From 0 m to 2 m.

Fig. 30. Fiji supports nine different species of mangroves and one hybrid. Three most abundant taxa include two red mangroves, Rhizophora mangle (red mangrove) and R. stylosa (spotted mangrove), and the black mangrove Bruguiera gymnorhiza. The red mangroves are found at the edge of the water, while black mangroves are generally found landward of these species. Close-up of a red mangrove community at Mago (top right). Small mangrove along the shoreline at Moala (center). Red mangroves can be identified by their prominent prop roots which help anchor them into soft substrates (lower right).

Deep Ocean Water

Submerged areas seaward of the fore reef that are too deep for observation via satellite. These deeper fore reef environments may be sand-bottom with scattered coral heads and rubble. In some locations deep water *Porites lobata* plates and tabular acroporids are dispersed over the bottom.

DEPTH RANGE: below 30 m

Deep Lagoonal Water

Submerged areas seaward of the fore reef that are too deep for observation via satellite. These are typically sand bottom, but may have some rock/coral rubble patches and often have high cover of macroalgae.

DEPTH RANGE: Below 30 m

Fig. 31. Examples of deep water. The lagoon at Moala (top right). Deep Ocean Water at Fulaga. The reef crest and lagoon are visible in the center of the image (center). Deep Ocean Water off Matuka. Image by Stacy Jupiter.

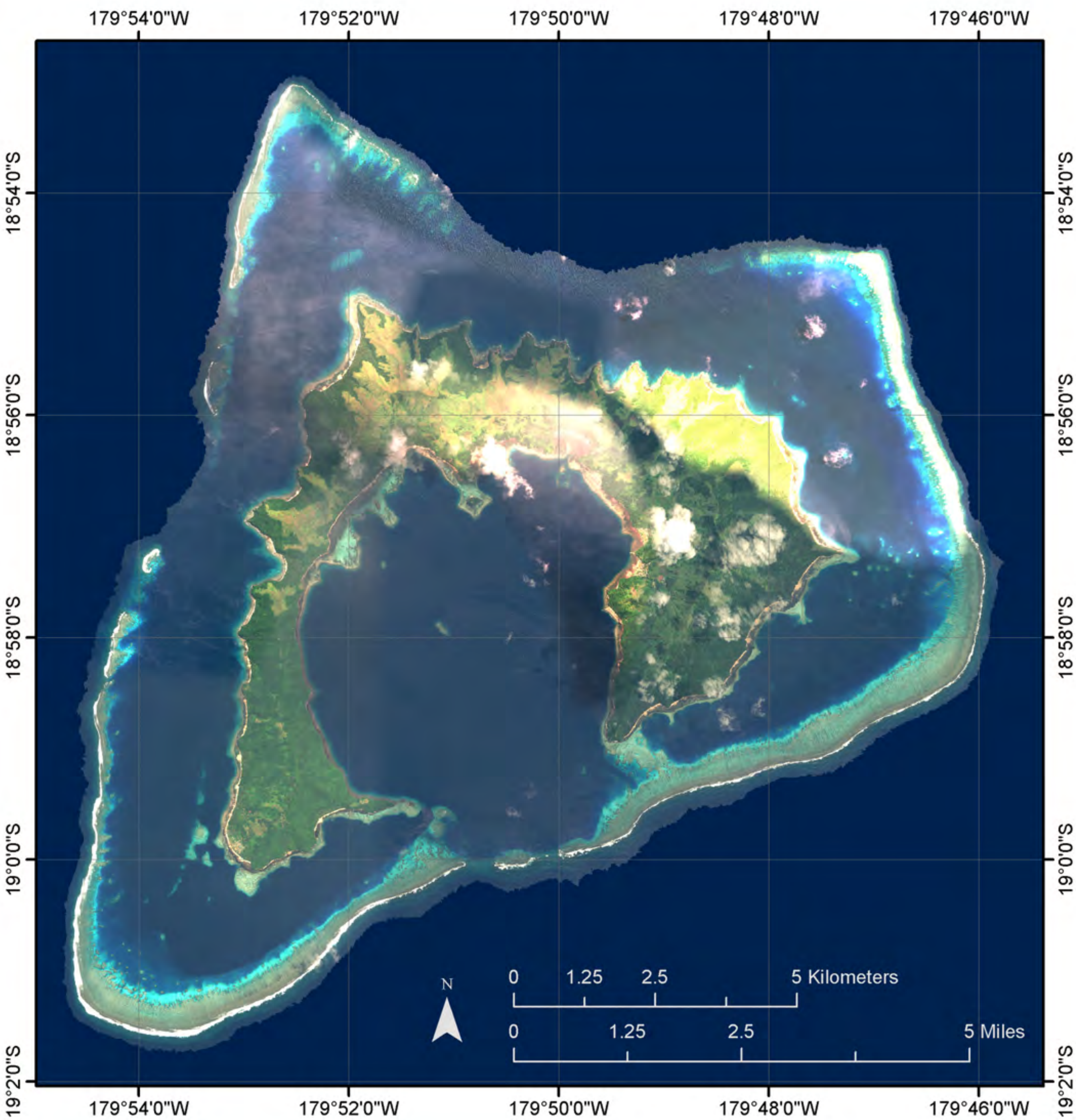


Fig. 32. WorldView-2 Satellite imagery for Totoya.

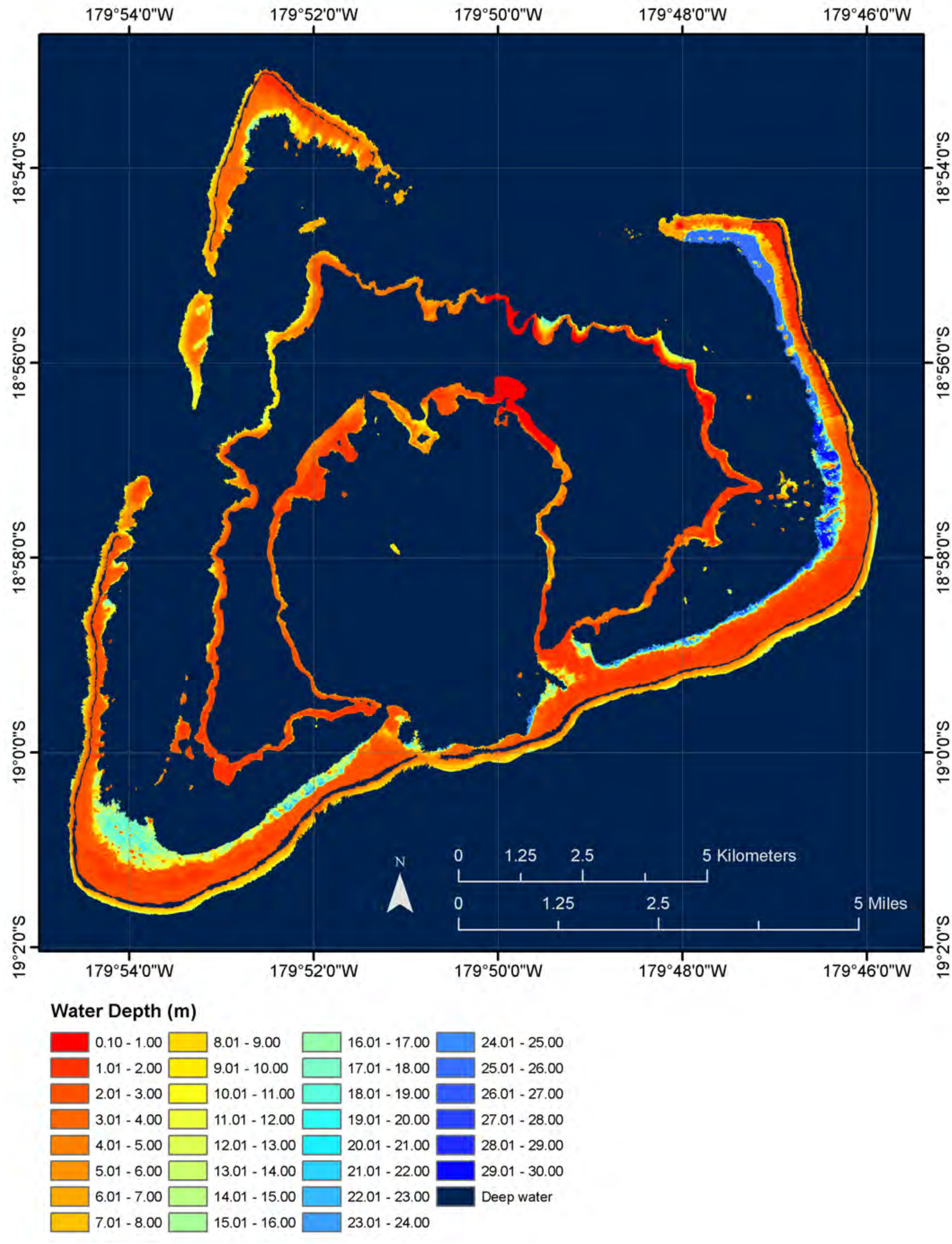


Fig. 33. Bathymetric map for Totoya.

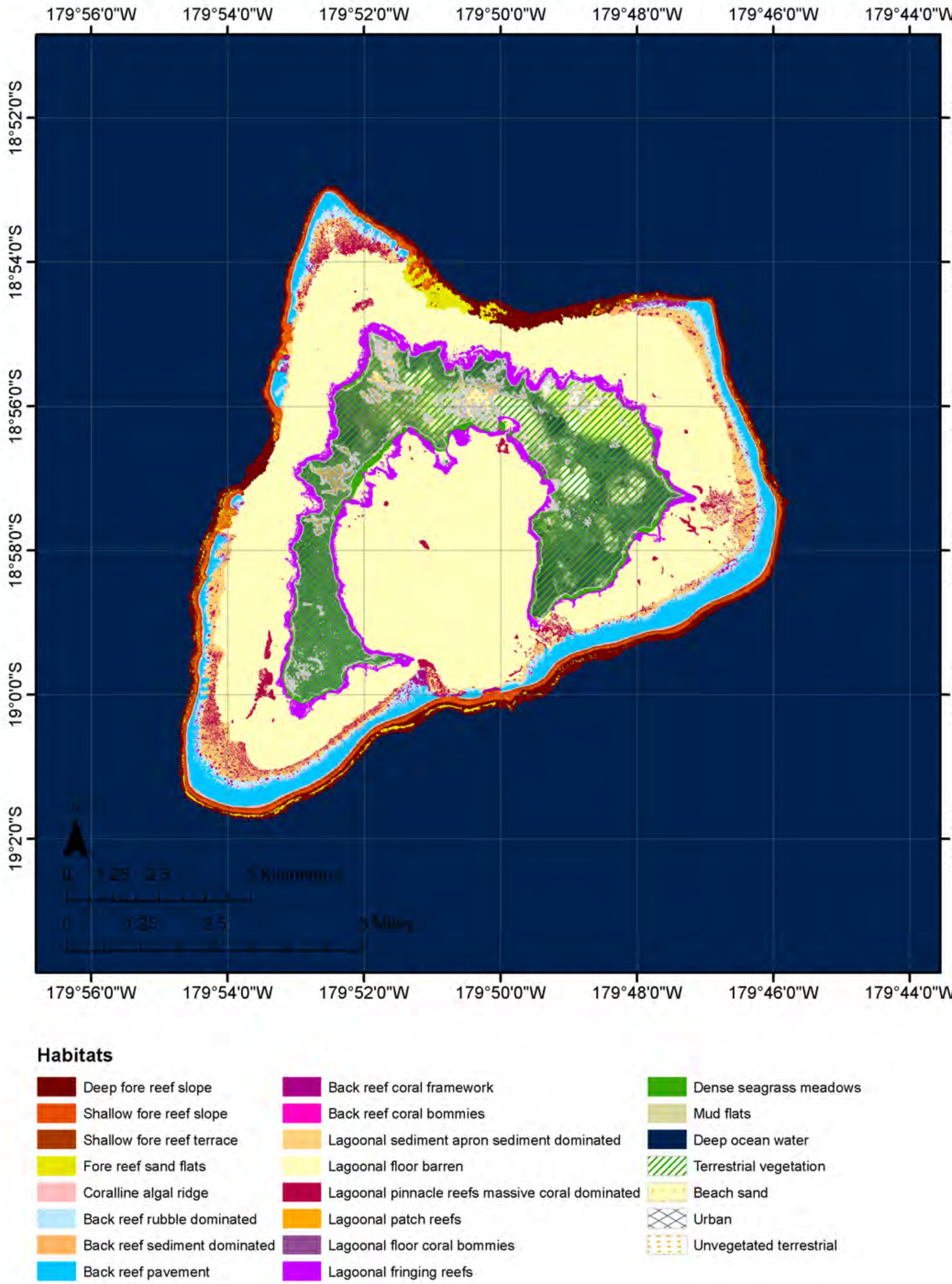


Fig. 34. Habitat map for Totoya.

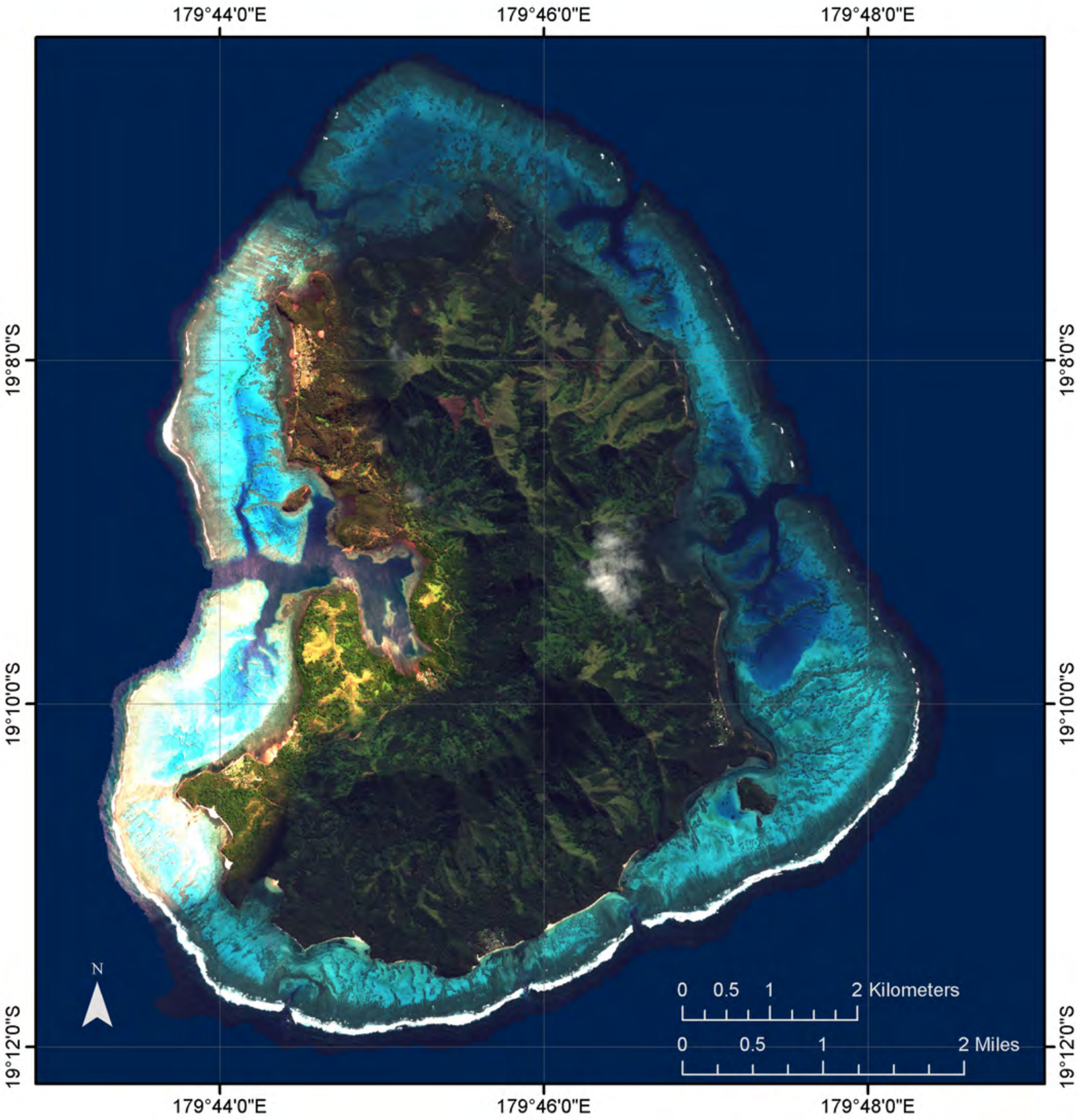


Fig. 35. WorldView-2 Satellite imagery for Matuka.

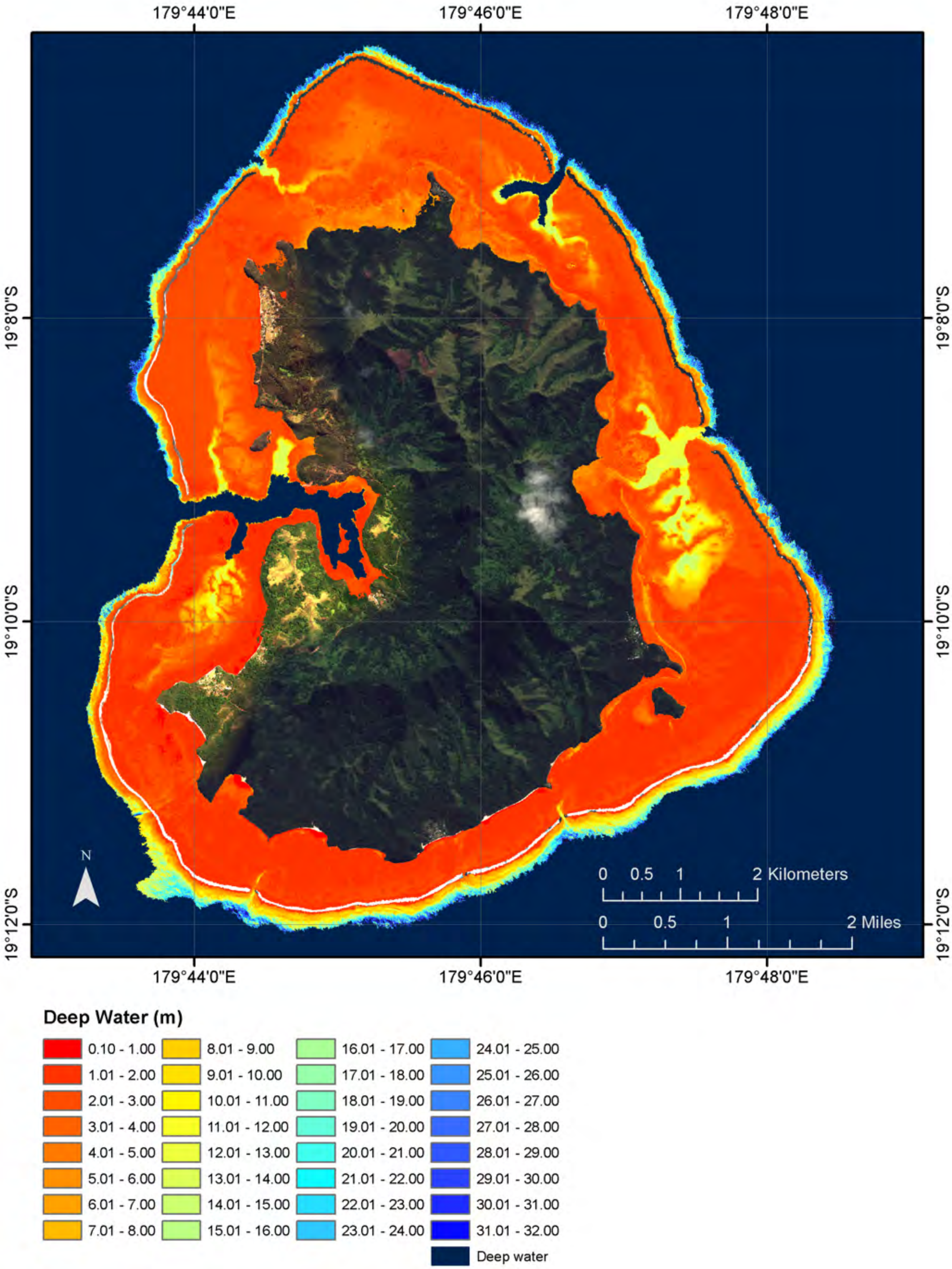


Fig. 36. Bathymetric map for Matuka.

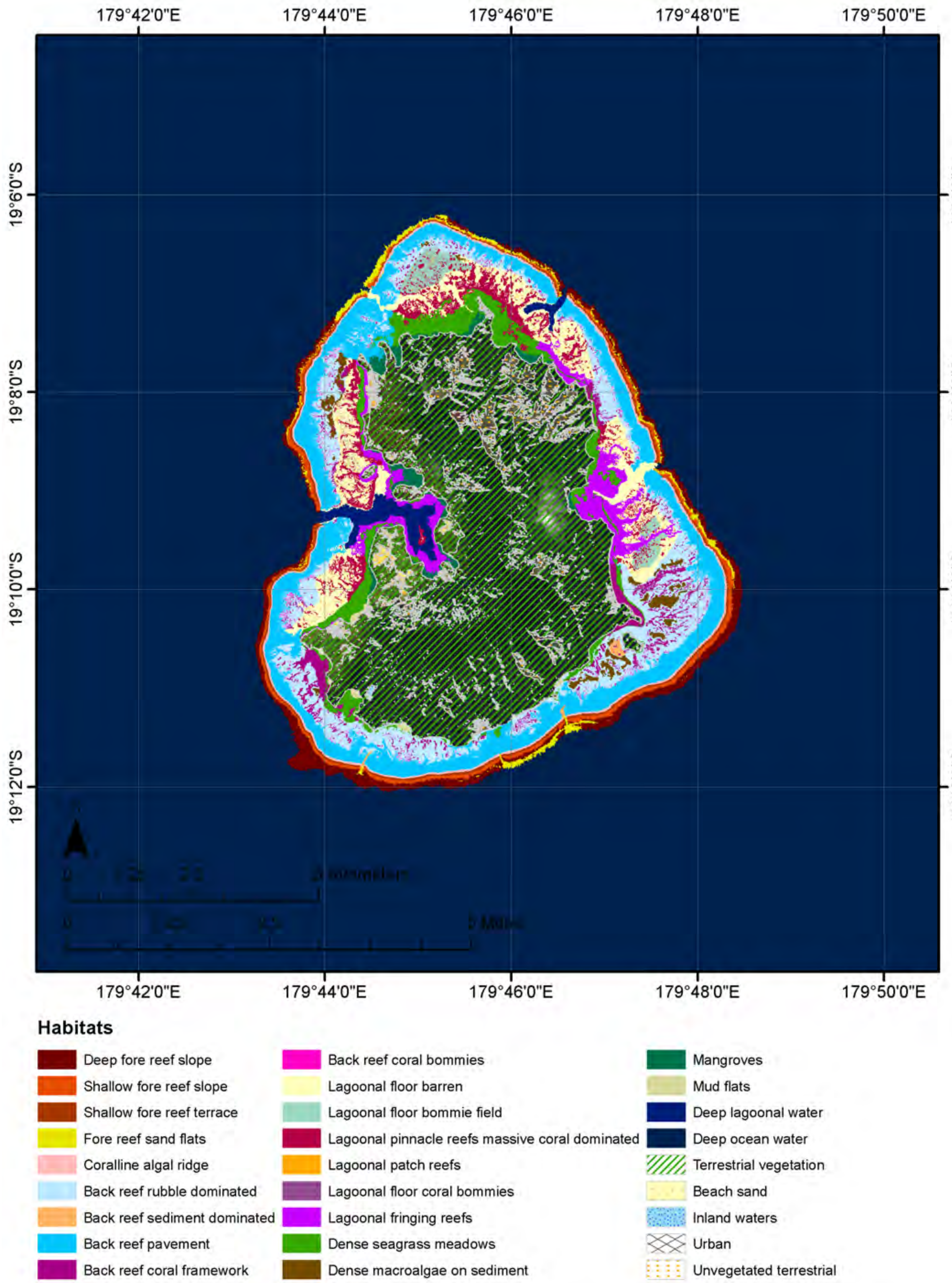


Fig. 37. Habitat map for Matuka.

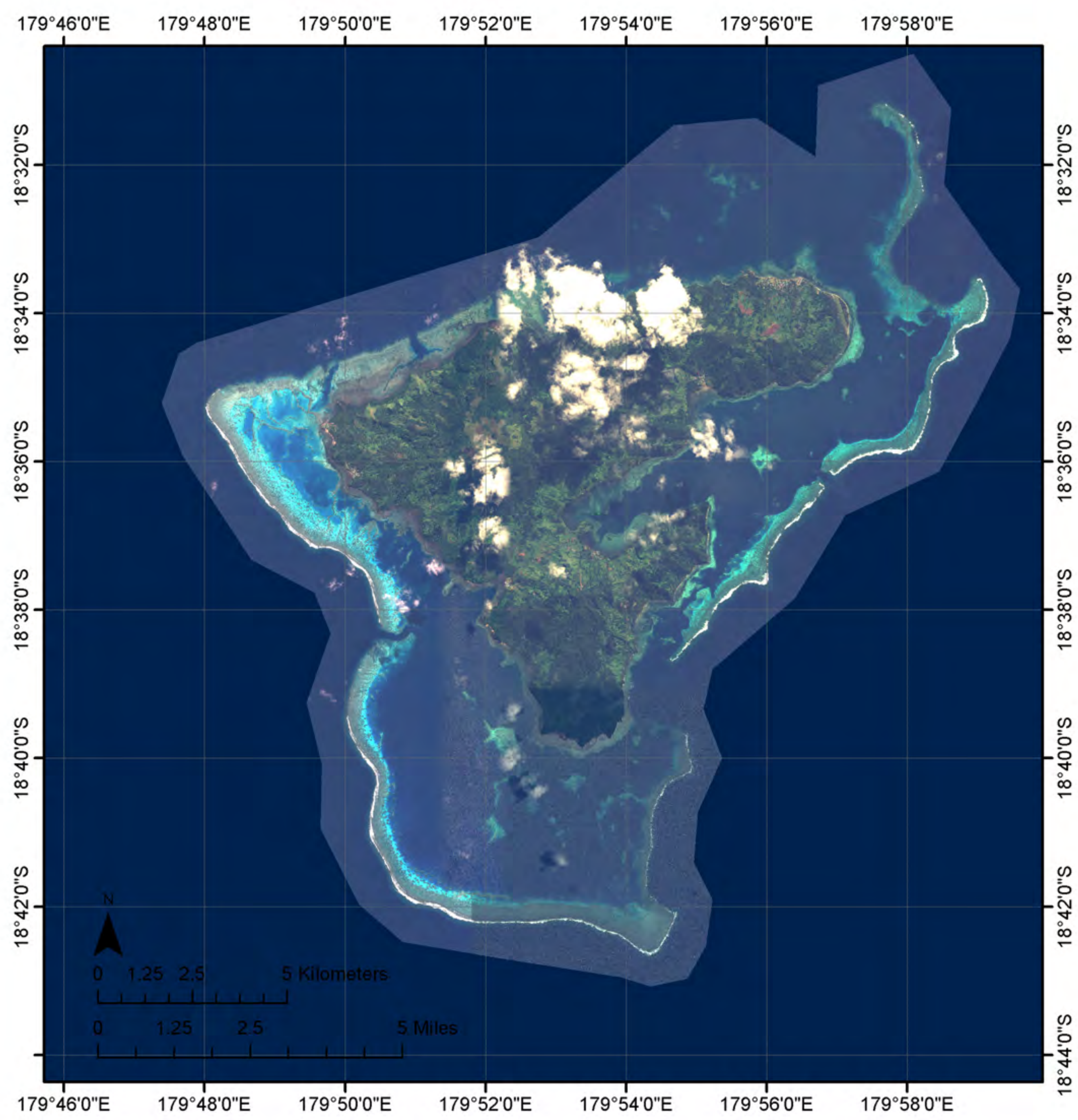


Fig. 38. WorldView-2 Satellite imagery for Moala.

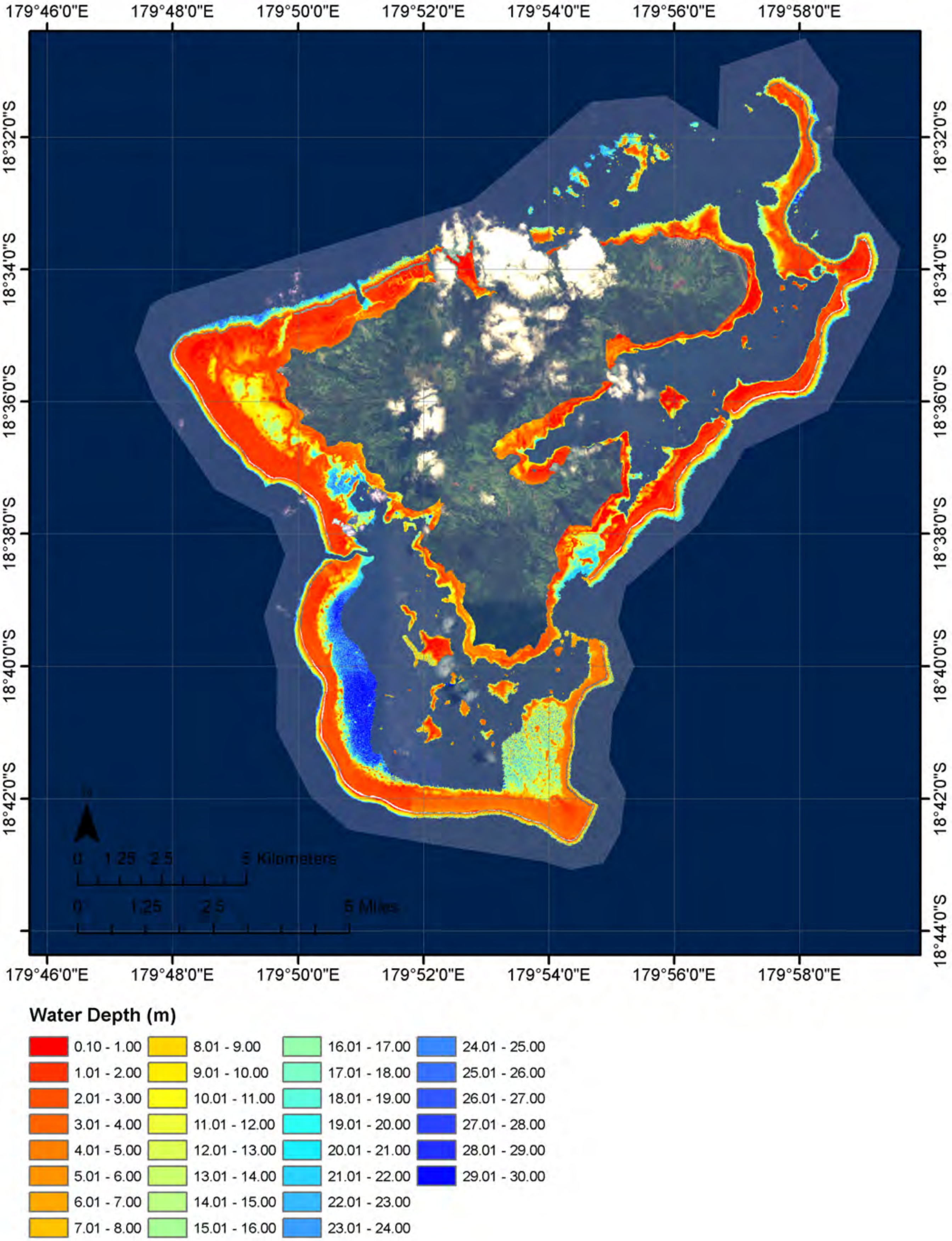


Fig. 39. Bathymetric map for Moala.

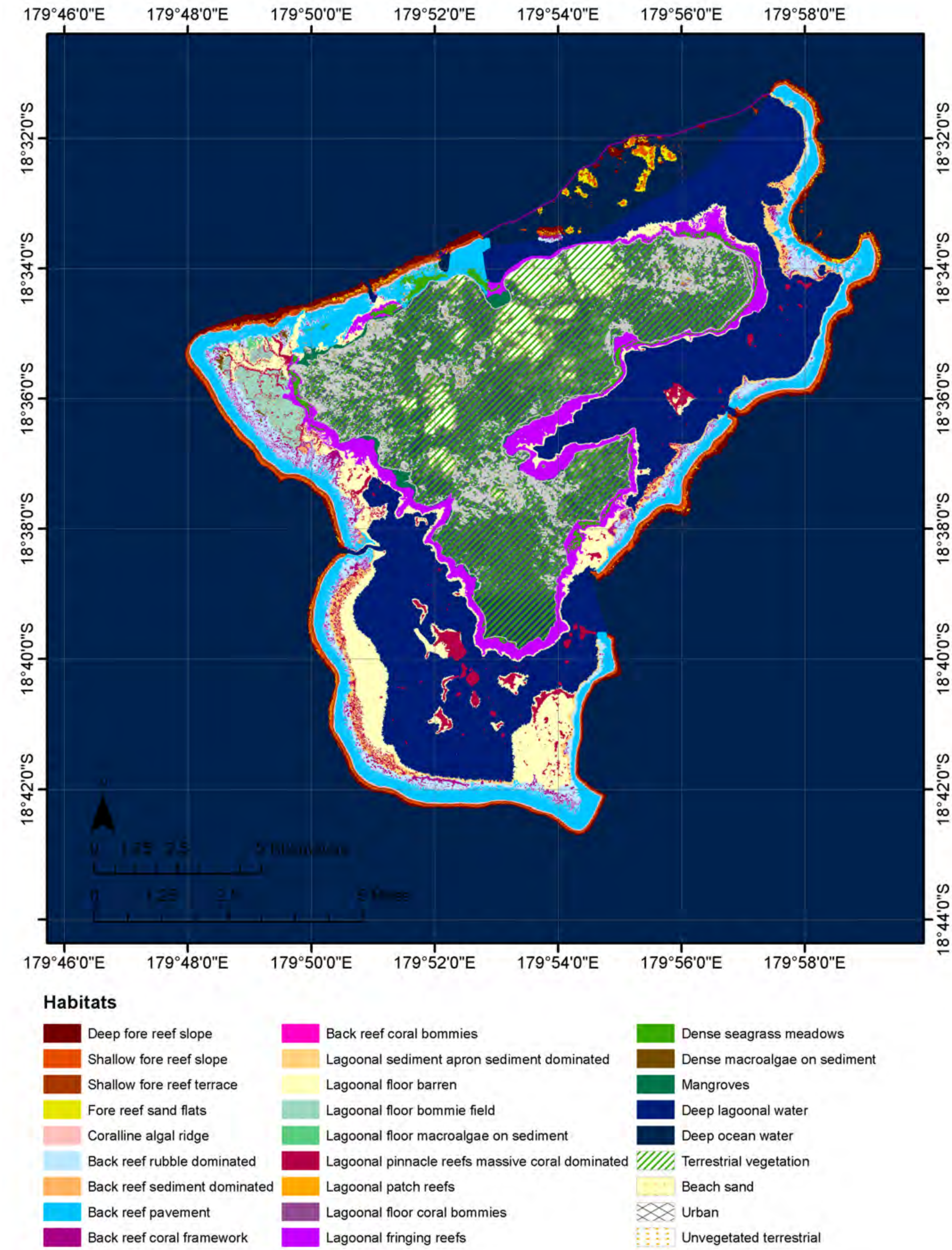


Fig. 40. Habitat map for Moala.

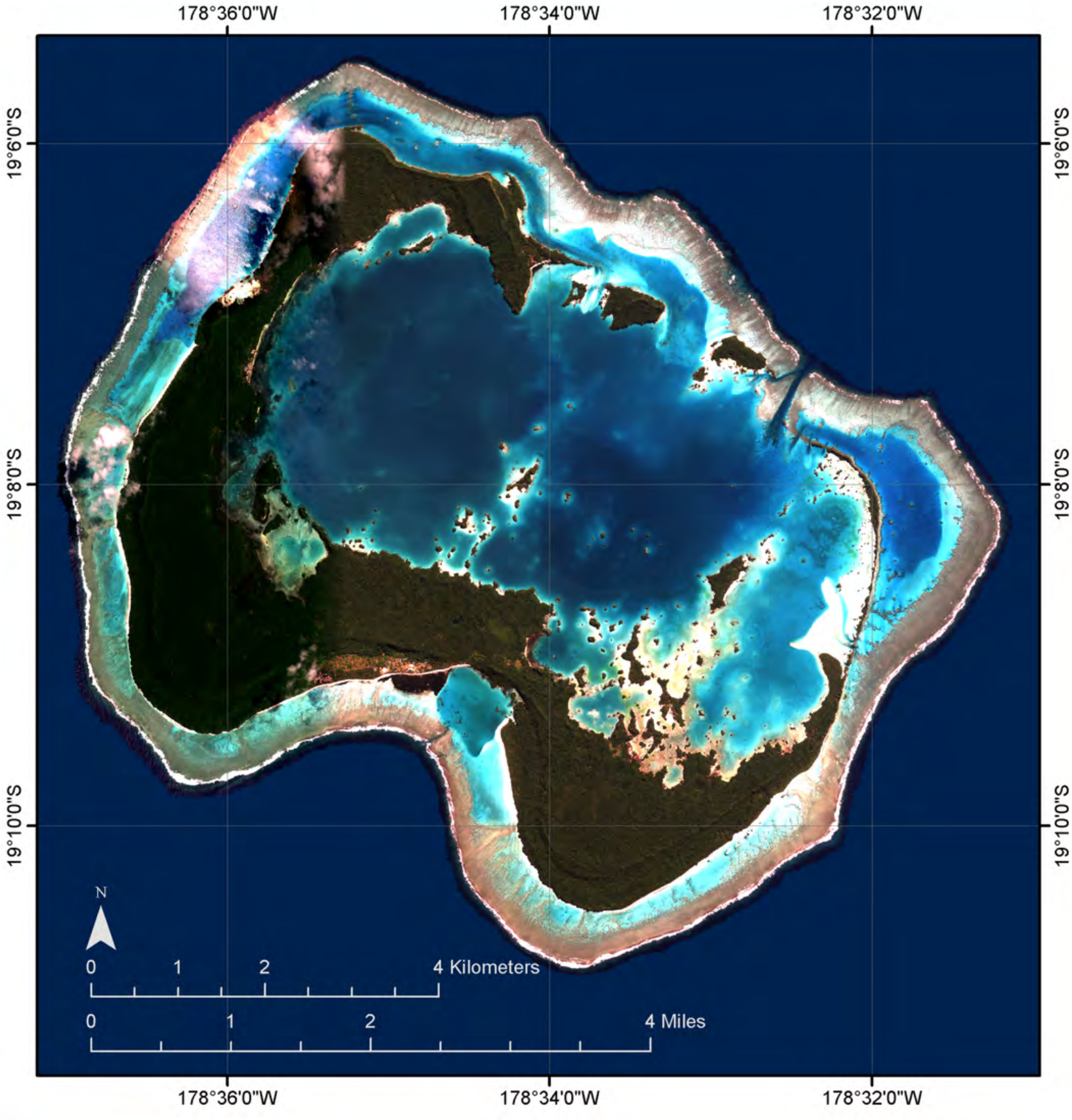


Fig. 41. WorldView-2 Satellite imagery for Fulaga.

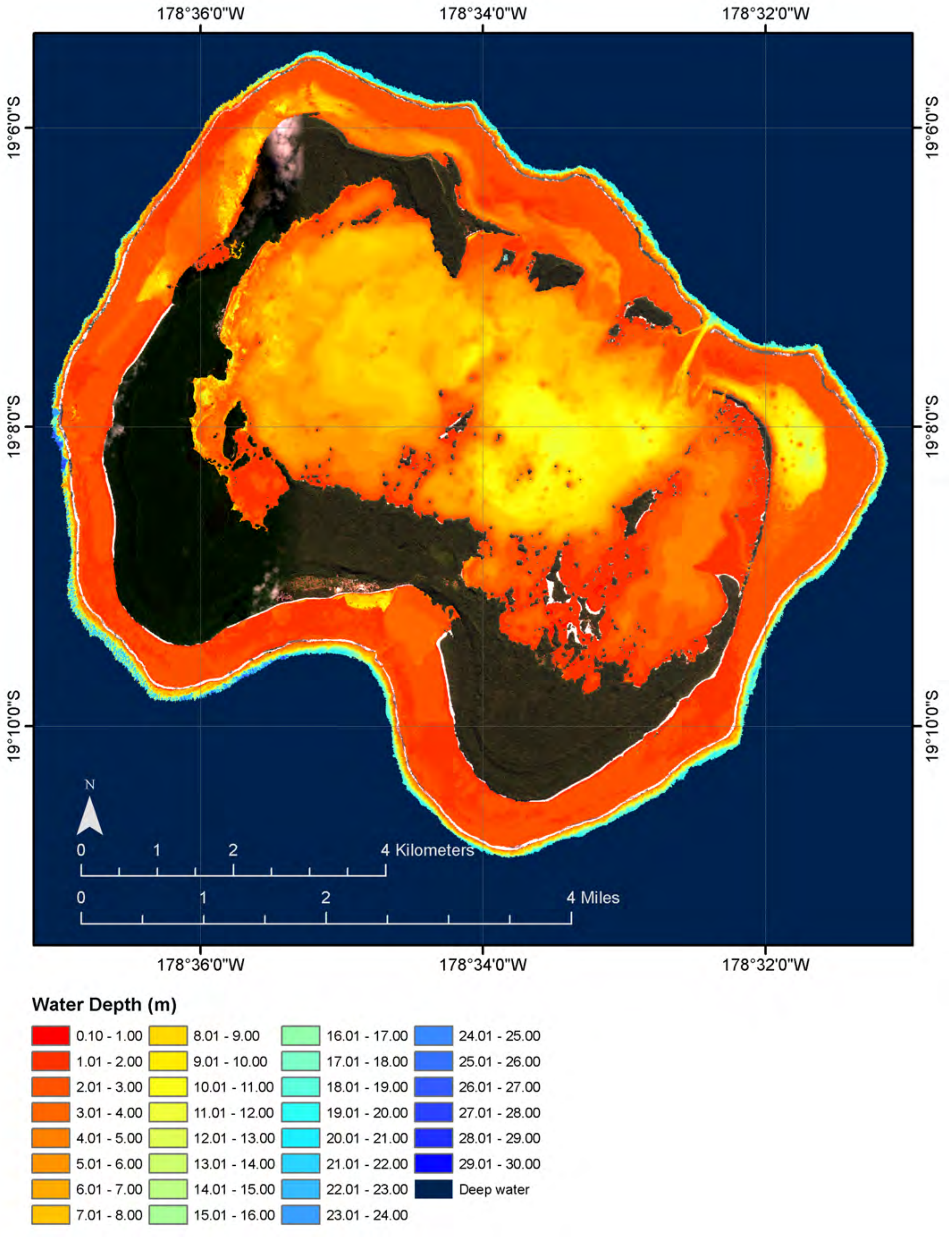


Fig. 42. Bathymetric map for Fulaga.

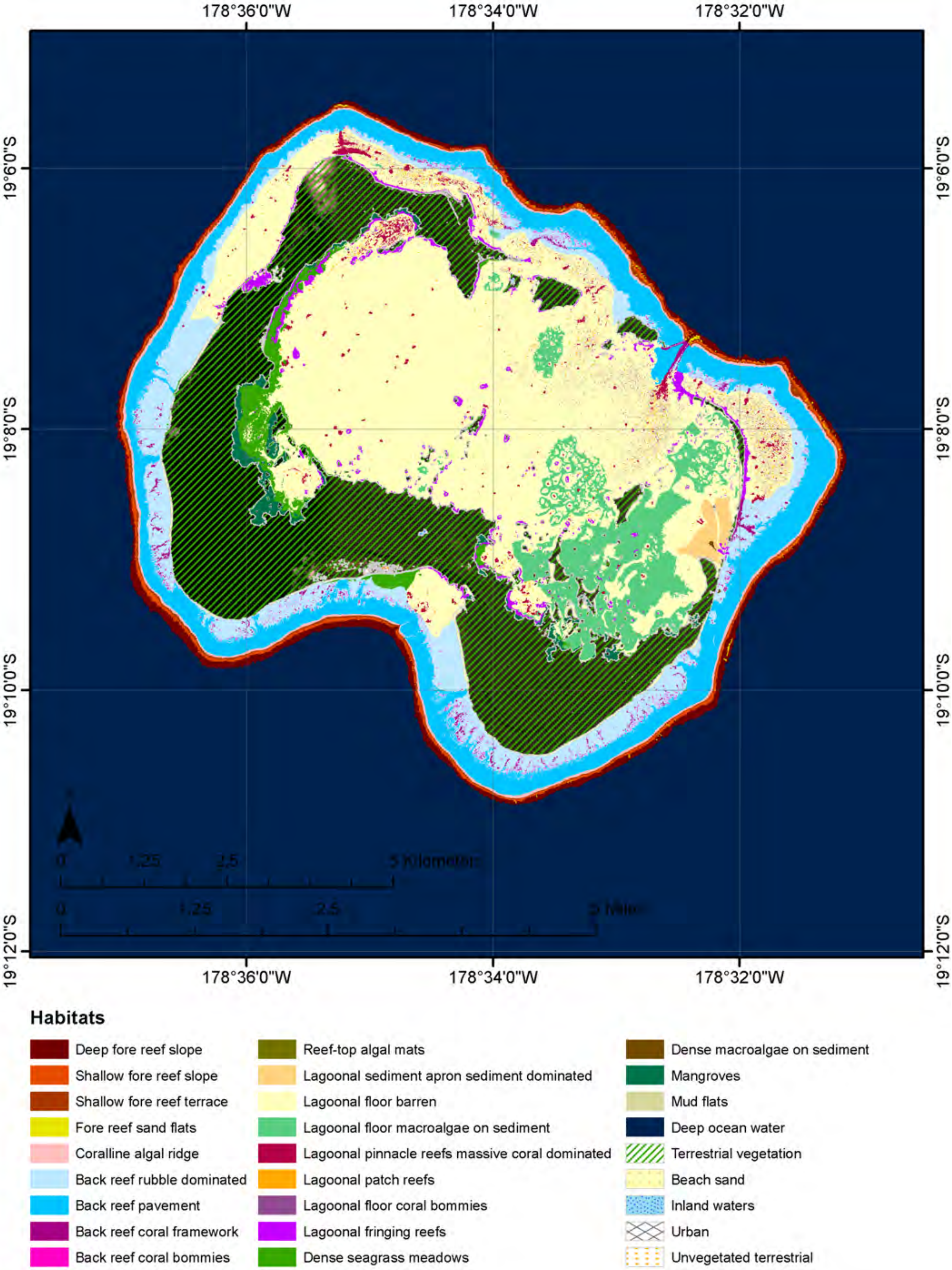


Fig. 43. Habitat map for Fulaga.

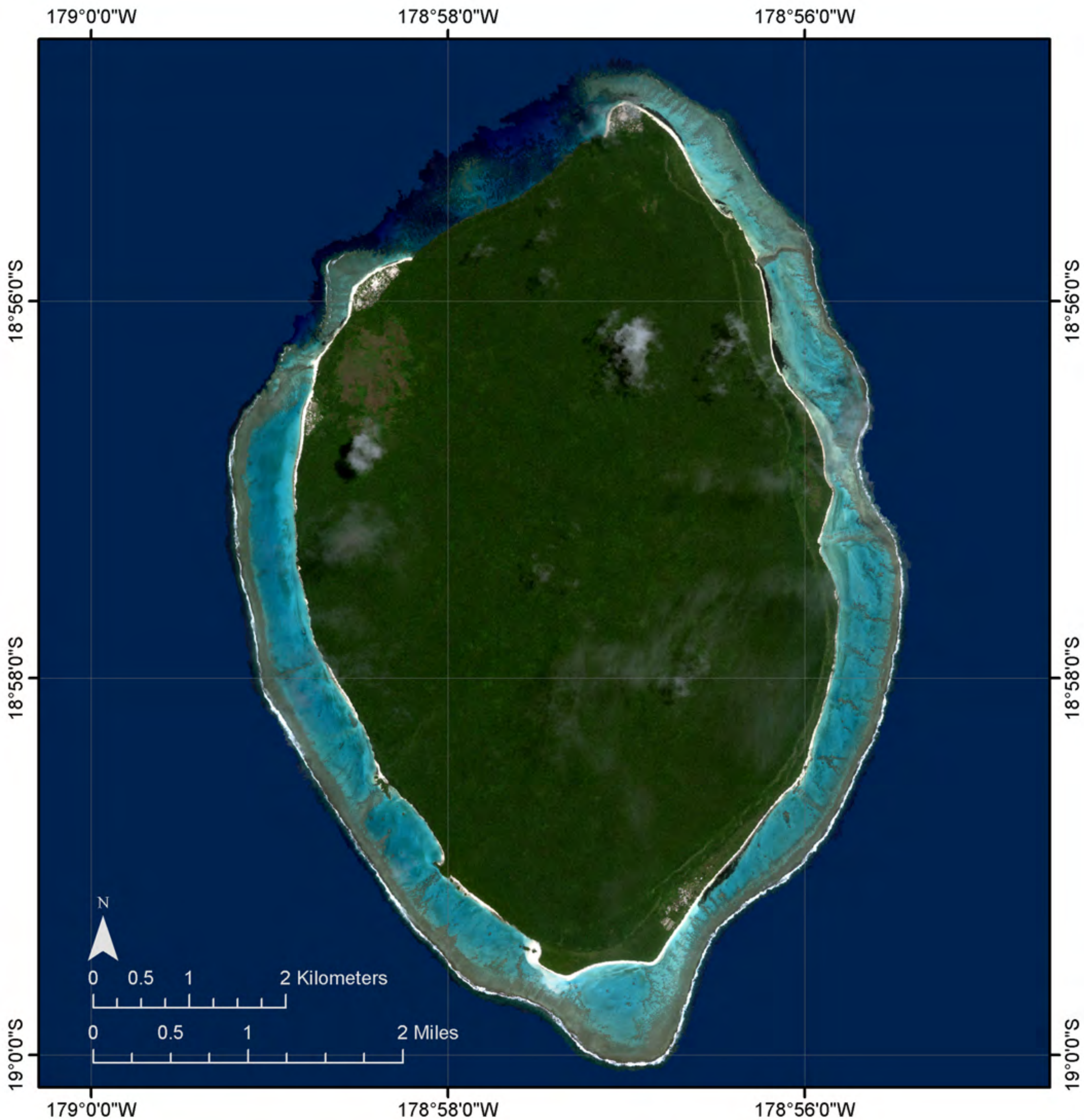


Fig. 44. WorldView-2 Satellite imagery for Kabara.

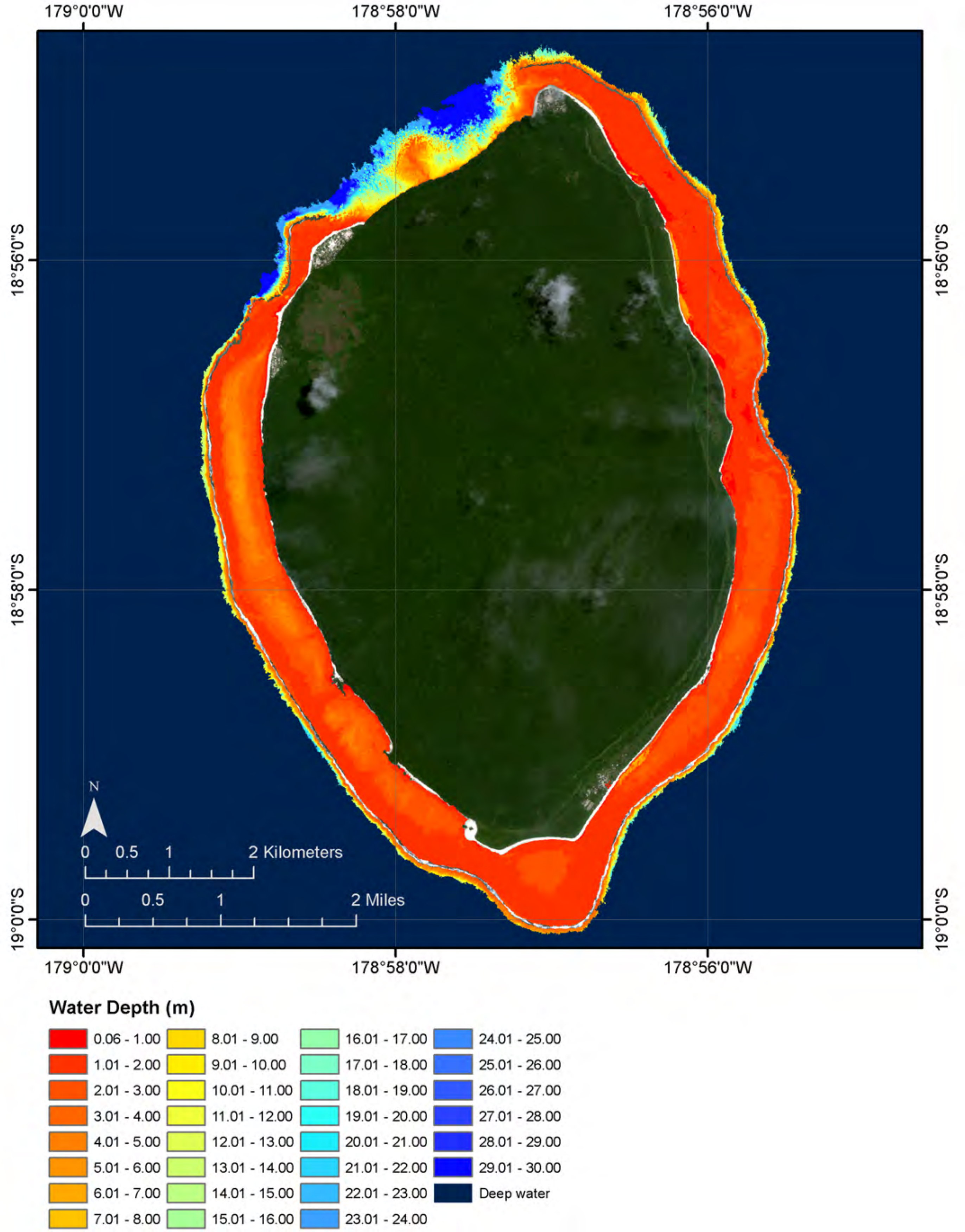


Fig. 45. Bathymetric map for Kabara.

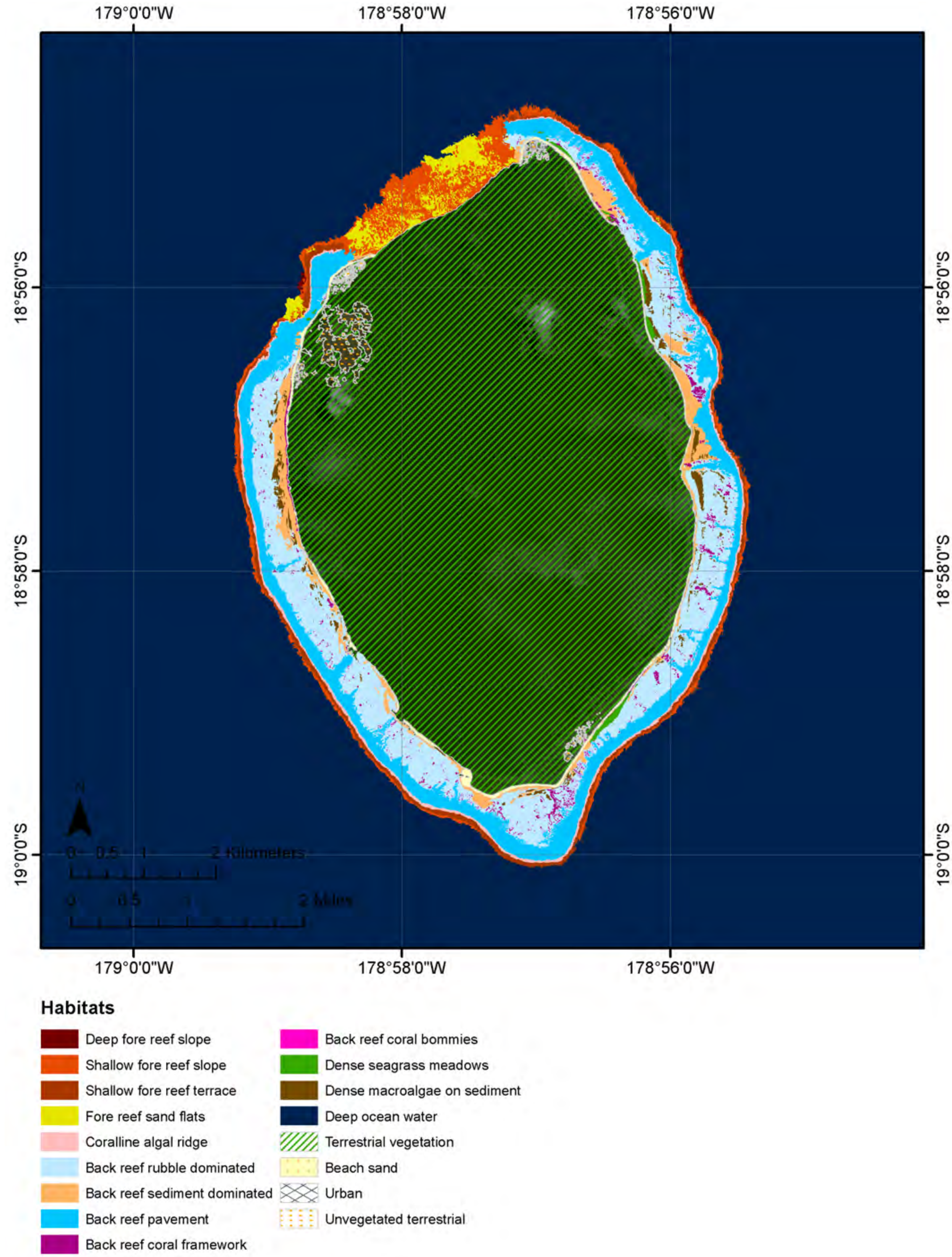


Fig. 46. Habitat map for Kabara.

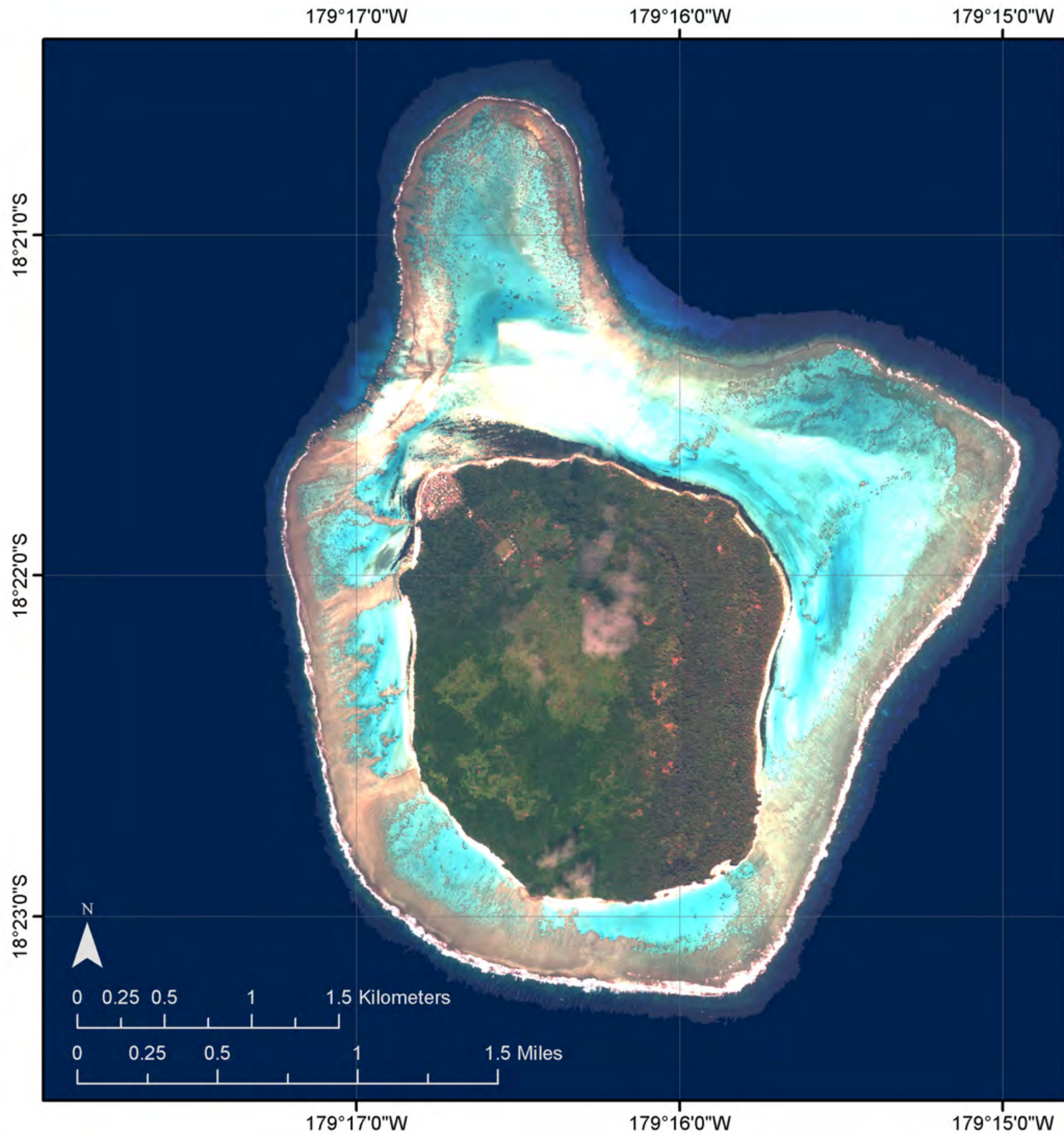


Fig. 47. WorldView-2 Satellite imagery for Vanua Vatu.

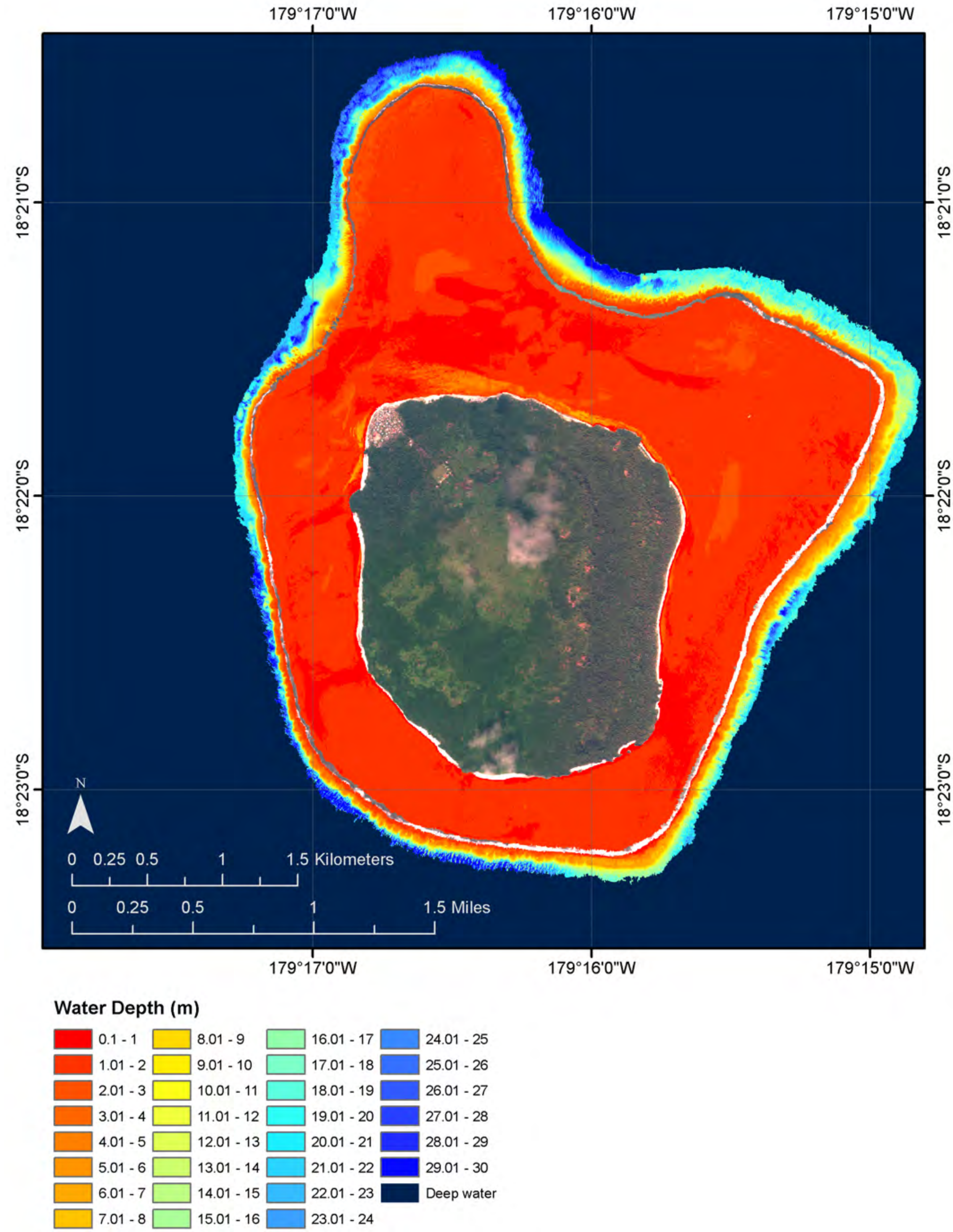


Fig. 48. Bathymetric map for Vanua Vatu.

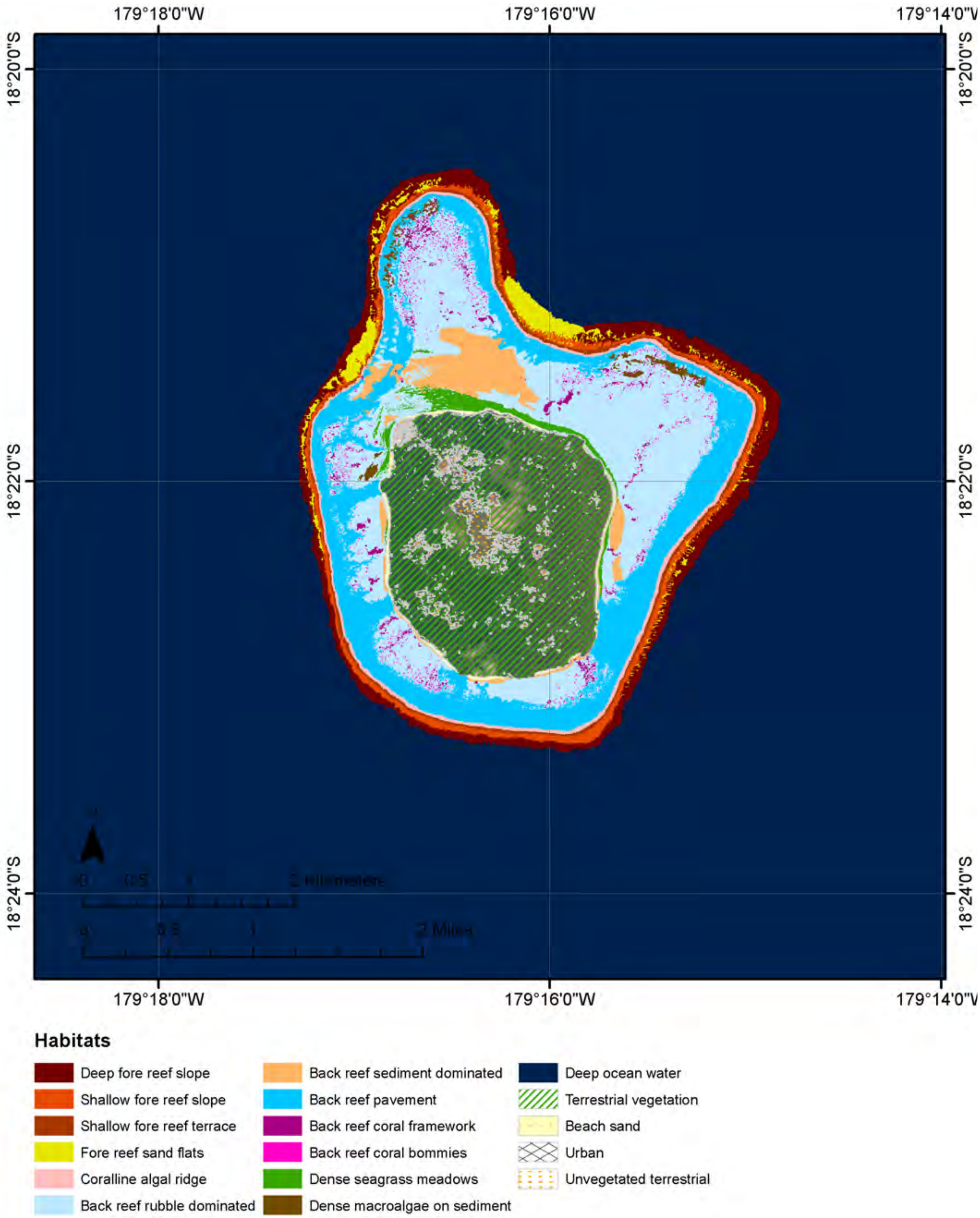


Fig. 49. Habitat map for Vanua Vatu.

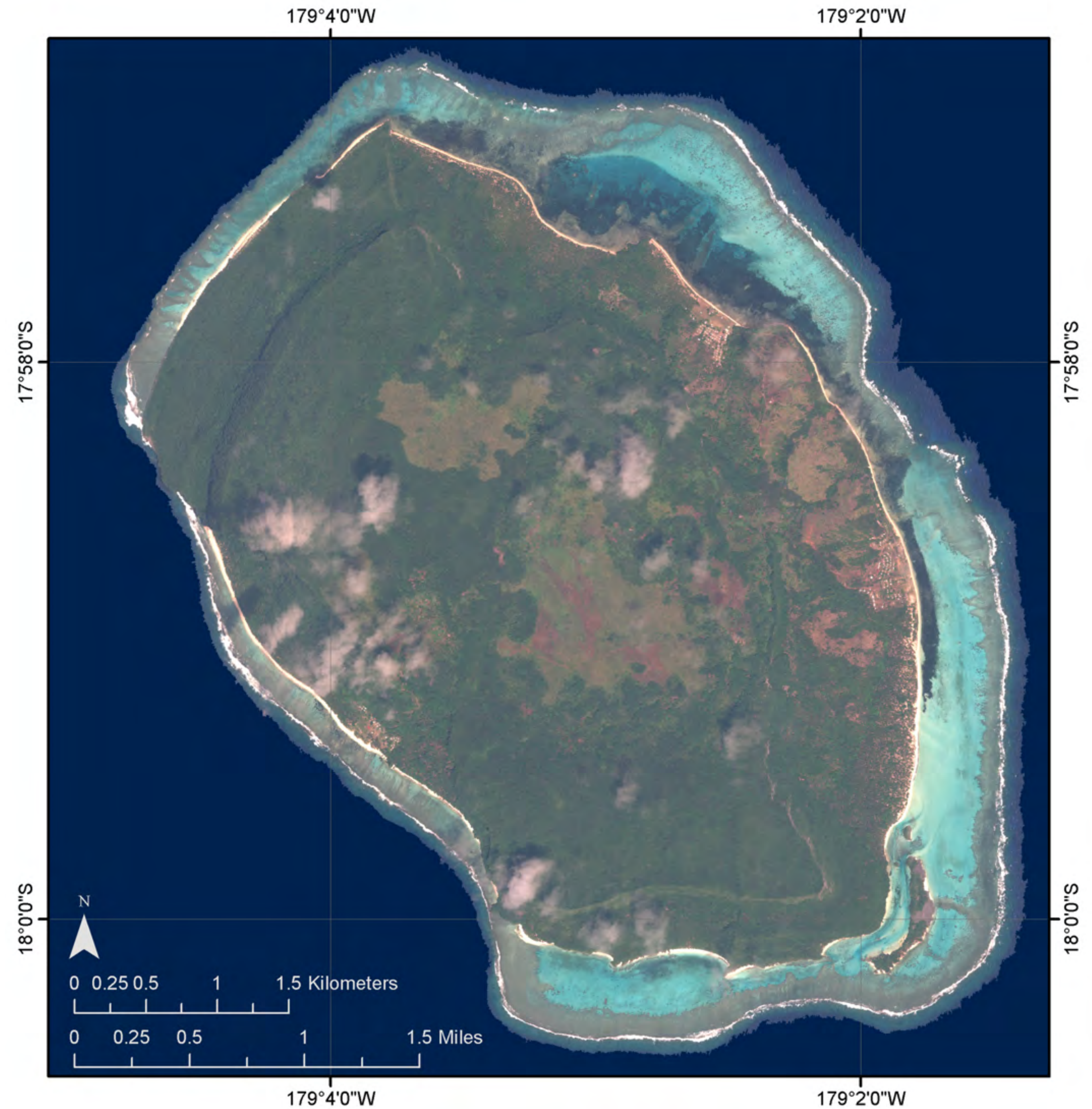


Fig. 50. WorldView-2 Satellite imagery for Nayau.

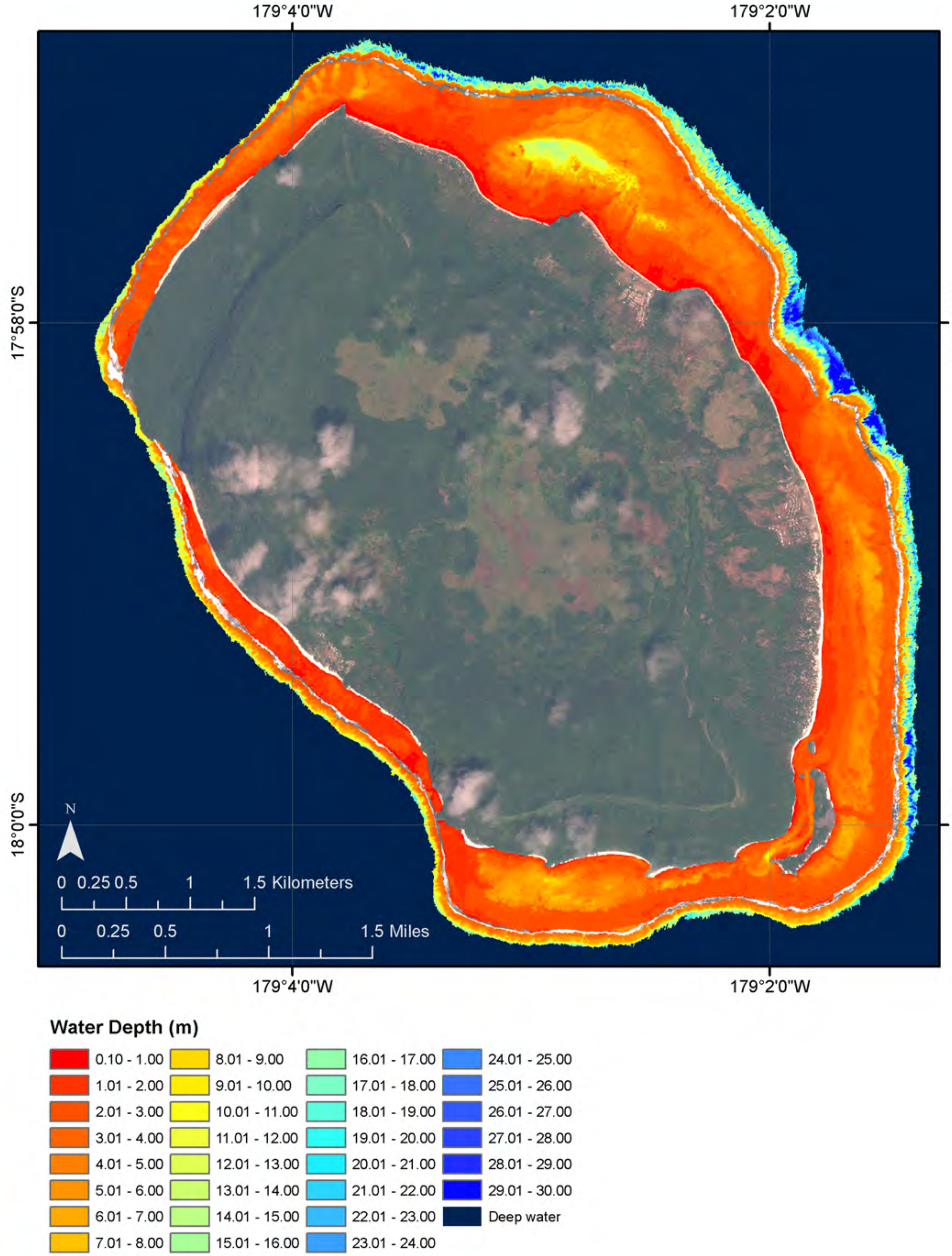


Fig. 51. Bathymetric map for Nayau.

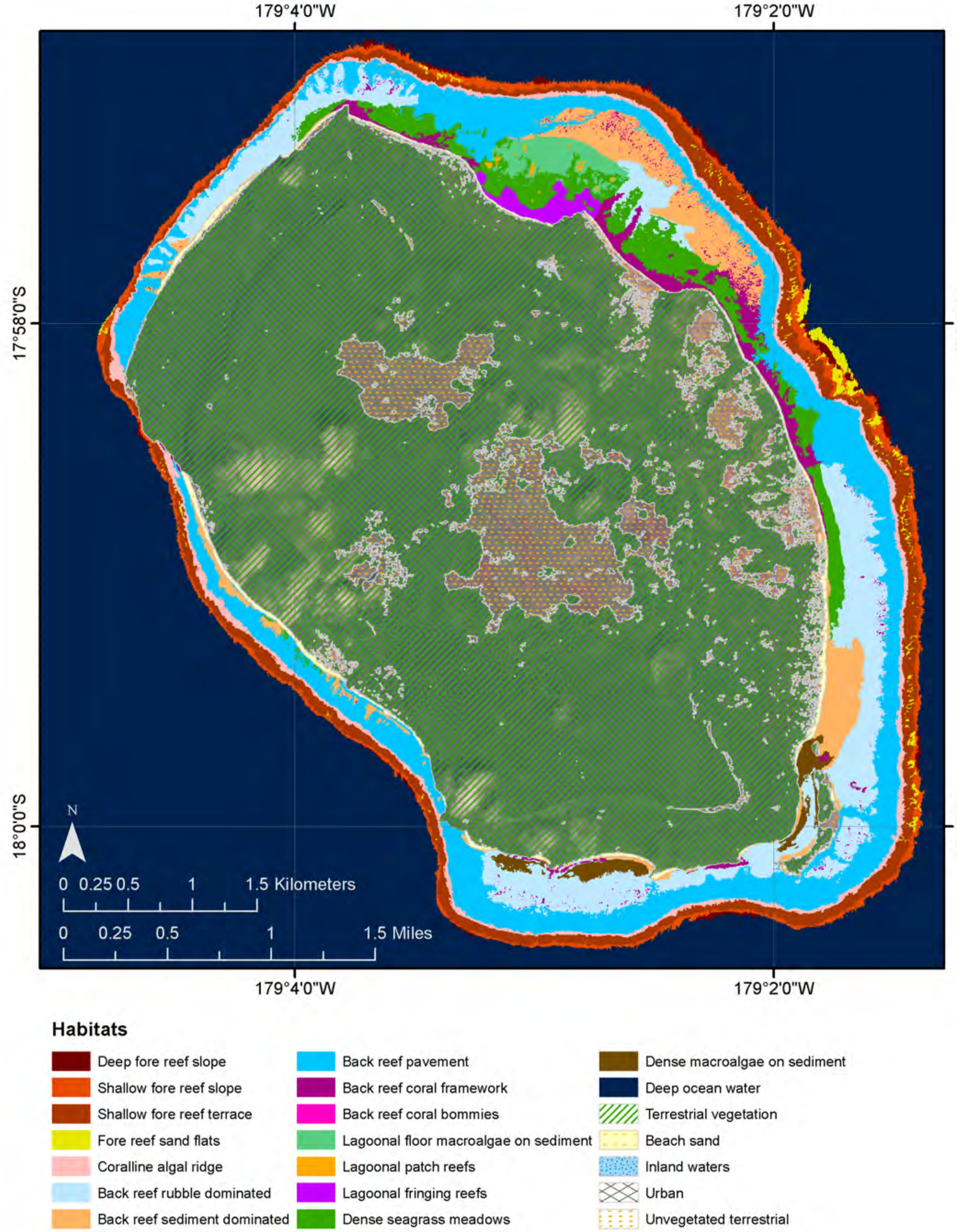


Fig. 52. Habitat map for Nayau.

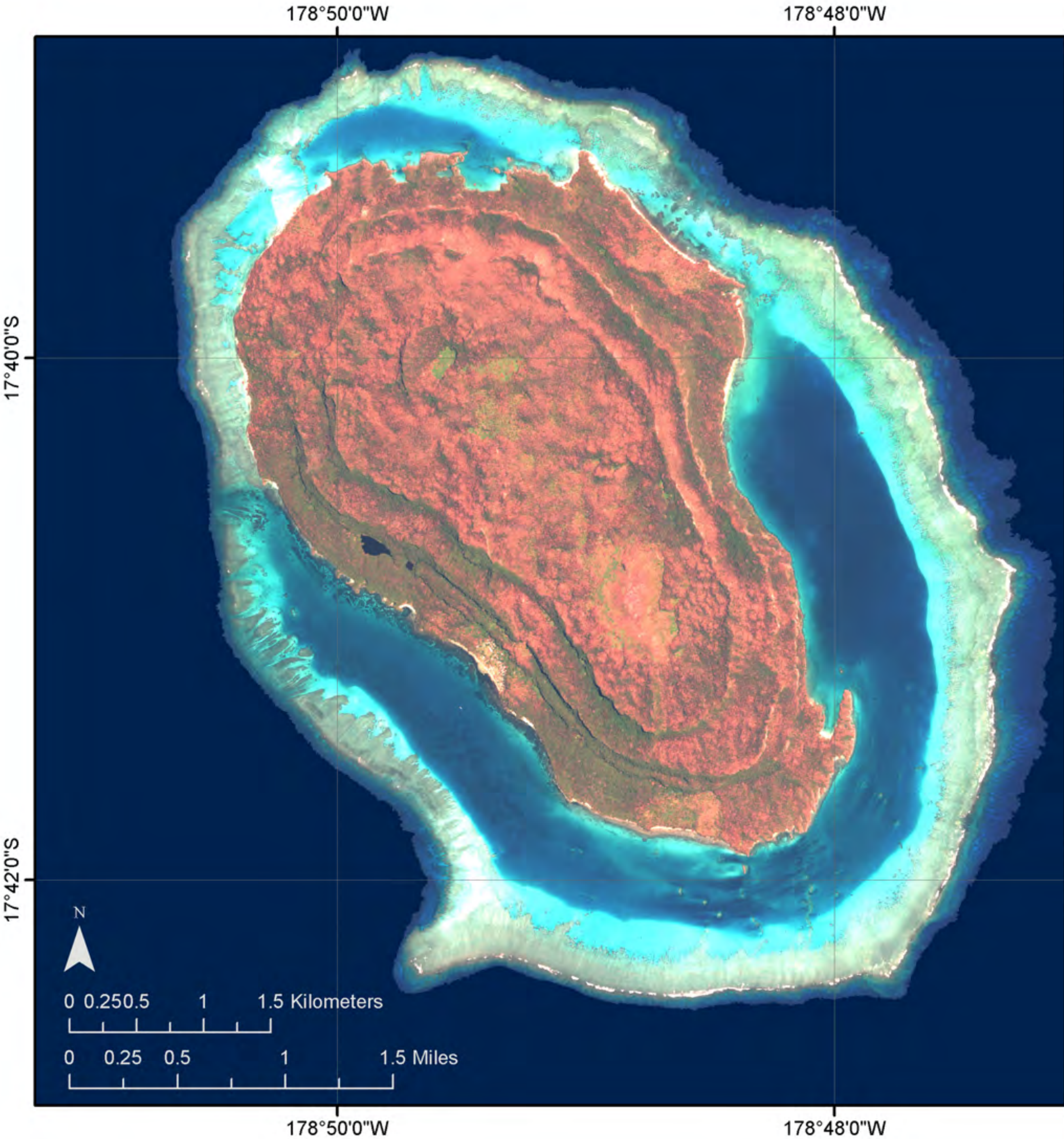


Fig. 53. WorldView-2 Satellite imagery for Tuvuca.

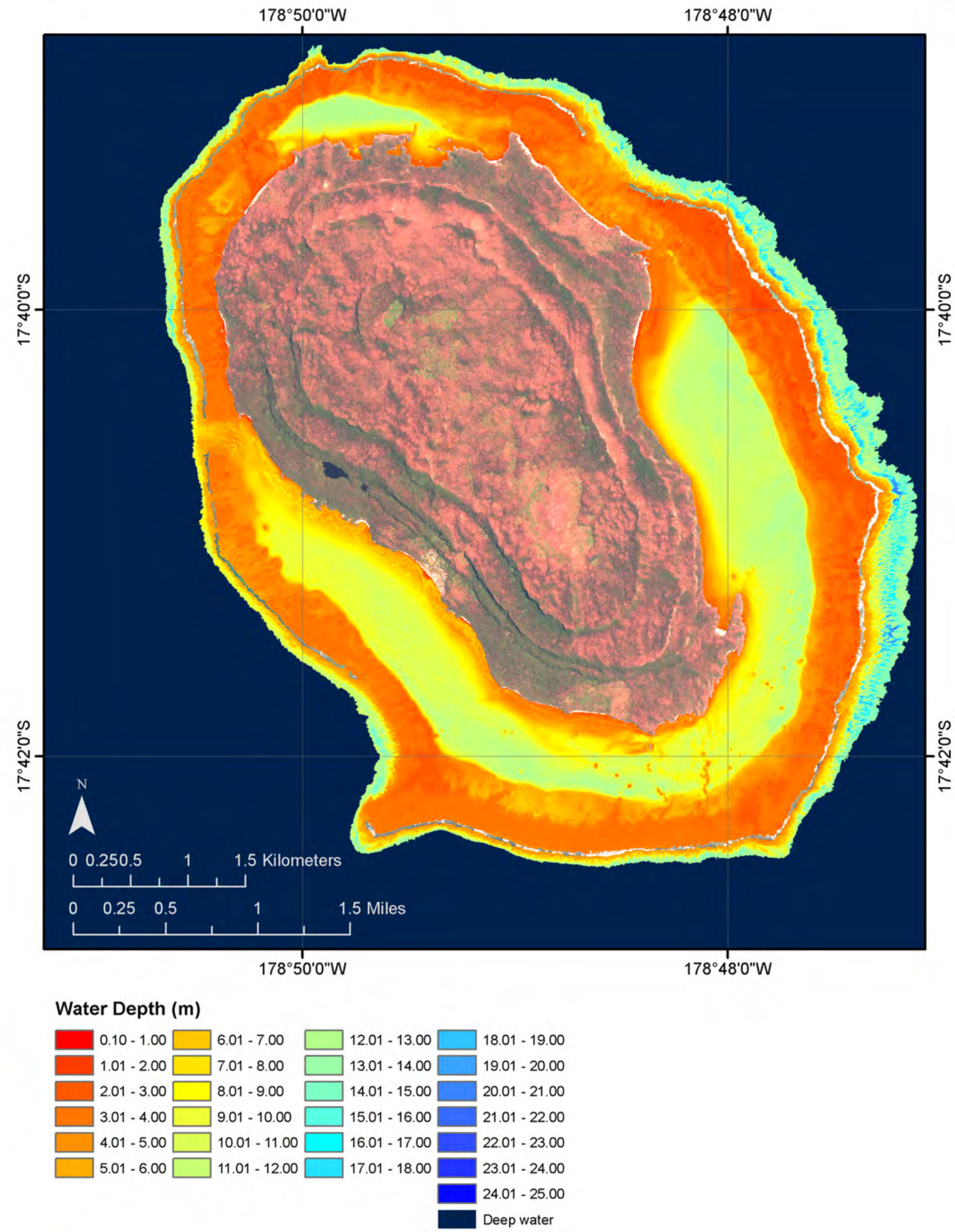


Fig. 54. Bathymetric map for Tuvuca.

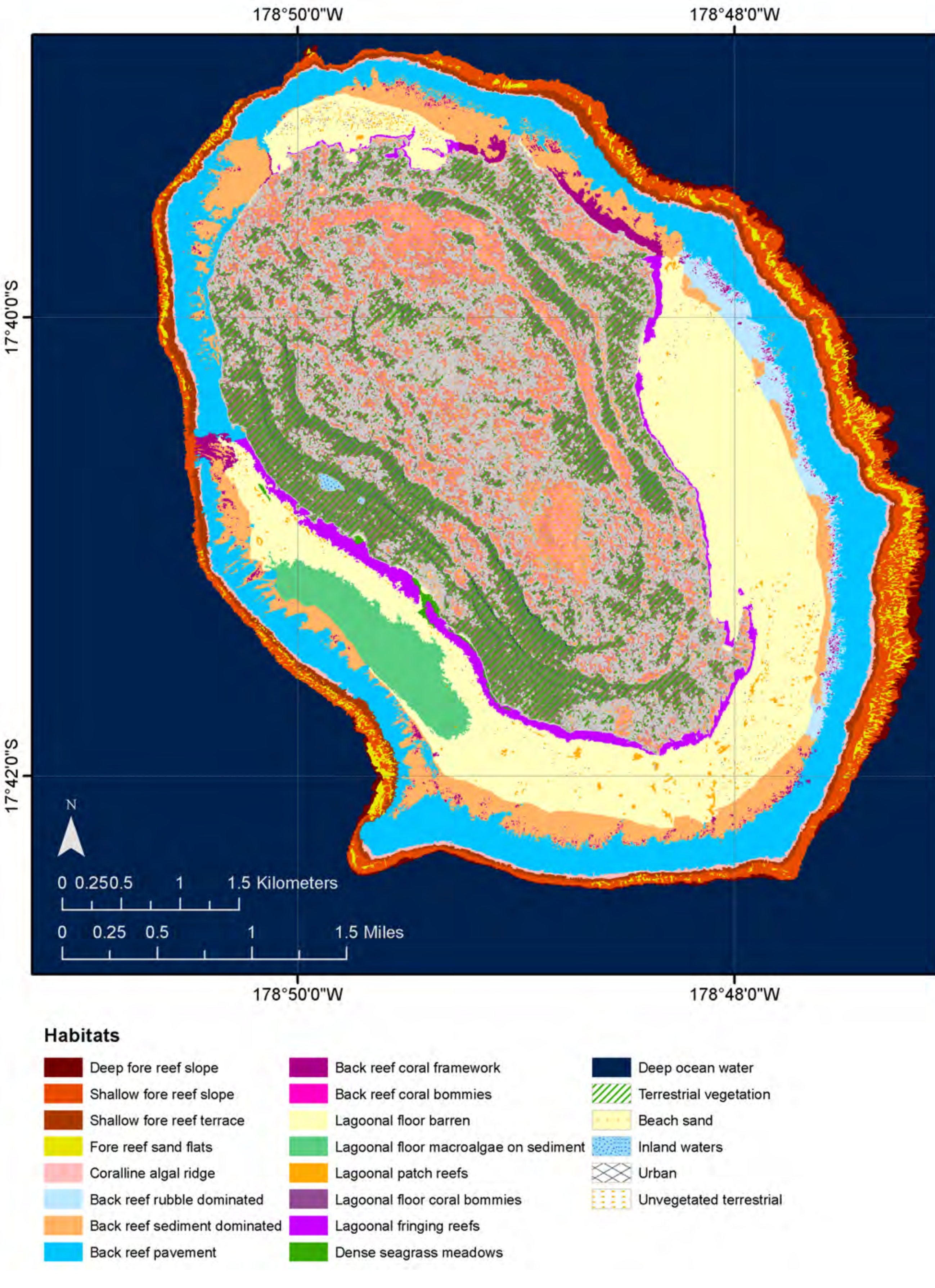


Fig. 55. Habitat map for Tuvuca.

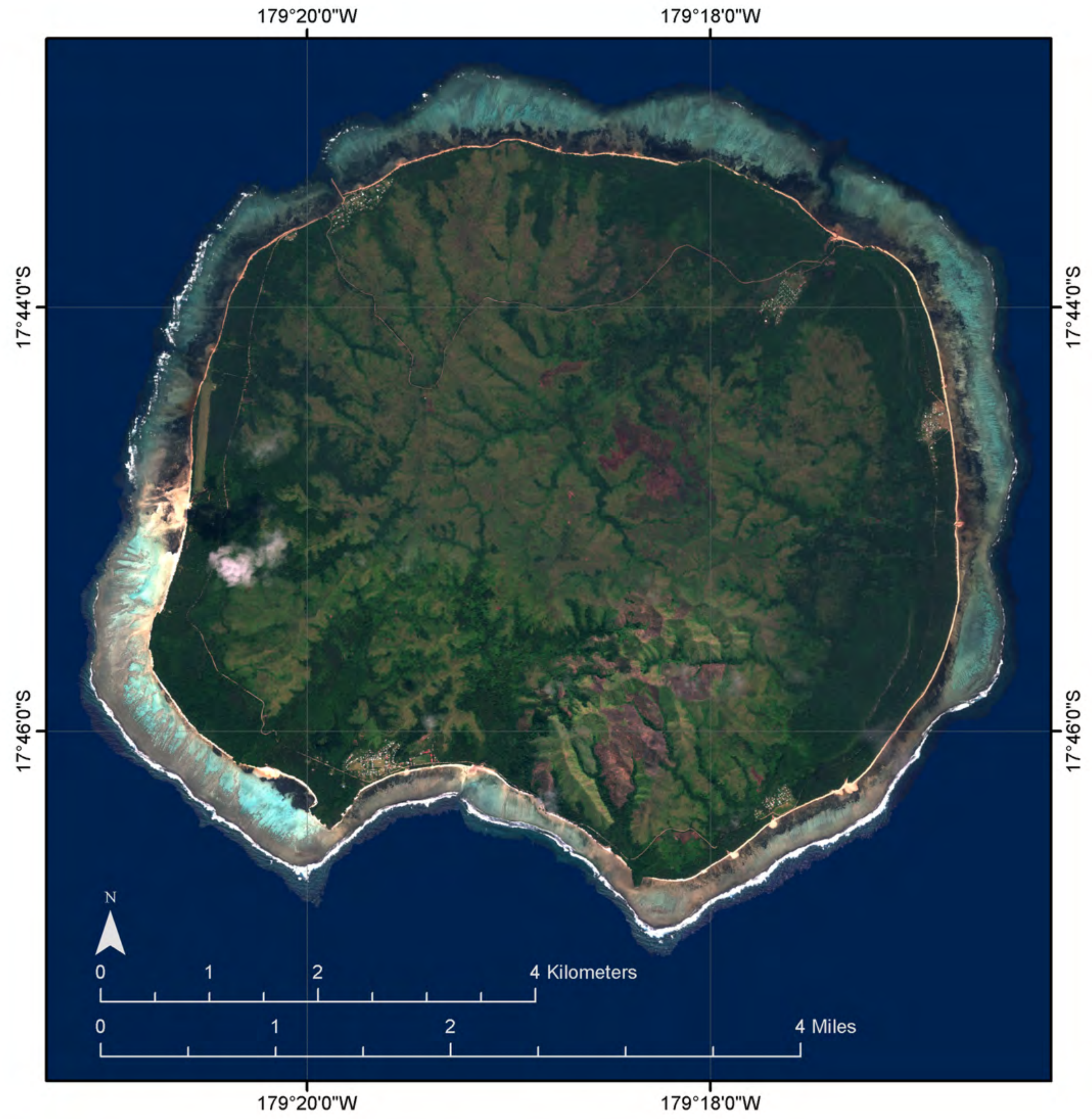


Fig. 56. WorldView-2 Satellite imagery for Cicia.

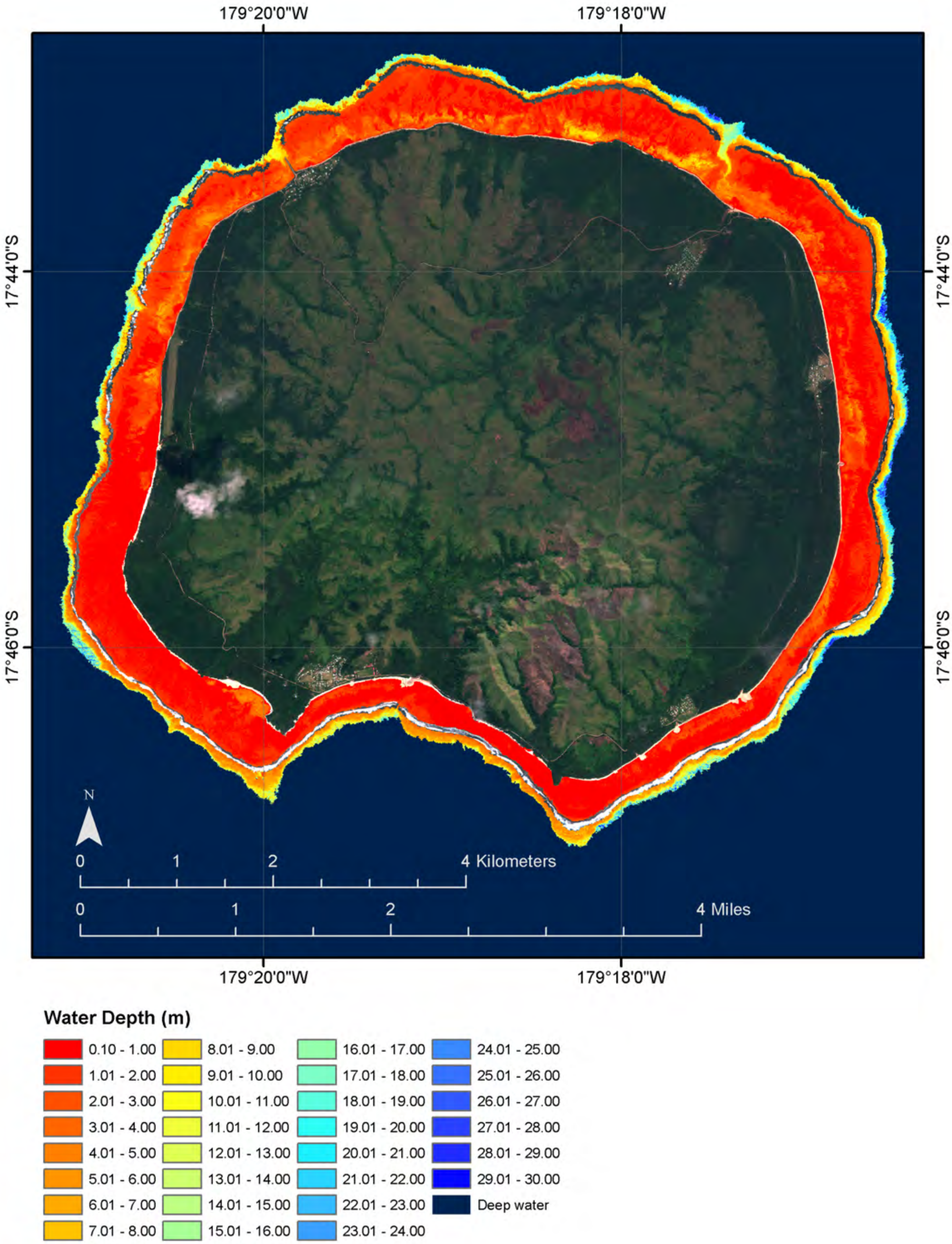


Fig. 57. Bathymetric map for Cicia.

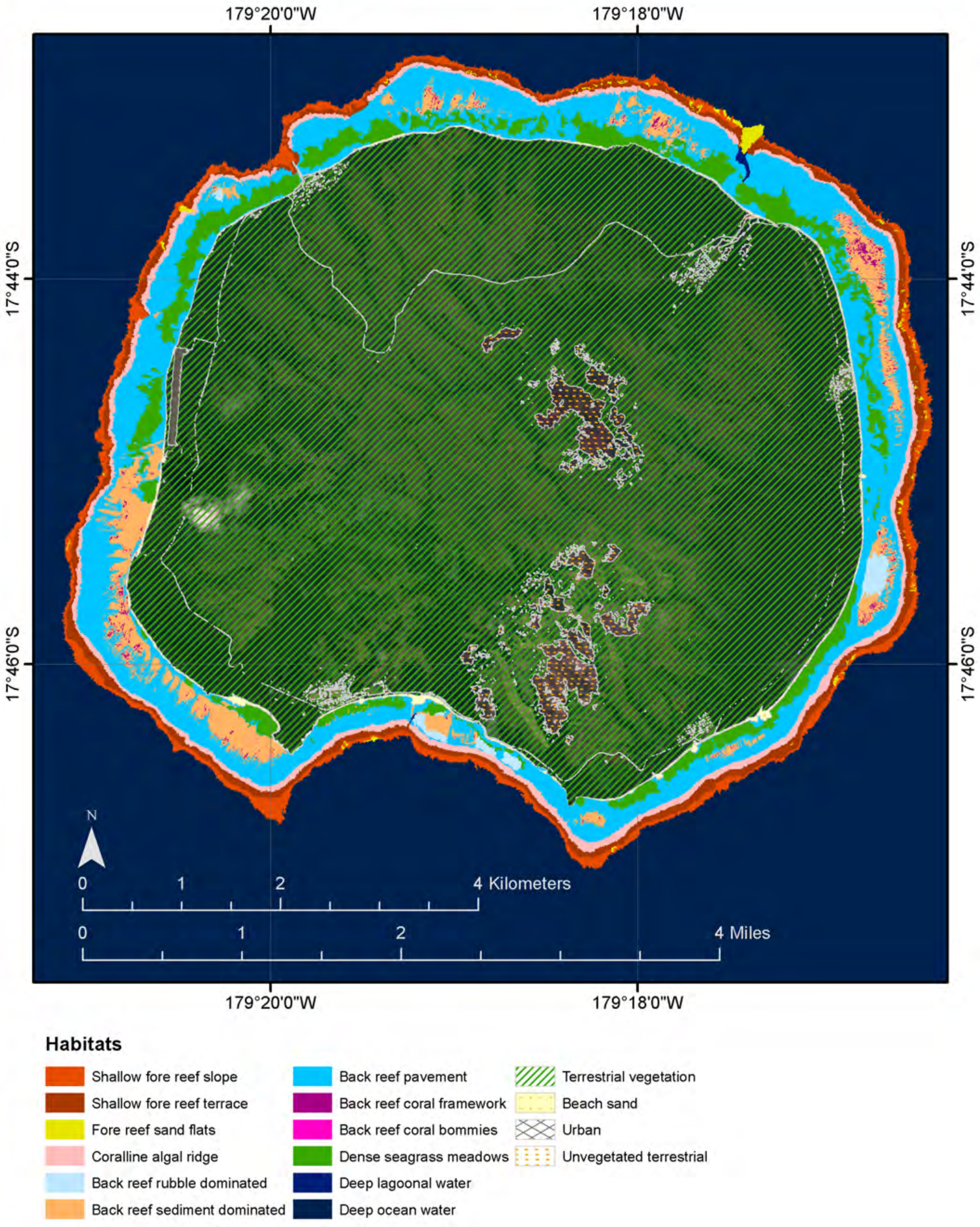


Fig. 58. Habitat map for Cicia.

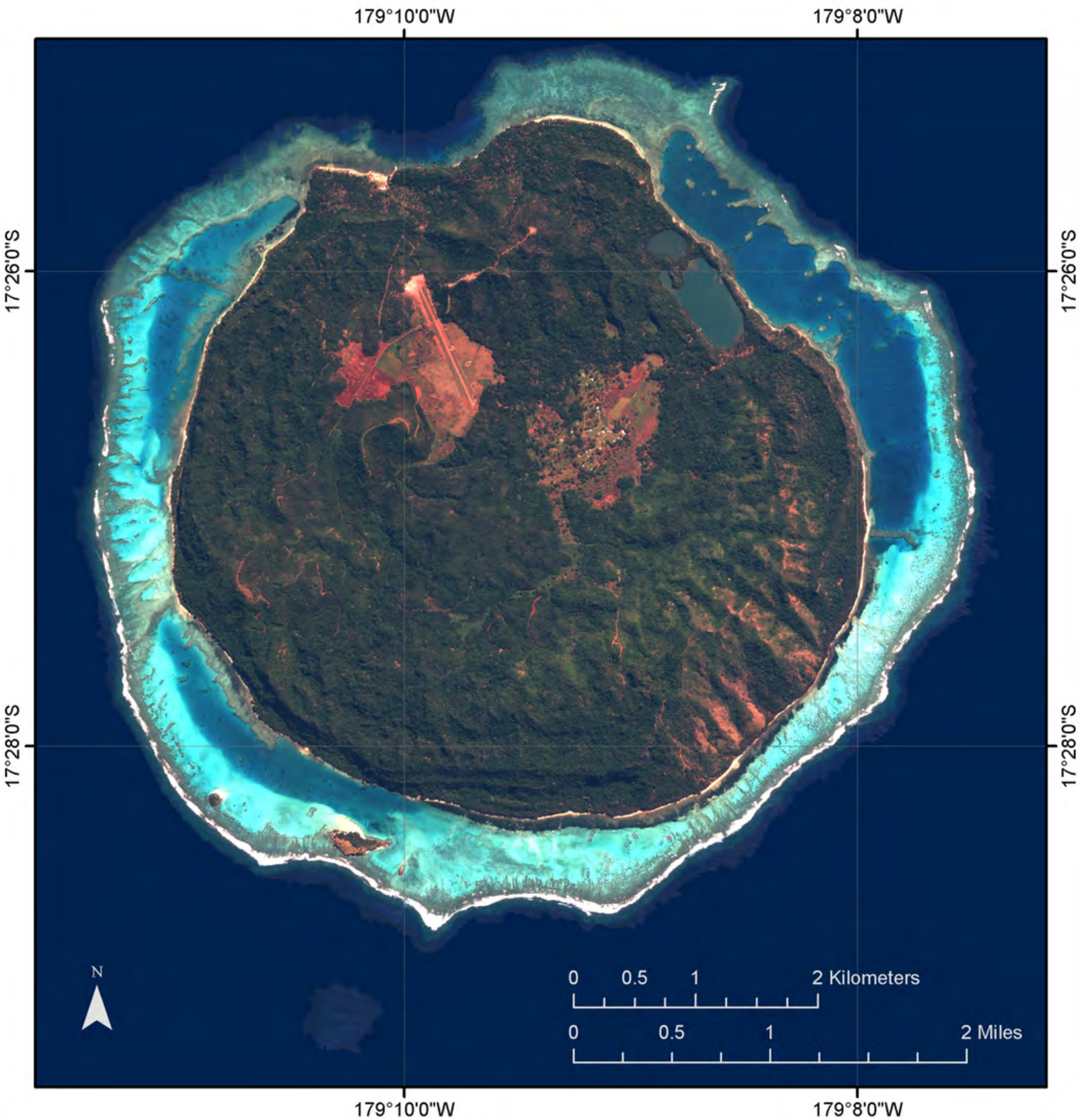


Fig. 59. WorldView-2 Satellite imagery for Mago.

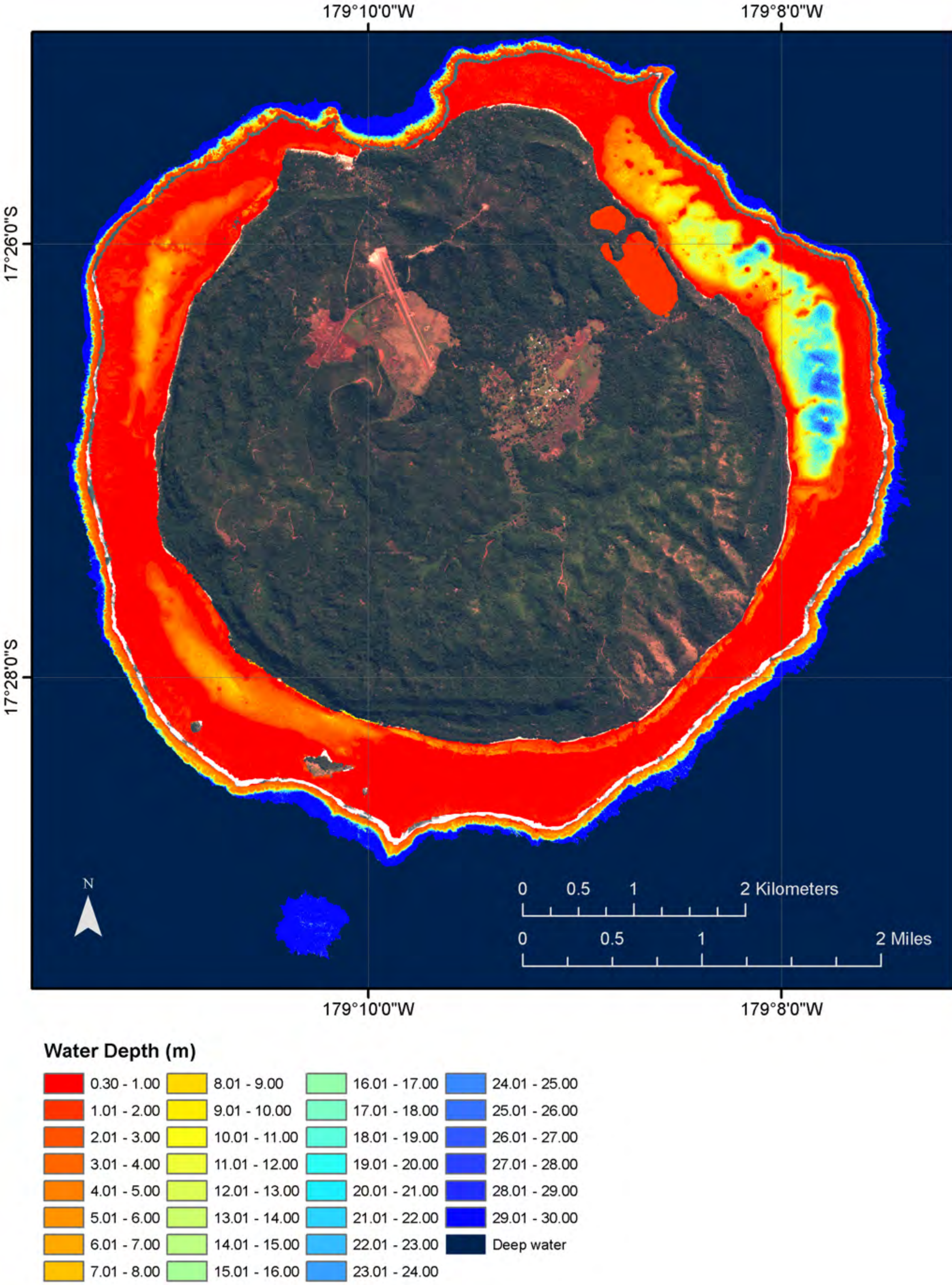


Fig. 60. Bathymetric map for Mago .

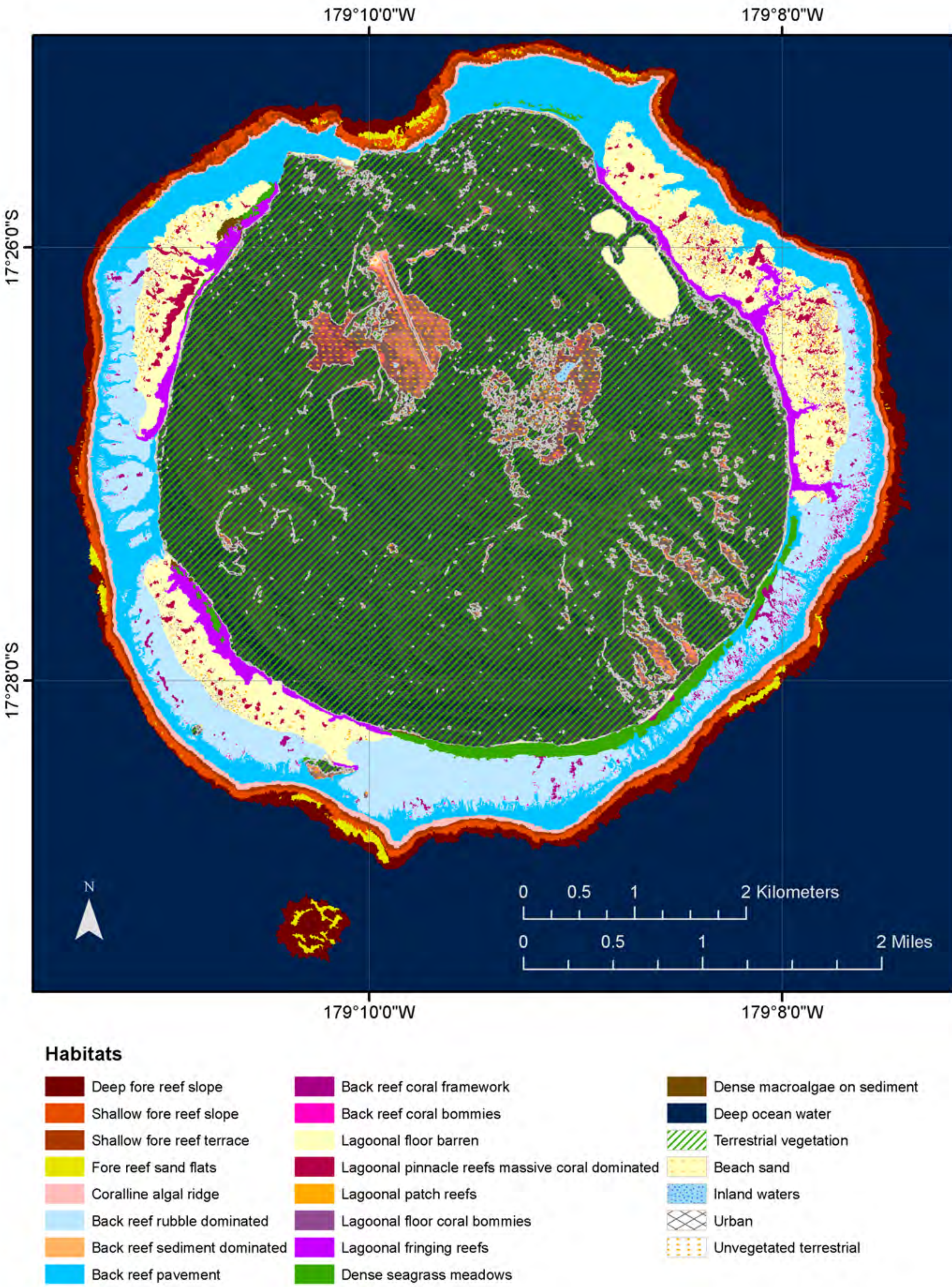


Fig. 61. Habitat map for Mago.

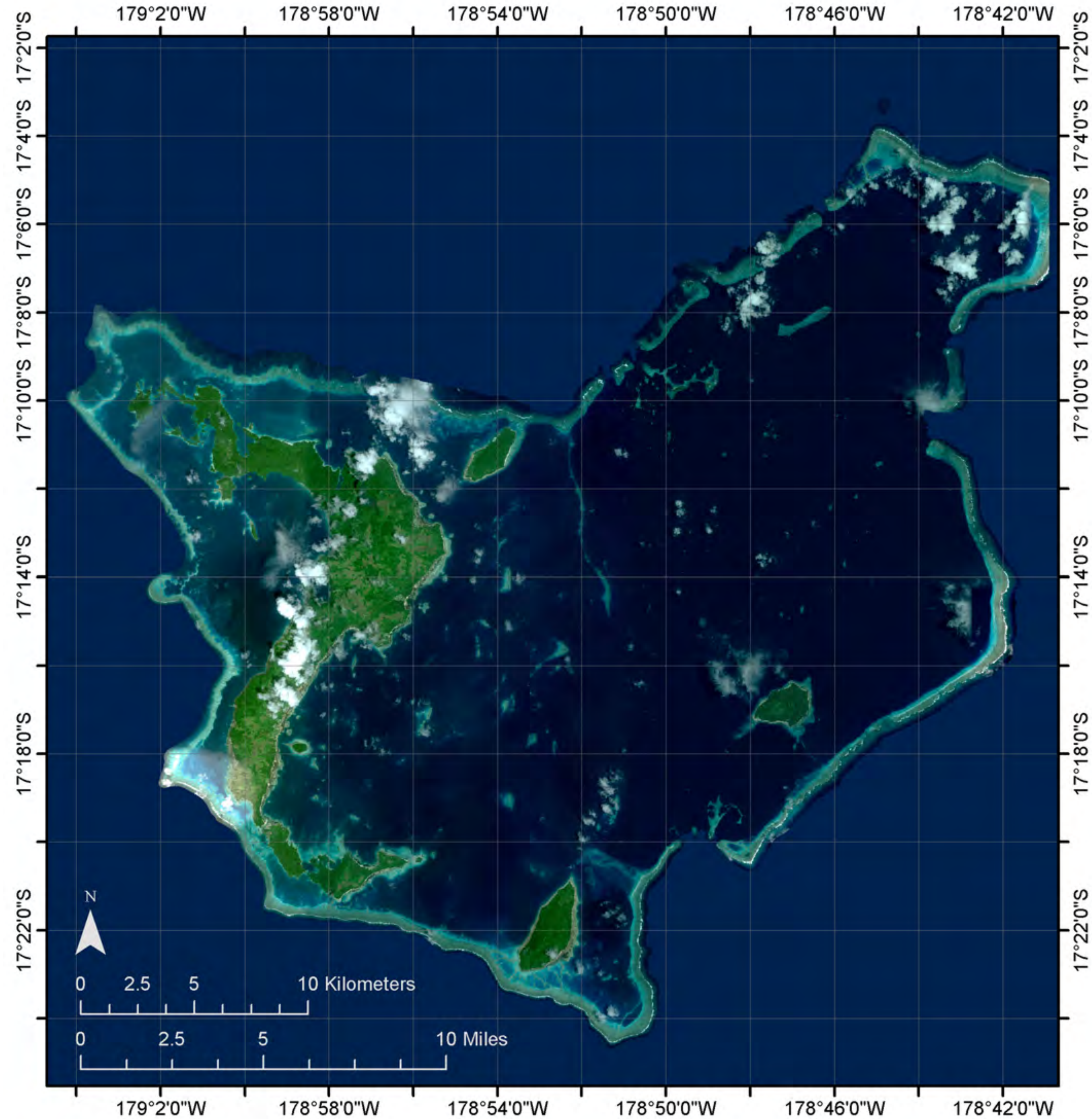


Fig. 62. WorldView-2 Satellite imagery for Vanua Balavu.

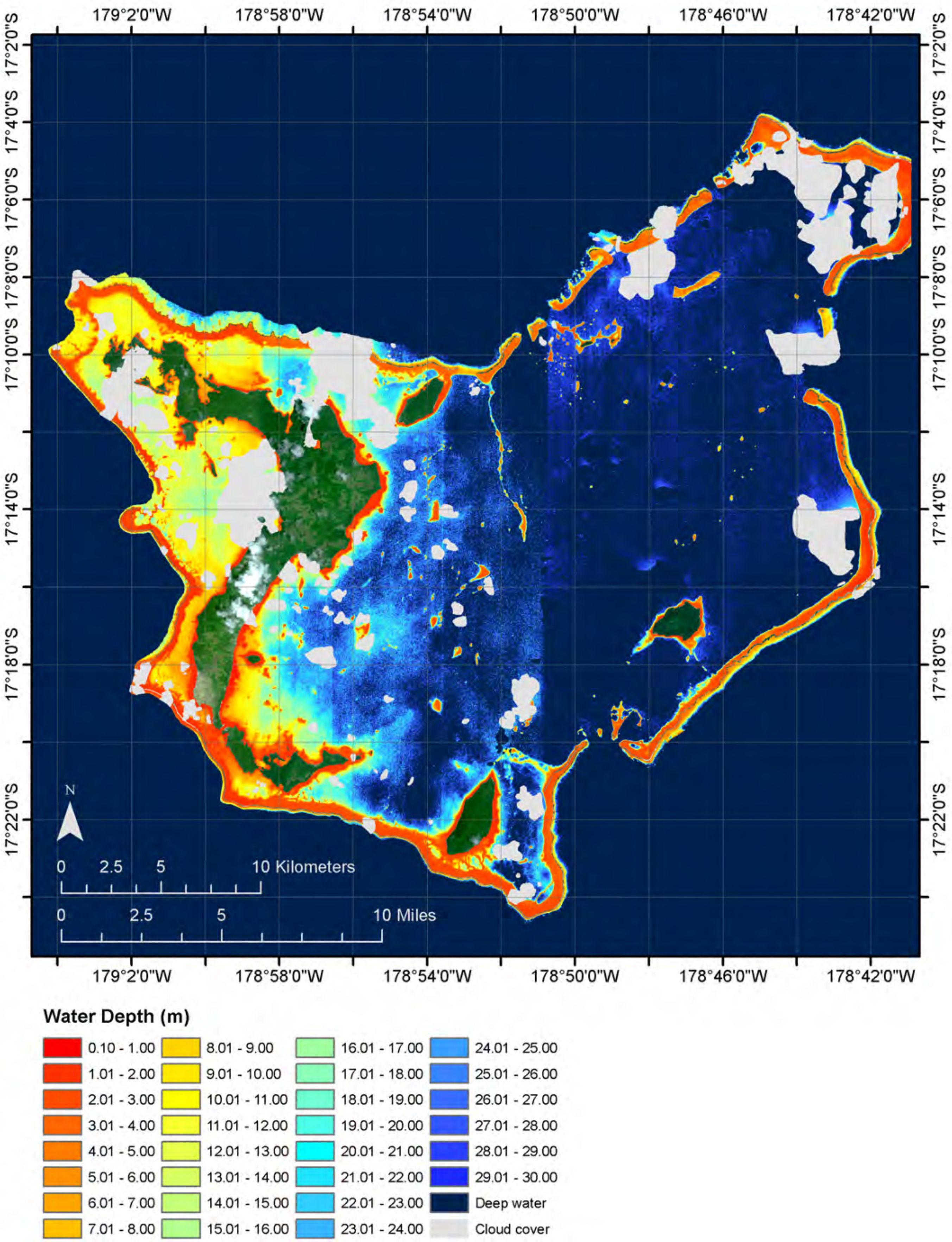


Fig. 63. Bathymetric map for Vanua Balavu.

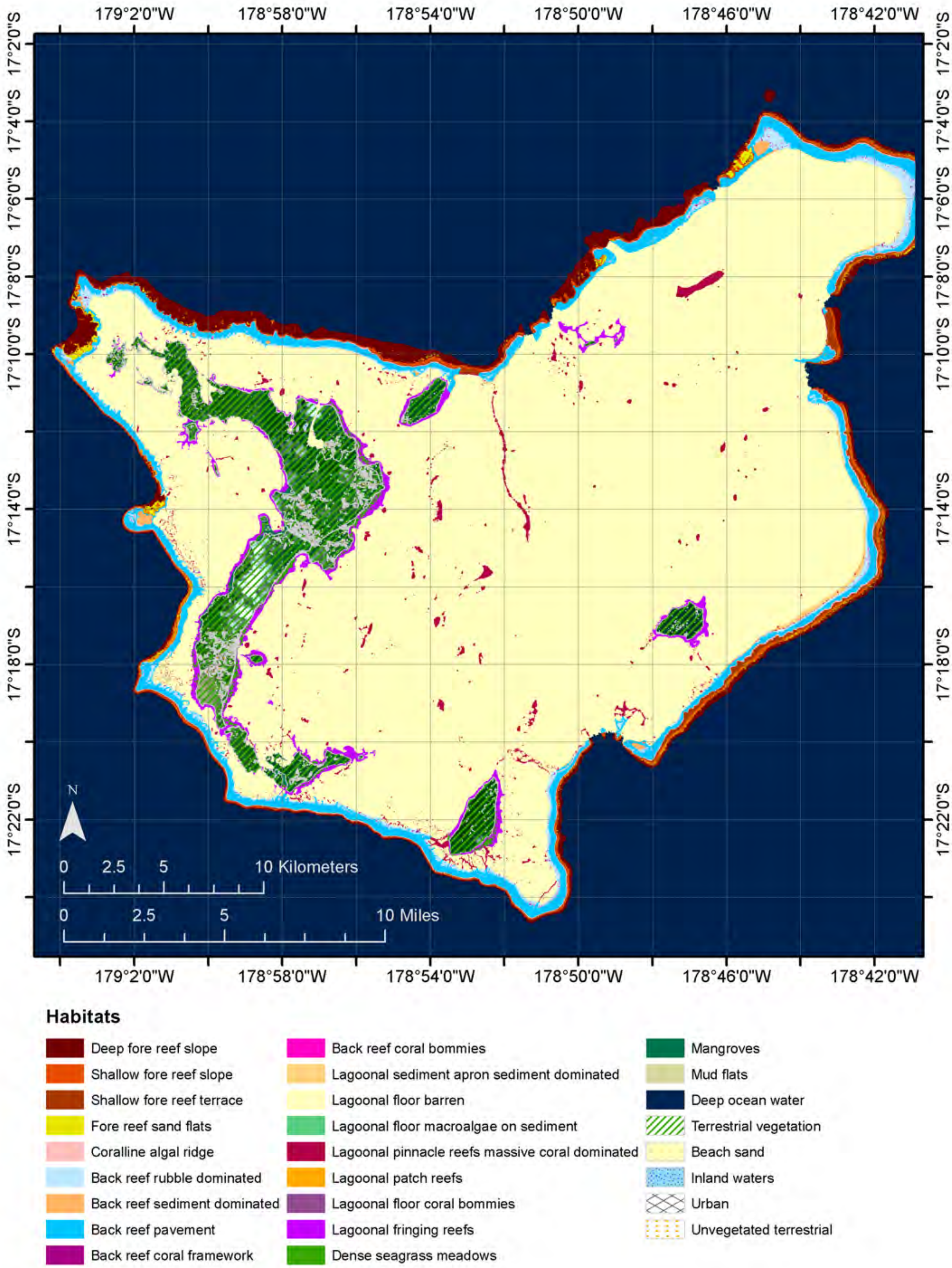


Fig. 64. Habitat map for Vanua Balavu.

Coral Reef Surveys

Fish Assessments

For fish, abundance and size structure was collected for over 450 species of fishes (Appendix 1), with an emphasis on species that have a major functional role on reefs or are major fisheries targets. Reef fishes were assessed along 4 m X 30 m belt transects. A T square marked in 5 cm increments was used to gauge fish size. A minimum of two transects per depth category and 6 transects per site were conducted by the "fish" dive team. A roving survey was also completed to document additional species that were not seen within belt transects.

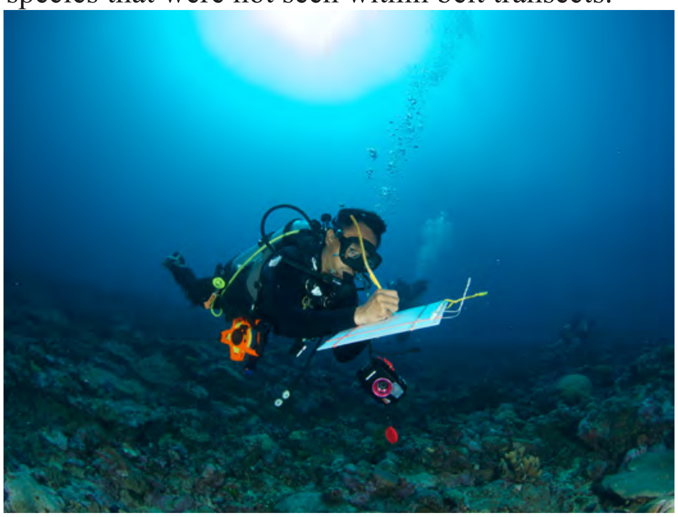


Fig. 65. A diver conducting a fish survey. The transect tape is attached to the divers BC and the end is secured to the bottom to gauge 30 m distance.

Biomass (kg) was determined by estimating body mass of each individual fish using length-weight relationships ($W=aL^b$). Constants (a, b) were obtained from Fishbase (www.fishbase.org). Each species was grouped into one of seven functional guilds (benthic carnivores, corallivores, herbivores, piscivores, planktivores, omnivores or others) and into an indicator category (targeted, target and indicator (i.e., corallivore), major (i.e., still of ecological or trophic significance) or minor (reduced ecological significance)) using published literature (e.g., summarized in Rotjan and Lewis, 2008; Barneche et al., 2009; Bruckner and Bruckner, 2015) and information obtained from Fishbase. Mean values (± standard error; SE) for fish biomass and density were calculated for each island, genus and functional guild per 100 m^2. To examine size structure, fish were pooled into eight size class bins. These bins increased by increments of 10 cm, excluding the bin for fish less than 5 cm, those exceeding 100 cm and fish from 6 and 10 cm.

Benthic cover

Cover of major functional groups (corals identified to genus, other invertebrates identified to phylum or class, and six groups of algae including macroalgae, crustose coralline algae, erect coralline algae, fine turfs, turf algae with sediment, and cyanobacteria) and substrate type (hardground, sand, loose rubble, fused rubble, recently dead coral, bleached coral, and live coral) were assessed along 10 m transects using recorded observations and/or photographic assessments. Recorded observations involved a point intercept method, whereas the organism and substrate was identified every 10 cm along a 10 m transect (total 100 points/transect), with a minimum of six transects examined per location. When possible, surveys were completed at 30, 25, 20, 15, 10 and 5 m depth.

Fig. 66. A diver conducting a benthic assessment. A ten meter lead line, subdivided into 10 cm intervals is deployed along the bottom. The diver records the substrate type and organism under each 10 cm point.

Coral assessments

A combination of quantitative methods including: belt transects, point intercept transects, radial plots and quadrats were used to assess corals, fish and other benthic organisms. Five measures were recorded for corals: 1) benthic cover (point intercept, see above); 2) coral diversity and abundance (by genus, except certain common species); 3) coral size class distributions; 4) recruitment; and 5) coral condition. Additional information was collected on causes of recent mortality, including signs of coral disease and

Fig. 67. A diver conducting a coral assessment. A 10 m lead line is deployed and all corals within 1 m of the line are identified and measured. A 1 m PVC pipe, is used to determine the proper width of the line and to aid in measurement of the corals.

Assessment of corals smaller than 4 cm was achieved by using a minimum of five 0.25 m^2 quadrats per transect, with each quadrat located at fixed, predetermined intervals (e.g. 2, 4, 6, 8, 10 m), alternating between the right and left side of the transect line. Recruits were identified in both point intercept surveys and belt transects. Recruits were divided into two categories: corals up to 2 cm diameter and larger corals, 2-3.9 cm diameter.

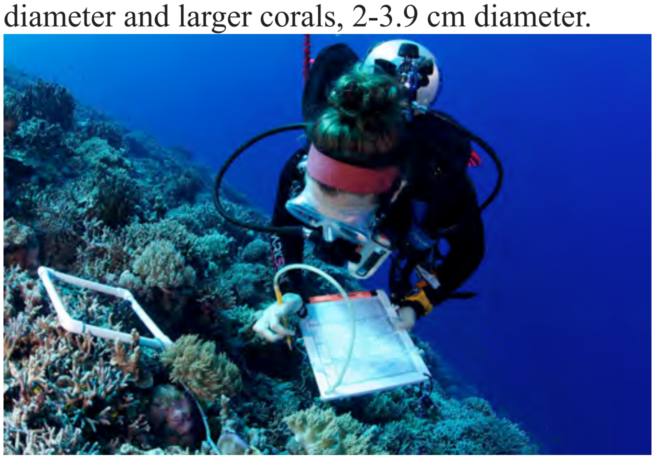


Fig. 68. Assessing recruits within a 25 X 25 cm quadrat.

Fig. 69. A small section of reef substrate (approx 15 cm x 20 cm) illustrating patterns of colonization. The substrate is colonized by turf algae, crustose coralline algae, macroalgae, cyanobacteria and four coral recruits (red circles).

Coral population structure and condition was assessed within belt transects (each 10 m x 1 m), with a minimum of two transects completed per depth. Each coral, 4 cm or larger was identified (to genus at minimum) and its growth form was recorded. Visual estimates of tissue loss were recorded for each colony over 4 cm in diameter using a 1 m bar marked in 1 cm increments for scale. If the coral exhibited tissue loss, estimates of the amount of remaining tissue, percent that recently died and percent that died long ago were made based on the entire colony surface. Tissue loss was categorized as recent mortality (occurring within the last 1-5 days), transitional mortality (filamentous green algae and diatom colonization, 6-30 days) and old mortality (>30 days).

For each coral with partial or whole colony mortality, the cause of mortality is identified if possible. The diagnosis included an assessment of the type of disease, extent of bleaching, predation, competition, overgrowth or other cause of mortality. Each coral was first carefully examined to identify cryptic predators. Lesions were initially diagnosed into four categories: recent tissue loss, skeletal damage, color change, and unusual growth patterns; an individual colony could have multiple characteristics (e.g. color change and recent tissue loss). The location (apical, basal, and medial) and pattern of tissue loss (linear, annular, focal, multifocal, and coalescing) was recorded and when possible a field name was assigned. If an outbreak of coral disease was documented, sampling of the affected corals was undertaken to further characterize the disease (see below).

Fig. 70. A colony of Diploastrea with white syndrome. The coral is about 30% live, with a narrow band of exposed skeleton (recently mortality) and a larger patch of long dead algal colonized skeleton.

Photographic assessment

Belt transects, 1 m x 10 m were photographed along depth gradients to supplement in situ recorded benthic and coral data. One scientist extended a 10 m long lead line along depth contours at 30, 20, 15, 10 and 5 m depth. The line was marked with cable ties at 10 cm intervals. Continuous digital still photographs were taken of the reef substrate from a height of approximately 0.6-0.75 meters above the substrate, using a one meter bar divided into 5 cm increments placed perpendicular to the transect tape as a scale bar. Approximately 20 photographs were taken per transect to allow for overlap between adjacent images with two photo transects (each 10 m in length) per depth. A second scientist used a 1 m x 1 m quadrat, flipping over the quadrat a total of 10 times per transect.

Images were downloaded and analyzed using Coral Point Count (CPCE) software developed by the National Coral Reef Institute (NCRI). To determine benthic community composition, coral cover, cover of other algae and other invertebrates and cover of different substrate types a total of 50 points were randomly placed on each 1 m x 1 m image and the attribute directly below the point was recorded. The coral community structure was also assessed within the same transects to determine the size (planar surface area), amount of partial mortality and condition. Planar surface area was measured by tracing the outline of individual corals.

Fig. 71. A diver photographing a 1 m X 1 m quadrat.

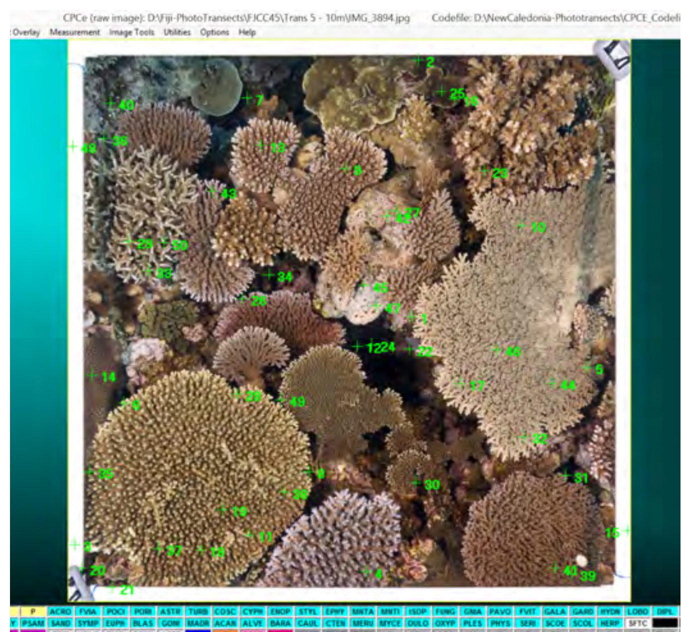


Fig. 72. Example of one 1 m X 1 m quadrat photographed on a reef in Fiji and imported into CPCE. 50 random points have been placed on the image.

Date	Lat	Long	Site name	Island	Reef zone	Reef type	Exposure
3-Jun-13	-18.996	-179.9032	FJTO01	Totoya	back reef	barrier reef	leeward
3-Jun-13	-18.9728	-179.9068	FJTO02	Totoya	fore reef	barrier reef	leeward
3-Jun-13	-18.9273	-179.8907	FJTO03	Totoya	fore reef	barrier reef	leeward
4-Jun-13	-18.8886	-179.8677	FJTO04	Totoya	fore reef	barrier reef	windward
4-Jun-13	-18.8981	-179.8836	FJTO05	Totoya	fore reef	barrier reef	leeward
4-Jun-13	-18.9976	-179.8473	FJTO06	Totoya	channel	patch reef	currents/swell
5-Jun-13	-19.0032	-179.8485	FJTO07	Totoya	fore reef	barrier reef	leeward
5-Jun-13	-19.023	-179.8808	FJTO08	Totoya	fore reef	barrier reef	leeward
5-Jun-13	-18.9082	-179.7864	FJTO09	Totoya	fore reef	barrier reef	windward
6-Jun-13	-19.1178	179.7382	FJMT10	Matuka	fore reef	barrier reef	leeward
6-Jun-13	-19.1585	179.7304	FJMT11	Matuka	fore reef	barrier reef	leeward
6-Jun-13	-19.1534	179.7401	FJMT12	Matuka	back reef	patch reef	leeward
7-Jun-13	-19.1172	179.7783	FJMT13	Matuka	fore reef	barrier reef	windward
7-Jun-13	-19.129	179.7866	FJMT14	Matuka	fore reef	barrier reef	windward
8-Jun-13	-18.5919	179.97308	FJML15	Moala	fore reef	barrier reef	windward
8-Jun-13	-18.5204	179.96562	FJML16	Moala	fore reef	barrier reef	leeward
8-Jun-13	-18.5325	179.92	FJML17	Moala	fore reef	patch reef	leeward
9-Jun-13	-18.5461	179.9013	FJML18	Moala	fore reef	patch reef	leeward
9-Jun-13	-18.5794	179.8201	FJML19	Moala	fore reef	barrier reef	leeward
9-Jun-13	-18.5577	179.8785	FJML20	Moala	fore reef	barrier reef	leeward
10-Jun-13	-18.5972	179.9337	FJML21	Moala	back reef	patch reef	leeward
10-Jun-13	-18.6168	179.9389	FJML22	Moala	fore reef	barrier reef	windward
10-Jun-13	-18.5575	179.9851	FJML23	Moala	fore reef	barrier reef	windward
11-Jun-13	-19.124	-178.548	FJFU24	Fulaga	lagoonal	back reef	leeward
11-Jun-13	-19.094	-178.5809	FJFU25	Fulaga	fore reef	barrier reef	windward
11-Jun-13	-19.1011	-178.6011	FJFU26	Fulaga	fore reef	barrier reef	leeward
12-Jun-13	-19.1299	-178.6174	FJFU27	Fulaga	fore reef	barrier reef	leeward
12-Jun-13	-19.1411	-178.5706	FJFU28	Fulaga	lagoonal	patch reef	leeward
12-Jun-13	-19.1184	-178.5918	FJFU29	Fulaga	lagoonal	patch reef	leeward
13-Jun-13	-18.9414	-178.9847	FJKA30	Kabara	fore reef	barrier reef	leeward
13-Jun-13	-18.9194	-178.9577	FJKA31	Kabara	fore reef	pinnacles	leeward
13-Jun-13	-18.9136	-178.9455	FJKA32	Kabara	fore reef	barrier reef	windward
14-Jun-13	-18.9545	-178.9874	FJKA33	Kabara	fore reef	barrier reef	leeward
14-Jun-13	-18.9228	-178.9363	FJKA34	Kabara	fore reef	barrier reef	windward
15-Jun-13	-18.3864	-179.2786	FJVV35	Vanua Vatu	fore reef	barrier reef	swellward
15-Jun-13	-18.3439	-179.2803	FJVV36	Vanua Vatu	fore reef	barrier reef	leeward
15-Jun-13	-18.3584	-179.2847	FJVV37	Vanua Vatu	fore reef	barrier reef	leeward
16-Jun-13	-17.9512	-179.067	FJNA38	Nayau	fore reef	barrier reef	leeward
16-Jun-13	-17.9569	-179.0723	FJNA38SN	Nayau	fore reef	reef flat	leeward
16-Jun-13	-17.9759	-179.0767	FJNA39	Nayau	fore reef	fringing reef	leeward
16-Jun-13	-17.9651	-179.0789	FJNA40	Nayau	fore reef	barrier reef	leeward
17-Jun-13	-17.6498	-178.8354	FJTV41	Tuvuca	fore reef	barrier reef	leeward
17-Jun-13	-17.7041	-178.8291	FJTV42	Tuvuca	fore reef	barrier reef	leeward
17-Jun-13	-17.6935	-178.8325	FJTV43	Tuvuca	fore reef	barrier reef	leeward
18-Jun-13	-17.7167	-179.3243	FJCC44	Cicia	fore reef	barrier reef	leeward
18-Jun-13	-17.7238	-179.3386	FJCC45	Cicia	fore reef	barrier reef	leeward
18-Jun-13	-17.7265	-179.3408	FJCC46	Cicia	fore reef	barrier reef	leeward

Table. 6. Coordinates, reef zone, reef type and exposure for survey locations examined in Lau Province, Fiji.

Date	Lat	Long	Site name	Island	Reef zone	Reef type	Exposure
19-Jun-13	-17.7671	-179.3491	FJCC47	Cicia	fore reef	barrier reef	windward
19-Jun-13	-17.7498	-179.3841	FJCC48	Cicia	fore reef	barrier reef	leeward
20-Jun-13	-17.4785	-179.1672	FJMG49	Mago	fore reef	barrier reef	windward
20-Jun-13	-17.4639	-179.1877	FJMG50	Mago	fore reef	barrier reef	leeward
20-Jun-13	-17.4249	-179.1655	FJMG51	Mago	fore reef	fringing reef	leeward
21-Jun-13	-17.3028	-179.0309	FJVB52	Vanua Balavu	fore reef	barrier reef	leeward
21-Jun-13	-17.1394	-179.0600	FJVB53	Vanua Balavu	fore reef	barrier reef	leeward
21-Jun-13	-17.2376	-179.0386	FJVB54	Vanua Balavu	fore reef	barrier reef	leeward
22-Jun-13	-17.1534	-179.0049	FJVB55	Vanua Balavu	fore reef	barrier reef	leeward
22-Jun-13	-17.1395	-179.0599	FJVB56	Vanua Balavu	fore reef	barrier reef	leeward
22-Jun-13	-17.1715	-178.8871	FJVB57	Vanua Balavu	fore reef	barrier reef	leeward
22-Jun-13	-17.196	-178.8707	FJVB58	Vanua Balavu	patch reef	lagoonal	leeward
22-Jun-13	-17.2419	-178.8556	FJVB59	Vanua Balavu	patch reef	lagoonal	leeward
23-Jun-13	-17.1206	-178.8265	FJVB60	Vanua Balavu	fore reef	barrier reef	leeward
23-Jun-13	-17.1518	-178.8512	FJVB61	Vanua Balavu	fore reef	barrier reef	leeward
23-Jun-13	-17.2824	-178.9267	FJVB62	Vanua Balavu	patch reef	lagoonal	leeward
24-Jun-13	-17.2923	-178.8856	FJVB63	Vanua Balavu	patch reef	lagoonal	leeward
24-Jun-13	-17.2877	-178.9281	FJVB62B	Vanua Balavu	patch reef	lagoonal	leeward
24-Jun-13	-17.3364	-178.86	FJVB64	Vanua Balavu	linear reef	lagoonal	leeward
25-Jun-13	-17.3355	-178.8337	FJVB65	Vanua Balavu	back reef	barrier reef	windward
25-Jun-13	-17.3234	-178.8167	FJVB66	Vanua Balavu	patch reef	lagoonal	leeward
25-Jun-13	-17.2709	-178.7774	FJVB67	Vanua Balavu	back reef	fringing reef	windward
26-Jun-13	-17.1066	-178.6897	FJVB68	Vanua Balavu	patch reef	lagoonal	leeward
26-Jun-13	-17.0895	-178.7692	FJVB69	Vanua Balavu	fore reef	barrier reef	windward
26-Jun-13	-17.1352	-178.7775	FJVB70	Vanua Balava	patch reef	lagoonal	leeward

Table. 6. Coordinates, reef zone, reef type and exposure for survey locations examined in Lau Province, Fiji (cont.).

Fig. 72. A number of reefs had vertical drop-offs, overhangs, caves and canyons such as the two reefs shown here. Surveys were not conducted on vertical surfaces. Images by Anderson Mayfield.

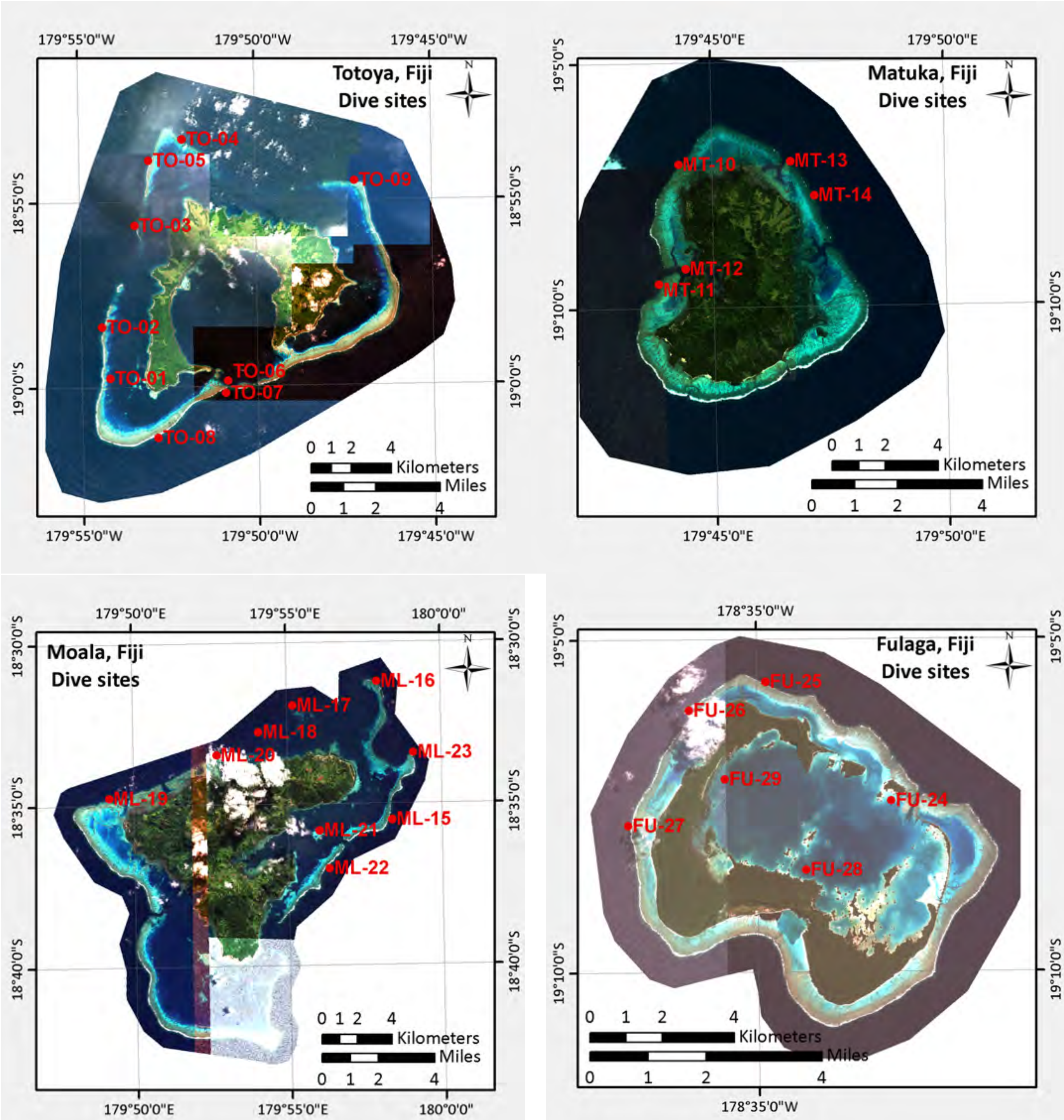


Fig. 73. Location of SCUBA assessments off Totoya, Matuka, Moala and Fulaga, Fiji.

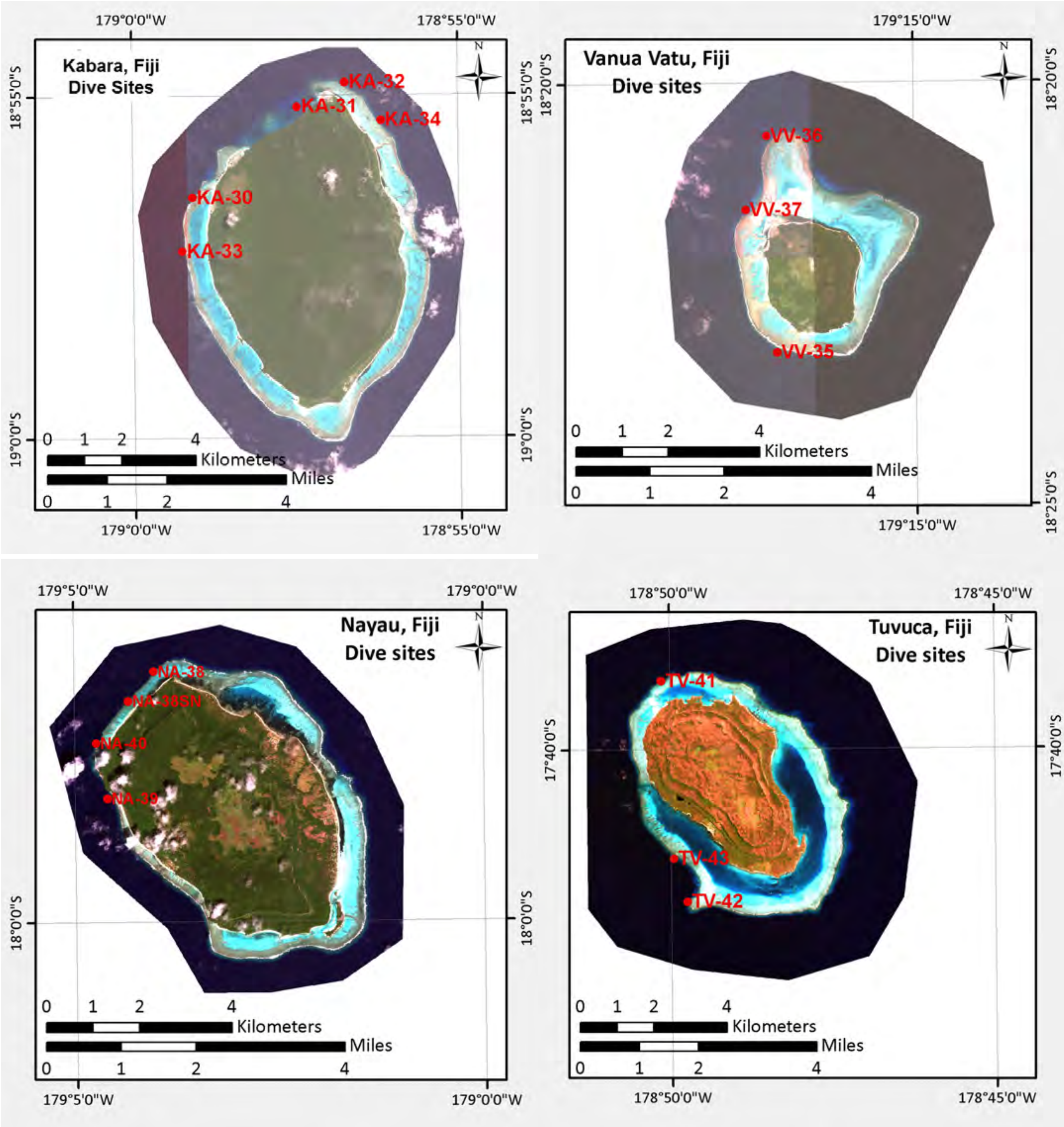


Fig. 74. Location of SCUBA assessments off Kabara, Vanua Vatu, Nayau and Tuvuca, Fiji.

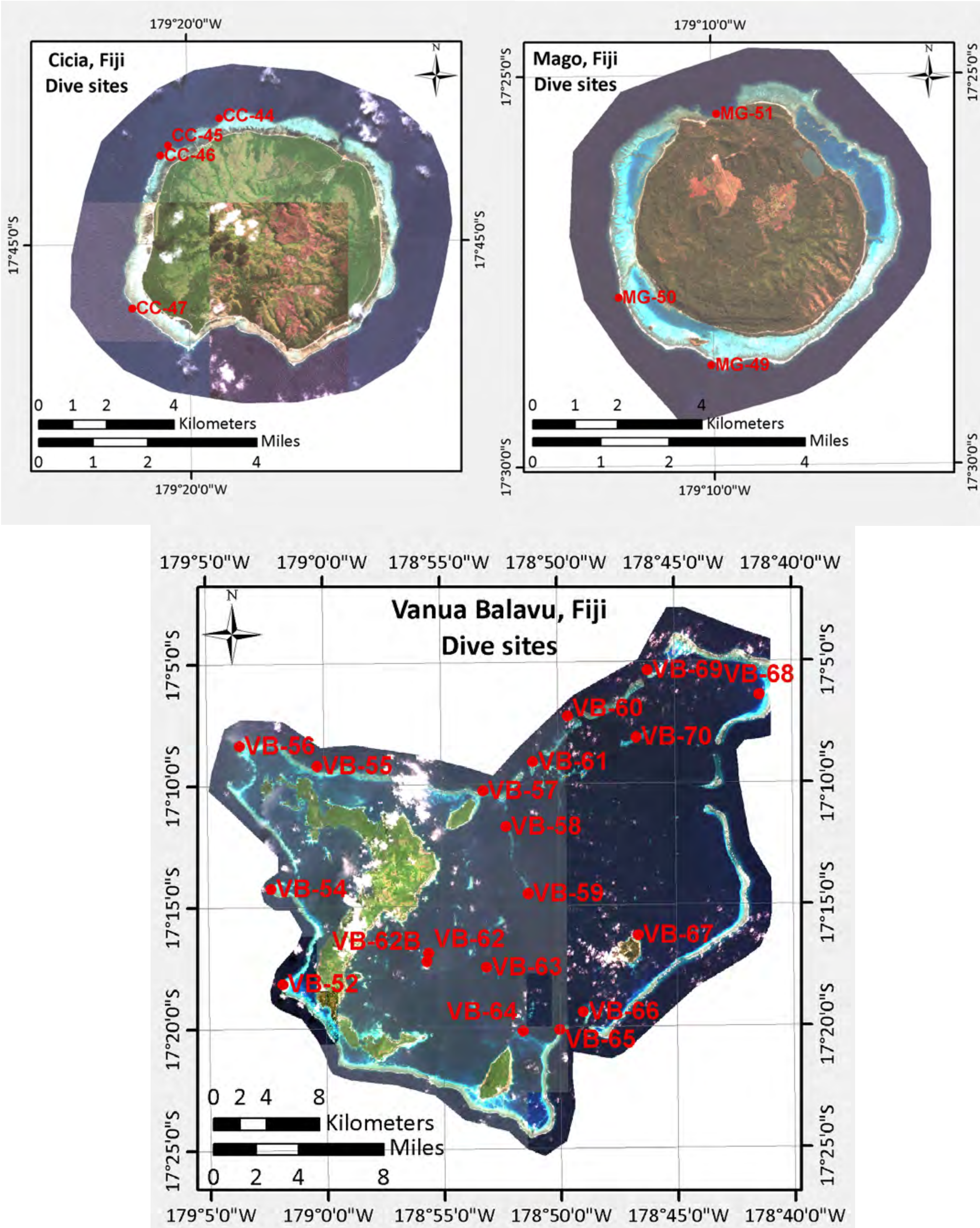


Fig. 75. Location of SCUBA assessments off Cicia, Mago and Vanua Balavu, Fiji.

Substrate composition and cover

During benthic surveys, substrates in coral reef environments were classified as pavement (hard bottom), live coral, dead coral, fused rubble, loose rubble and sand. The majority of the bottom was pavement (41-61% cover) and live coral (22-50% cover). Benthic cover of rubble (predominantly loose, unconsolidated rubble) ranged from 2.8-11% with the highest amount of rubble at Tuvuca (11.2%), Vanua Balavu (8.6%), Matuka (6.8%) and Totoya (5.9%). Dead coral covered approximately 5% of the substrate with the lowest cover at Vanua Vatu (1.4%) and Kabara (2.3%) (Fig. 76).

An examination of substrate data, pooled by depth for all sites and islands suggests that the percent cover of different substrate types was very similar among depths (Fig. 77). However, closer examination by island suggests that there is variation between depths, and also among sites within an island and between depths at an individual site (Fig 78).

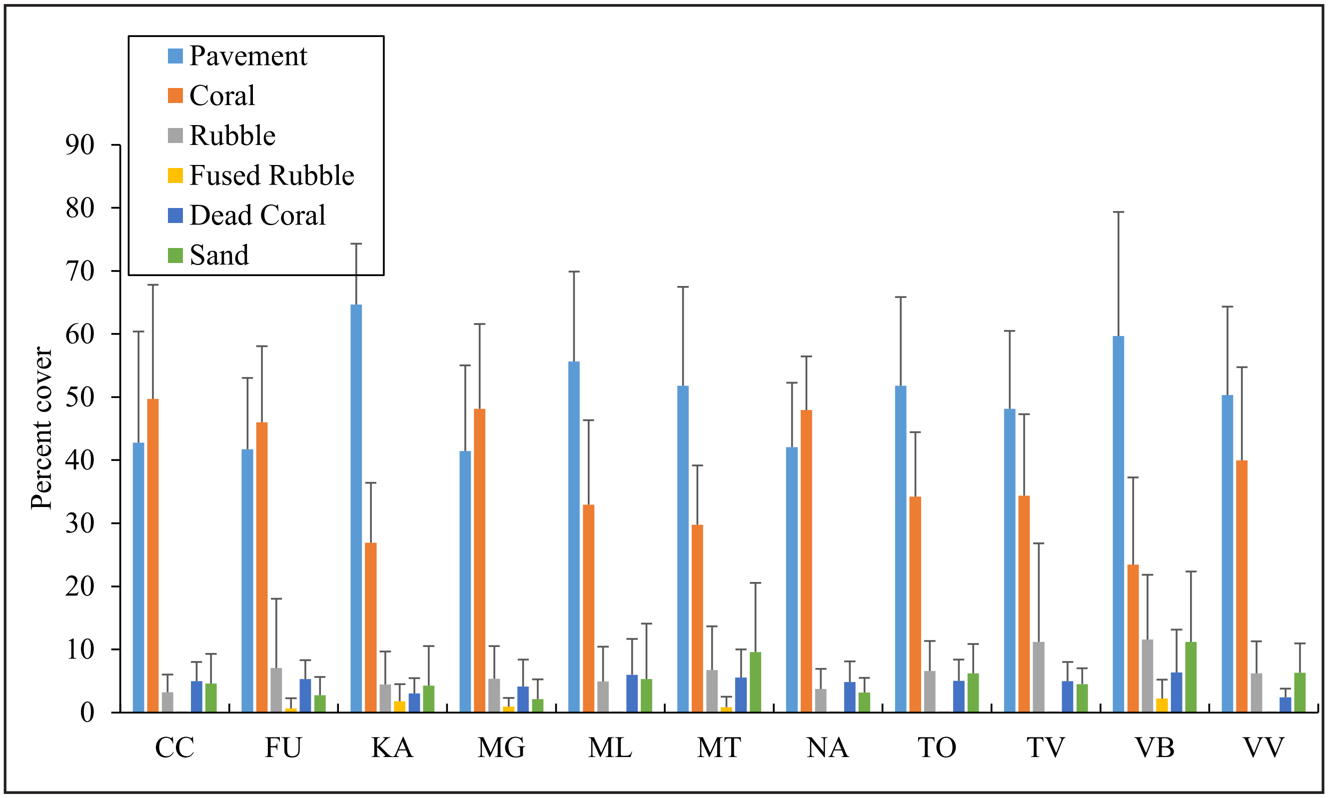


Fig. 76. Cover of different benthic substrates within reef habitats off 11 islands in Lau Province, Fiji. Substrate types were subdivided into pavement (hard bottom), loose rubble, fused rubble, sand, live coral and dead coral. Data are pooled by island for all depths and reefs.

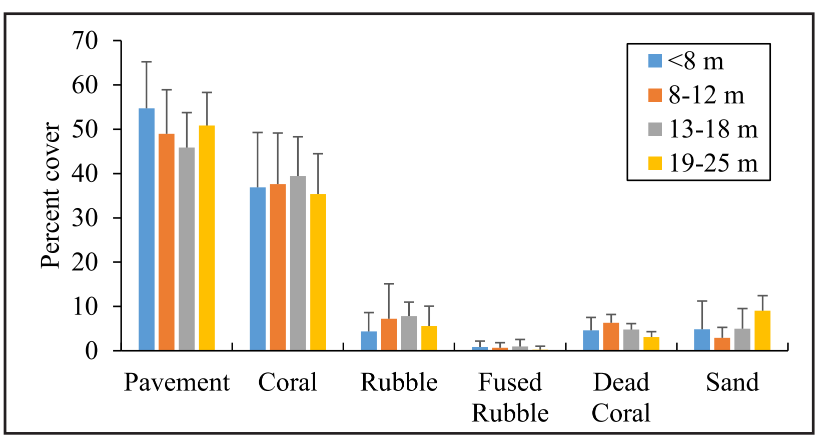
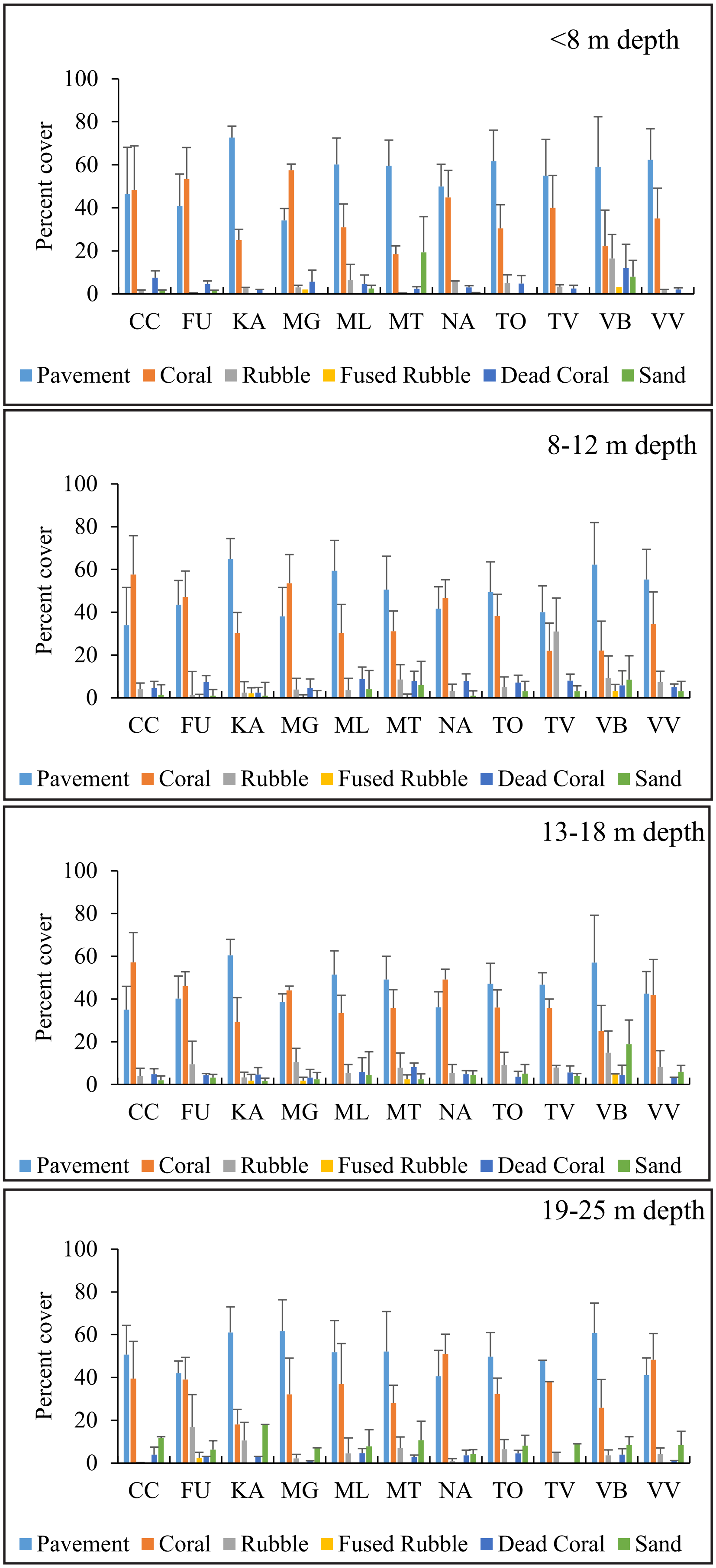


Fig. 77. Cover of different benthic substrates within reef habitats pooled for the 12 islands in Lau Province, Fiji into four depth classes, <8 m, 8-12 m, 13-18 m and 19-25 m.



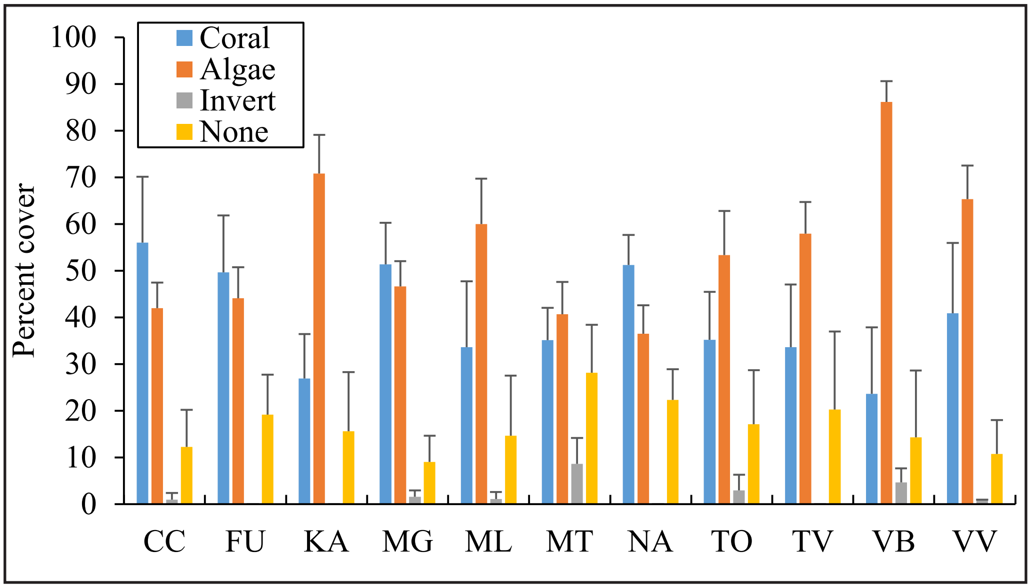
Of the six main substrate categories, pavement and live coral cover varied most among islands. The lowest mean coral cover and highest cover of pavement was record at Kabara (27% and 65% respectively) and Vanua Balavu (23% and 60%). Coral cover was highest at the shallowest survey sites (<8 m) at three islands (Fulaga, Mago, and Tuvuca), highest at mid depths (8-18 m) at Totoya, Matuka, Kabara and Cicia, and highest at the deepest depths (19-25 m) at Vanua Balavu, Vanua Vatu, Nayau, and Moala (Fig. 78).

Fig. 78. Cover of different benthic substrates within reef habitats off 12 islands in Lau Province, Fiji broken down by the four depth classes, <8 m, 8-12 m, 13-18 m and 19-25 m. Islands listed in the figures include: Cicia (CC), Fulaga (FU), Kabara (KA), Mago (MG), Moala (ML), Nayau (NA), Totoya (TO) Tuvuca (TV), Vanua Balavu (VB) and Vanua Vatu (VV).

Fig. 79. Many reefs had high cover of corals dominated by small to medium-sized table acroporids, especially on the tops of pinnacles as seen here.

Live Cover

Four main categories of cover were examined on reefs in Lau Province, coral, algae, other invertebrate and uncolonized substrate. Nearly 85% of the bottom was colonized by live organisms, while uncolonized substrate (15.8%) was predominantly small patches of sand between colonized pavement. Coral cover (mean= 36%) was slightly higher than algal cover on four islands, Cicia, Fulaga, Moala and Nayau. Algal cover ranged from 37-86% (mean=55%), with highest coverage at Vanua Balavu, Kabara, Vanua Vatu, Moala and Tuvuca, respectively. Other invertebrates made up a low portion of the total cover except at Matuka (8.7%) and Vanua Balavu (4.7%) (Fig. 80).



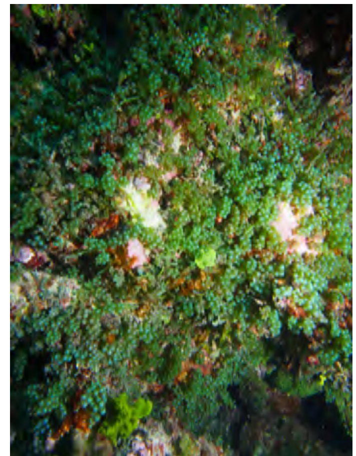


Fig. 81. Macroalgae often covered dead coral and rubble at the base of the reef.

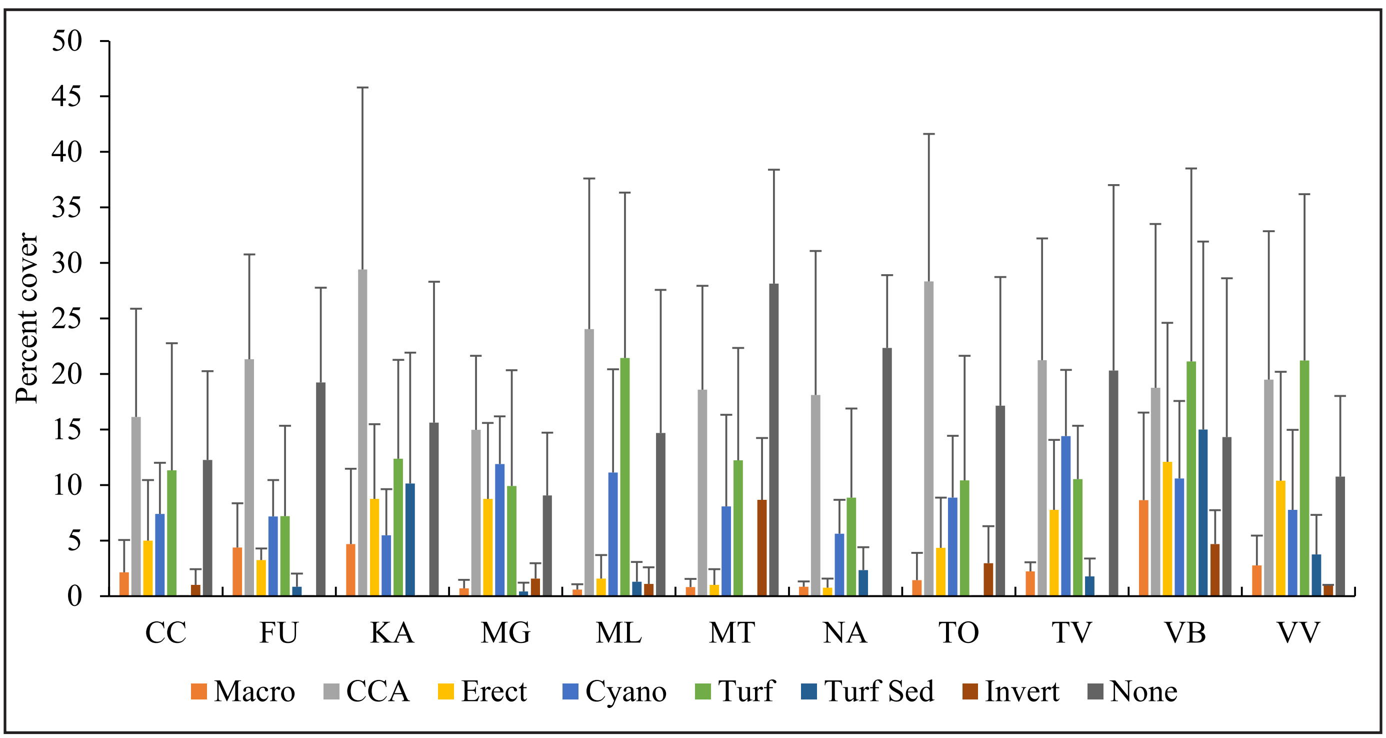


Fig. 80. Cover of living organisms and bare substrate at each of the 12 islands surveyed in the Lau Province, Fiji. Living organisms included six functional groups of algae: Macroalgae (M), turf algae (T), turf algae with sediment (TS), crustose coralline algae (CCA), erect coralline algae (E), and cyanobacteria (CY); stony corals, and other invertebrates. Bare substrate is recorded here as "none". Data are pooled for all depths and reefs examined in each island system.

Algal cover varied considerably among sites, depths and habitats. Some reefs had very dense patches of macroalgae, especially *Halimeda* and *Caulerpa*, but this tended to be on vertical slopes and at the base of the reef. In contrast, it was much less common on horizontal reef surfaces examined in this study occurring at a mean coverage of 4%. The highest cover of macroalgae was recorded at Vanua Balavu (8.6%), Kabara (4.7%) and Fulaga (4.3%), and all other sites having <3% cover. Turf algae ranged from 3-22% cover, with the highest cover at Moala, Vanua Balavu and Vanua Vatu (22%) and high cover of turf with sediment at Kabara (10.1%) and Vanua Balavu (15%), possibly due to the large number of lagoonal sites examined in this area. Most reefs had a high cover of CCA, with over 25% cover at Kabara, Totoya and Moala and the lowest at Cicia (16%) and Mago (15%). Cyanobacterial mats were

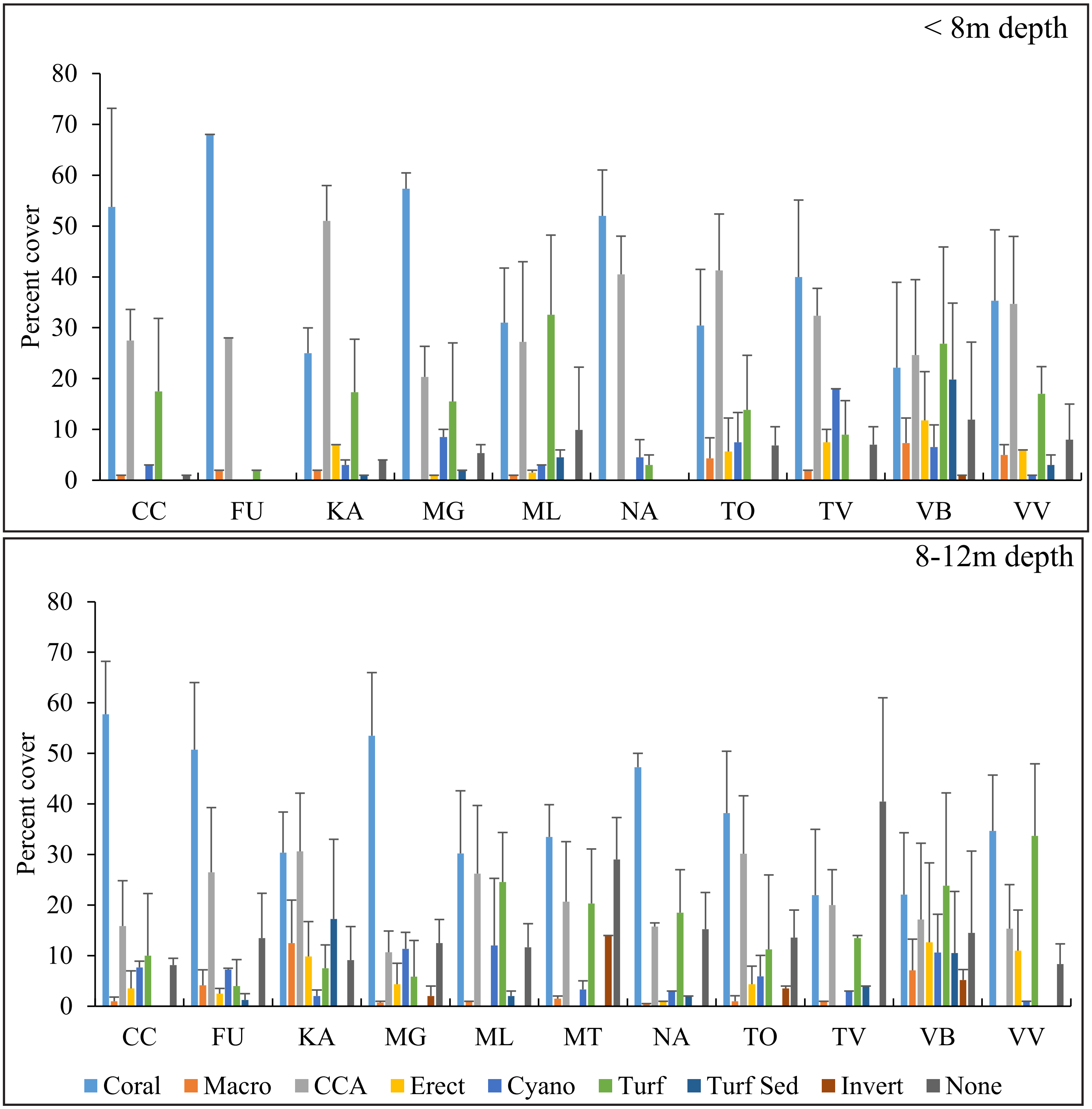
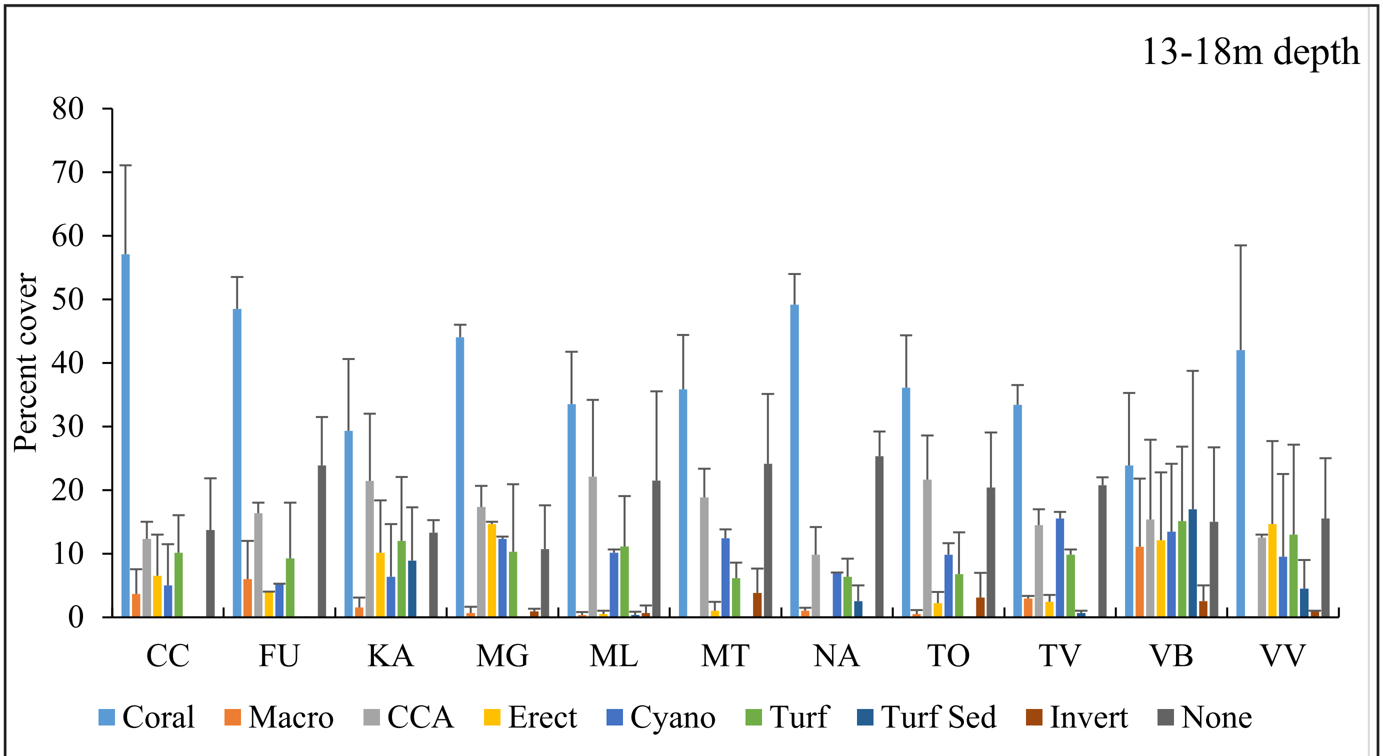
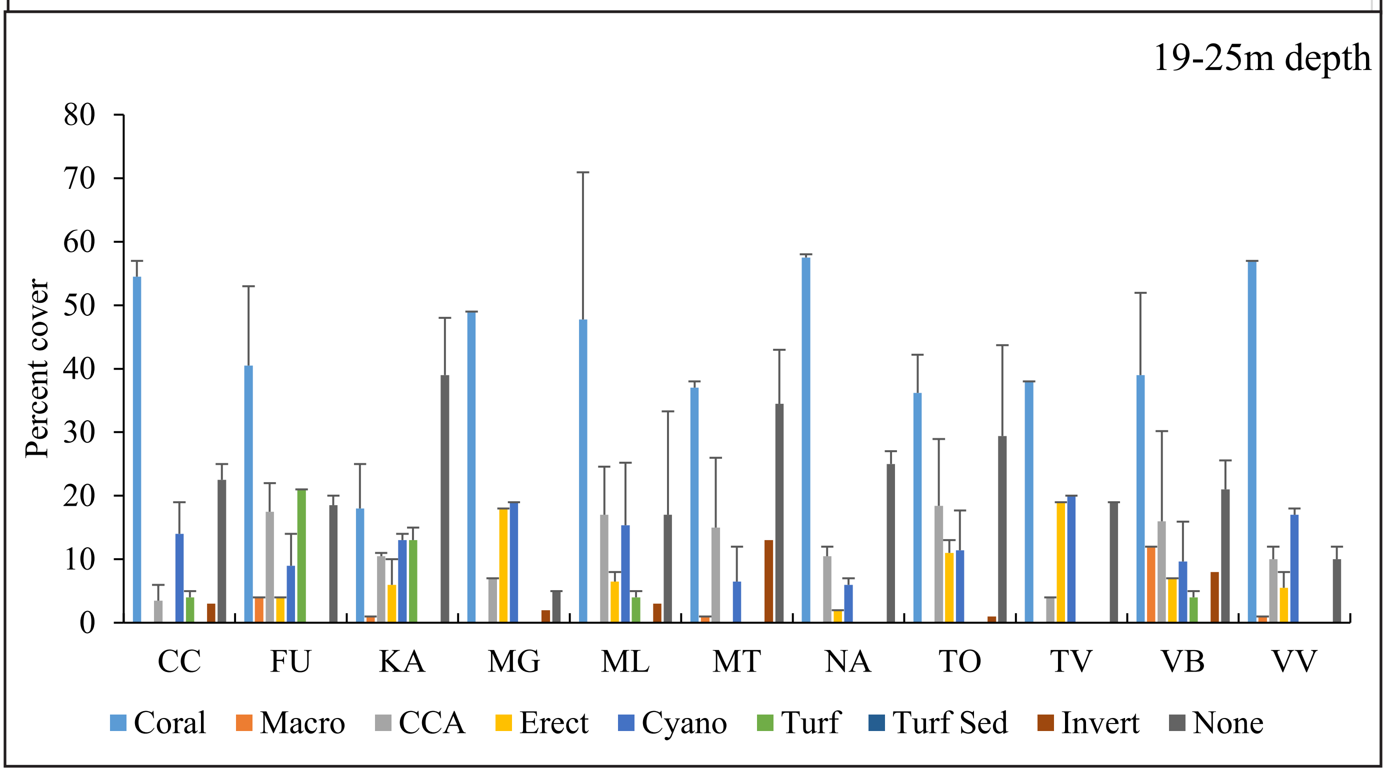


Fig. 82. Cover of living organisms and bare substrate at each of the 12 islands surveyed in the Lau Province, Fiji at different depth categories. <8m (top), 8-12 m (bottom), 13-18 m (top, page 83) and 19-25 m (bottom, page 83).



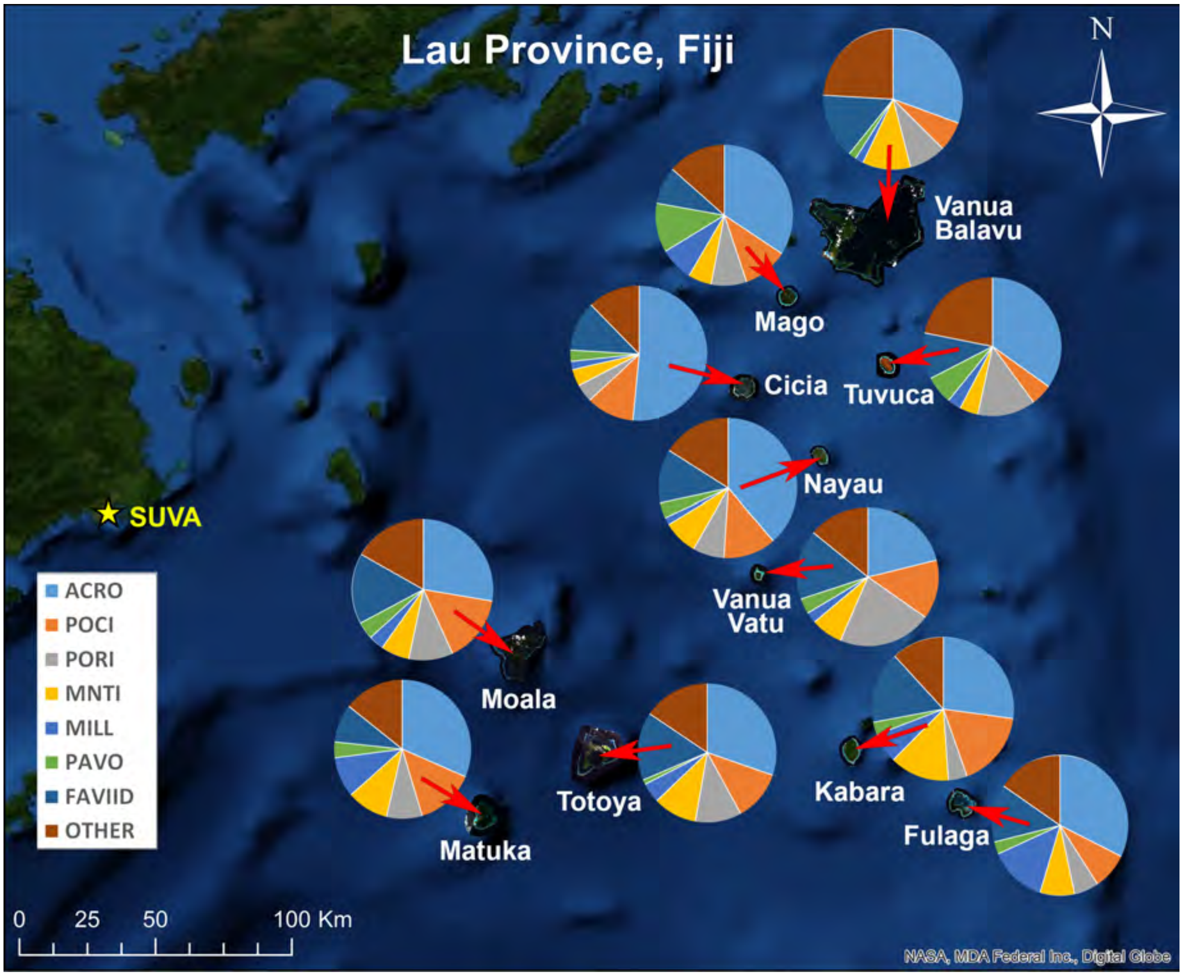


also a common feature (mean cover, all islands = 9.3%) with over 10% cover at Tuvuca, Mago, Moala and Vanua Balavu and over 5% at all other sites. Vanua Balavu, and Vanua Vatu also had a substantial amount of erect coralline algae (e.g. *Halimeda*) with >10% cover.

Within individual islands, the cover of macroalgae did not differ substantially between depths. In contrast, CCA was highest in shallow water, declining with depth. The cover of turf algae was also highest in shallow water, except at Fulaga. In contrast, the cover of cyanobacteria increased with depth in most locations (Fig 82).

Coral Cover

A total of 45 genera of scleractinian corals and one hydrozoan coral were recorded within benthic transects. Overall, *Acropora* was the dominant coral on these reefs, making up 35% of the living coral cover. Five functional groups of corals, *Acropora, Pocillopora, Porites, Montipora* and faviids (*Goniastrea, Montastraea, Favia, Favites* and *Cyphastrea*) made up over 80% of the total live coral cover in Lau Province, while 28 genera made each made up less than 1% of the live coral cover. Hydrozoan corals (*Millepora*) were also an important component of the live cover, occupying on average 5% of the bottom. Of the faviid corals, *Goniastrea* was the most common (3.9%) followed by *Favia* (3.5%), with the other three submassive and massive faviids each contributing to about 2% of the total coral cover.



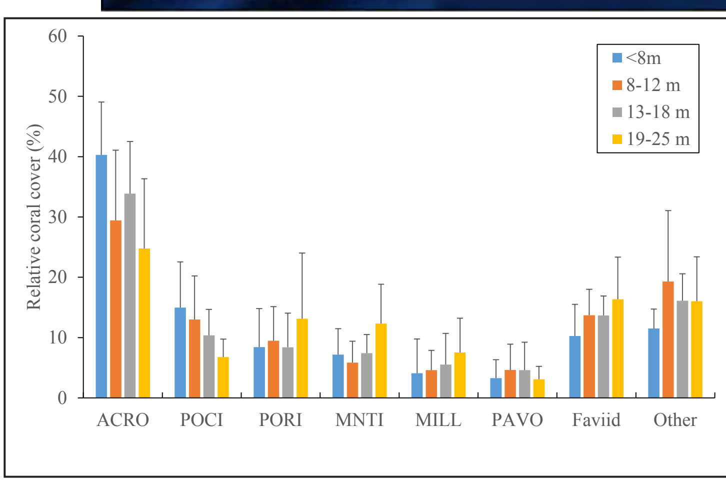


Fig. 83. Cover of the dominant coral taxa by island. Coral cover was dominated by Acropora (light blue), Pocillopora (orange), Porites (light purple), Montipora (yellow-orange), faviids (Goniastria, Favia, Montastraea, Favites and Cyphastrea; dark blue), Millepora, Pavona (green), and 28 other genera (brown)(above).

Fig. 84. Cover of the dominant coral taxa pooled for all islands into four depth categories (bottom left).

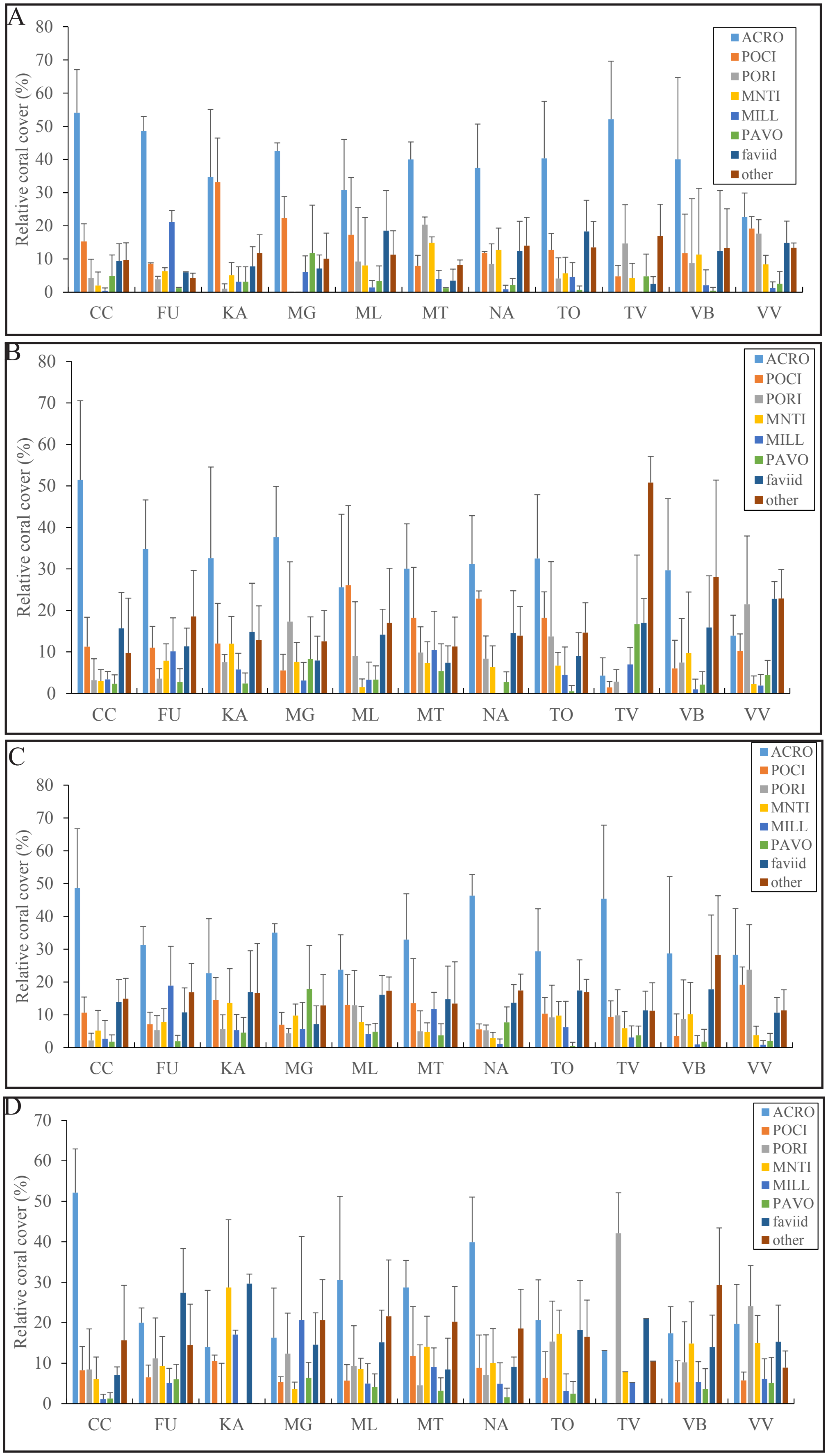


Fig. 84. Cover of the dominant coral taxa pooled on each island. A. cover at < 8m depth. B. Cover at 8-12 m. C. Cover at 13-18 m. D. Cover at 19-25 m.

The relative cover of different genera varied between islands. Cicia had the highest cover of *Acropora*, making up over half of all coral, followed by Nayau (39%) and Tuvuca (35%). The lowest cover of *Acropora* was recorded at Vanua Vatu (21% of the coral cover). *Pocillopora* cover was highest at Kabara (17.5%) and lowest (5%). The cover of *Porites* was greatest overall at Vanua Vatu (22%) and lowest at Cicia (4.5%). Vanua Balavu had the most diverse coral assemblages, with over 24% of the coral cover consisting of less common taxa (Fig. 83).

The live cover of *Acropora* and *Pocillopora* declined with depth, while *Porites, Montipora* and the five faviid genera was greatest at 18-25 m depth. In addition, the highest cover overall for *Porites* was noted at Tuvuca at 18-25 m. *Pavona* varied from 0-17% cover, with some reefs having large stands of *Pavona clavus,* especially Tuvuca at 8-12 m depth) Fig 84.

Some of the less common corals, especially *Diploastrea, Leptastrea, Galaxea, Merulina,* and *Lobophora* were locally abundant, making up 5-30% of the total live cover on certain reefs.

Reef Fish Assessments

Over the four-week research mission in Fiji, 359 belt transects were conducted to assess the structure of reef fish communities. The majority of transects were performed between 8 and 18 m depth (Table 7).

Island	<8 m	8-13 m	14-18 m	19-25 m	Total
Cicia	0	10	14	0	**24**
Fulaga	0	10	12	0	**22**
Kabara	0	17	8	0	**25**
Mago	0	8	9	0	**17**
Matuka	1	12	14	0	**27**
Moala	2	24	25	1	**52**
Nayau	0	9	9	0	**18**
Totoya	2	20	26	0	**48**
Tuvuca	0	10	6	0	**16**
Vanua Balavu	9	35	49	0	**93**
Vanua Vatu	0	6	11	0	**17**
Total	**14**	**161**	**183**	**1**	**359**

Table 7. Total number of belt transects, each 30 m X 4 m, completed in each depth category on reefs associated with 11 islands/atolls in Lau Province, Fiji.

Diversity

A total of 482 species (172 genera, 51 families) were recorded within transects. Over 60% of recorded species were observed in over five locations and 101 species were seen on a single reef. Of the 51 families recorded during the Mission, the 20 most common species belonged to just 10 families (Table 8). Of these 20 species, the Labridae and Pomacentridae families contained the highest numbers of species (4), followed by Chaetodontidae (3) and Acanthuridae and Scaridae (2). Six species were observed on every reef surveyed. The species observed less frequently belonged to a variety of families, feeding guilds and size classes. Diversity was fairly consistent between the 11 islands, with a total average of 250 species (Fig. 86). Reef fish diversity was highest at Vanua Balavu (375 species), followed by Totoya (278 species) and the lowest diversity was observed at Mago (211 species).

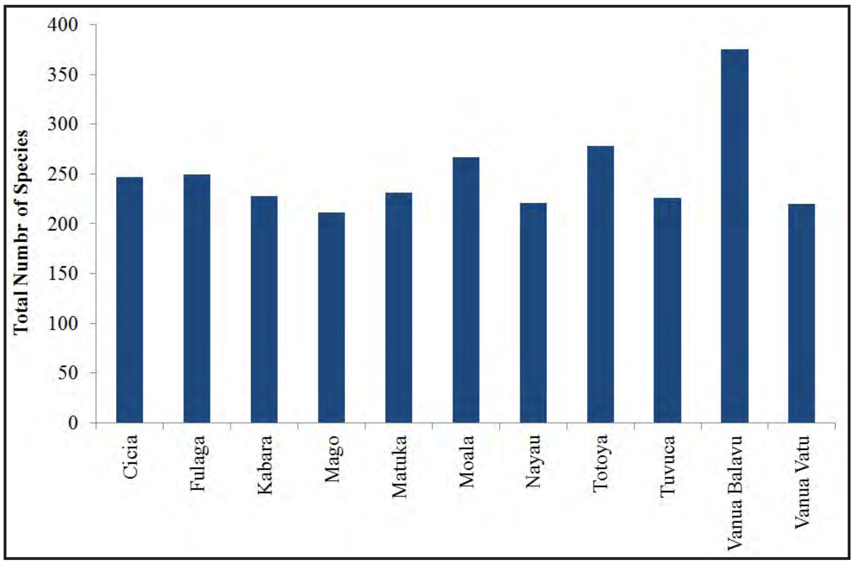


Fig. 86. The total number of species recorded in each island.

Overall, 32 species of Acanthurids, 23 species of Scarids and 8 Siganids were recorded (Fig. 88). Of these three key herbivorous families, diversity was fairly consistent for Acanthurids and Scarids. The highest diversity of Acanthurids and Siganids was at Vanua Balavu. Scarids were most diverse at both Moala and Totoya (Fig. 88).

Fig. 87. Reef fish communities were dominated by a high diversity of small bodied fishes.

Diversity of Lutjanids (23) and members of the subfamily Epinephelinae (10) were also generally consistent among islands (Fig. 89). This excludes Vanua Balavu, where Epinephelinae diversity was almost double that of most of the other islands (18 species). Although 10 species of Carangids were recorded overall, this was the least diverse of the key predatory families between the islands (range: 9-0 species). The highest diversity of Carangid species was recorded in Tuvuca, where diversity of both Lutjanids and Epinephelinae was lower in comparison to many of the other islands.

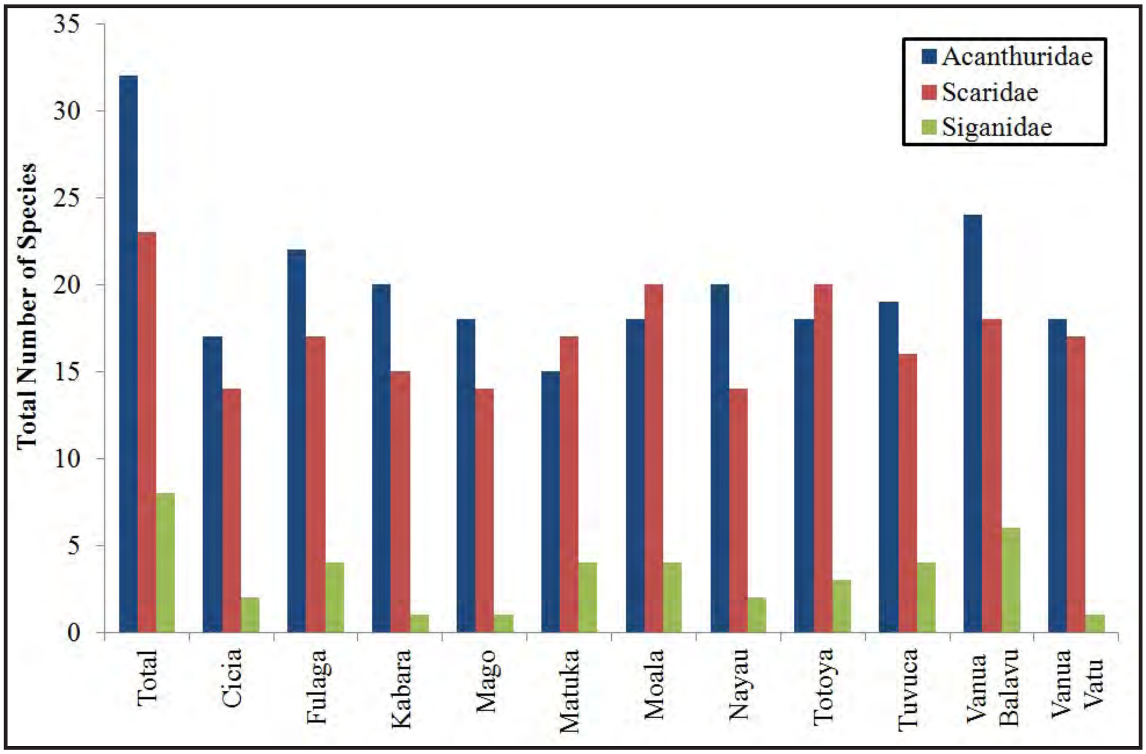


Fig. 88. The total number of species recorded for Acanthuridae, Scaridae and Siganidae families in each island.

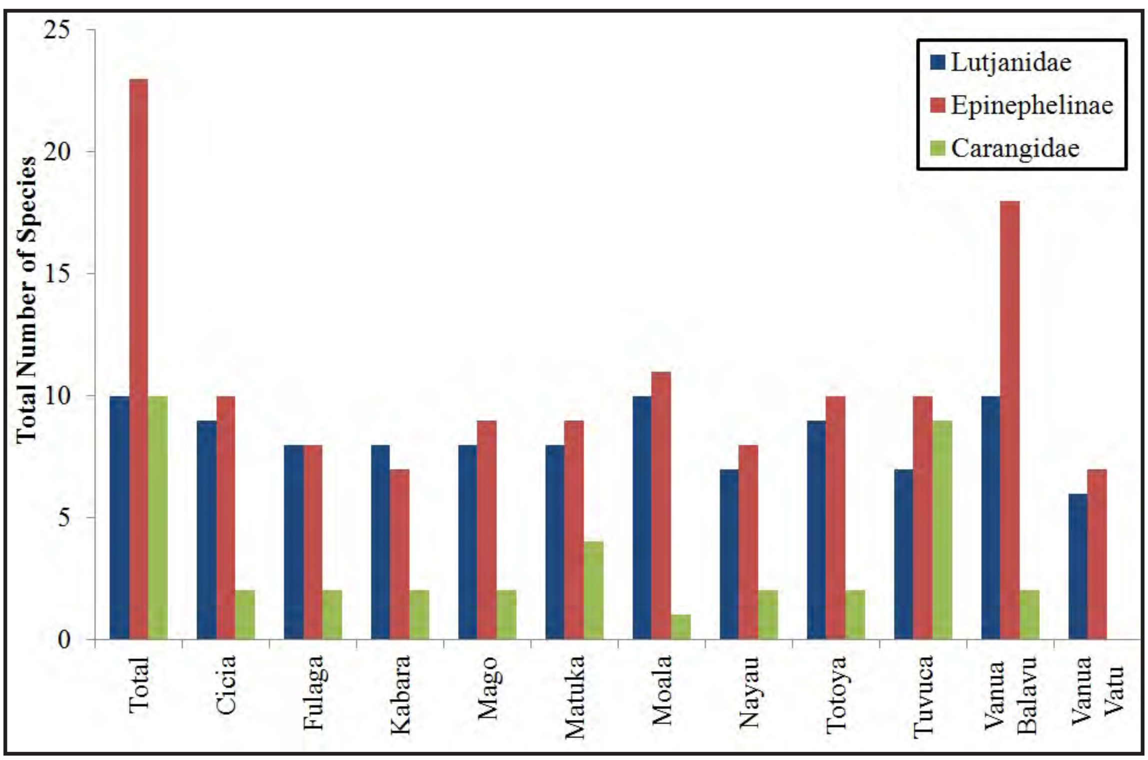


Fig. 89. The total number of species recorded for Carangidae, Lutjanidae and Epinephelinae families in each island.

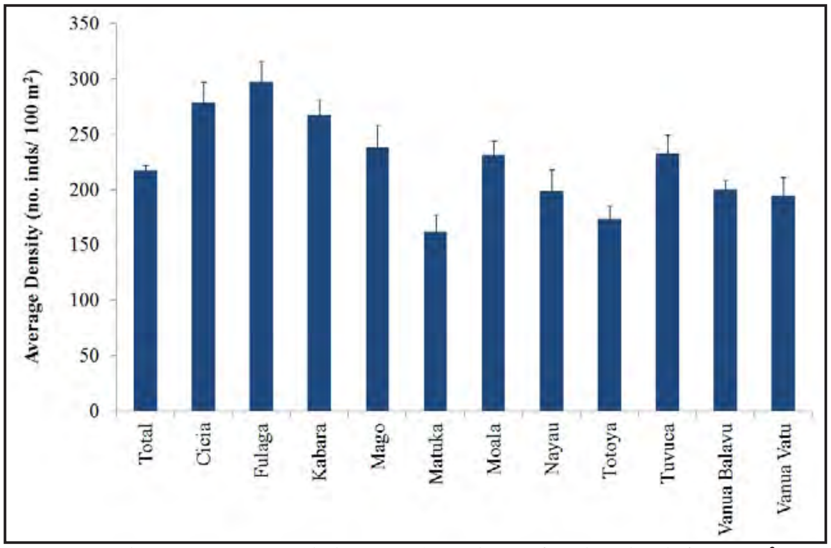


Fig. 90. The average total density (number of individuals/ 100 m^2 ±SE) recorded by island.

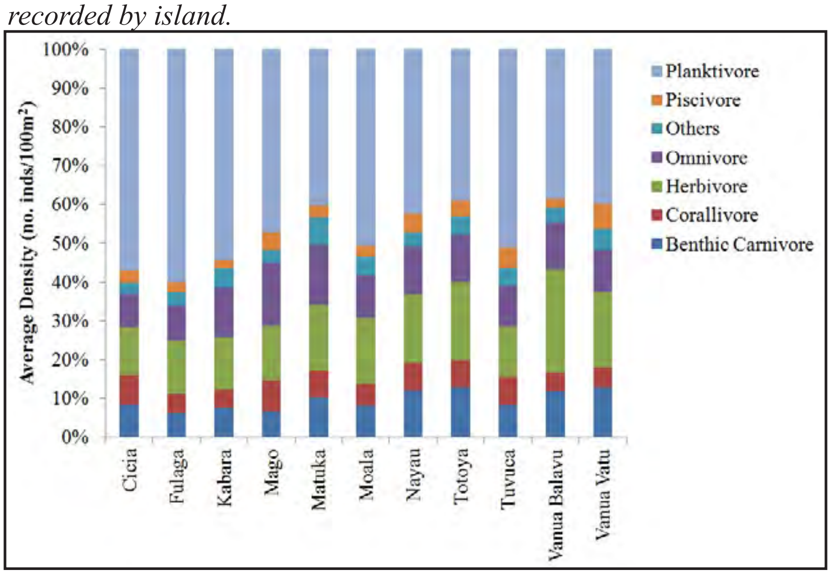


Fig. 91. The average total density (number of individuals/ 100 m^2 ±SE) by functional guild for each island.

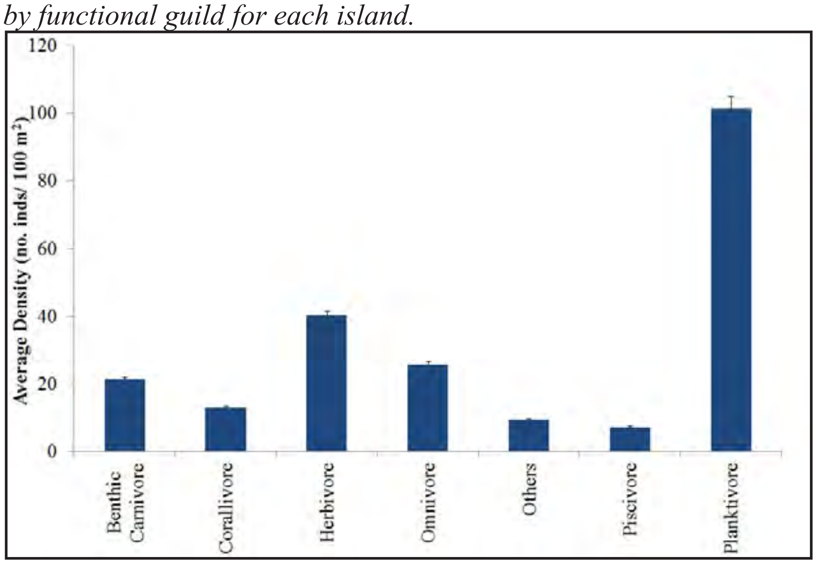


Fig. 92. The average total density (number of individuals/ 100 m^2 ±SE) recorded by feeding guild.

Density

Overall mean density was 218 individuals/100 m^2 (Fig. 90). Fulaga recorded the greatest average density (297 individuals/100 m^2), followed by Cicia (279 individuals/100 m^2) and Matuka the lowest (162 individuals/100 m^2).

Generally, the smaller-bodied and/or schooling genera contributed the most towards overall mean density in Fiji. Two Pomacentrid genera were the greatest contributors; *Chromis* (28%) and *Pomacentrus* (13%), followed by *Pterocaesio* (6%) and *Chaetodon* (4%). The majority of the other genera recorded during surveys had densities between 2-12 individuals/100 m^2.

Planktivores contained the highest mean density of all functional guilds with a 60% difference between this guild and the next highest guild, herbivores (101 and 40 individuals/100 m^2 respectively; Fig. 92). "Others", piscivores and corallivores contained much lower densities (7 to 13 individuals/100 m^2 respectively). Carnivore density was fairly high, with an average total of 21 individuals/100 m^2.

Fig. 93 The Longnose Filefish, Oxymonacanthus longirostris was a common carnivore.

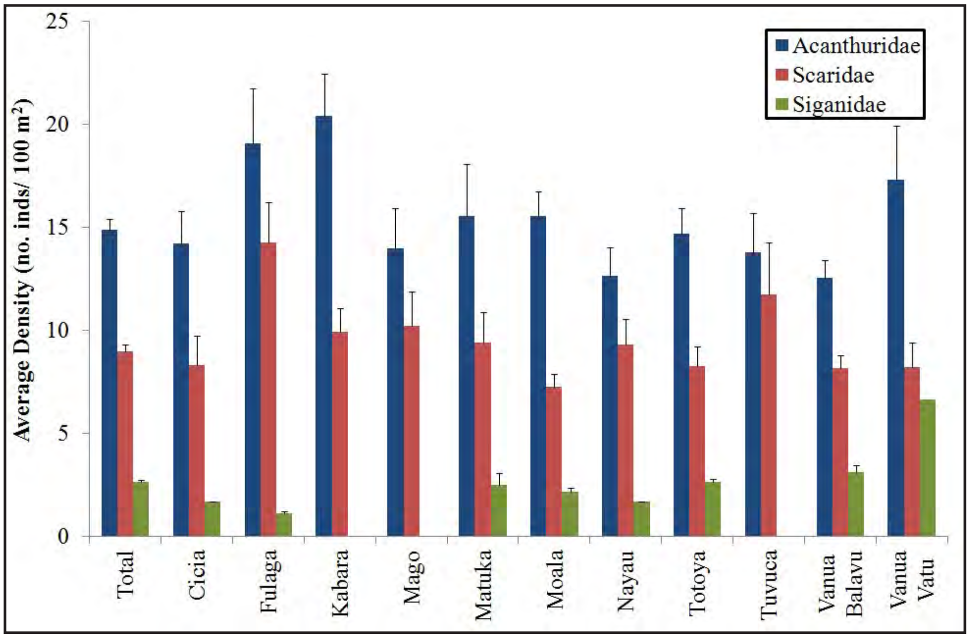


Fig. 94. The total average density (number of individuals/ 100 m² ±SE) recorded for Acanthuridae, Scaridae and Siganidae families in each island.

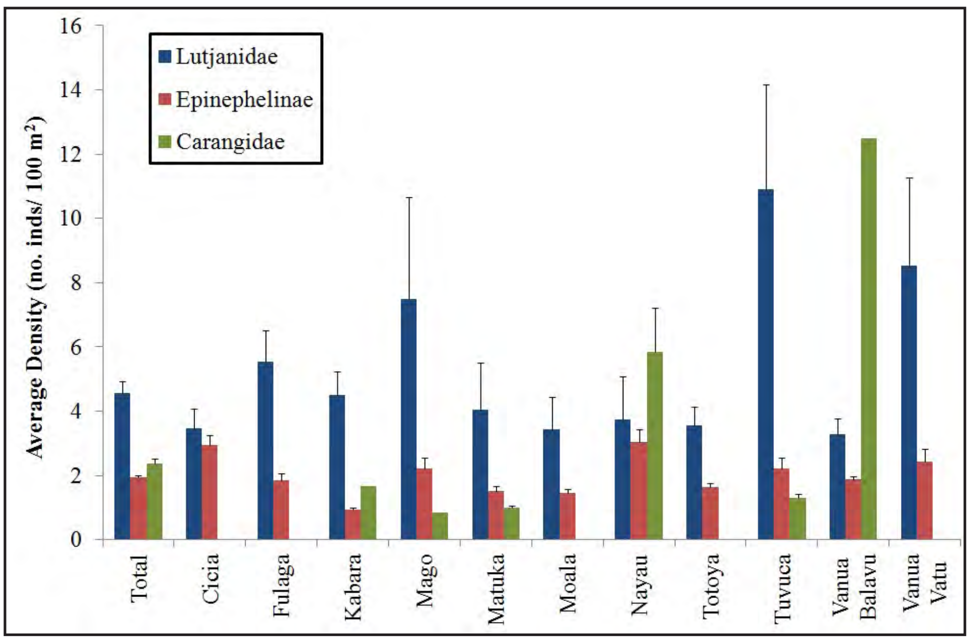


Fig. 95. The total average density (number of individuals/ 100 m² ±SE) recorded for Lutjanidae, Epinephelinae and Carangidae families in each island.

Acanthurids were common and fairly consistent at most sites, dominating the herbivore assemblage at all of the islands (15 individuals/100 m^2)(Fig. 94). The density of Scarids was approximately half that of Acanthurids (9 individuals/100 m^2) and Siganid density was low throughout all islands (3 individuals/100 m^2). Acanthurid density peaked at Kabara (20 individuals/100 m^2) and Fulaga (19 individuals/100 m^2). Scarid density was also high at Fulaga (14 individuals/100 m^2) and lowest in Moala (7 individuals/100 m^2). Siganid density also peaked at Vanua Vatu (7 individuals/100 m^2).

As expected, predatory density was far lower than the herbivores (Fig. 95). Lutjanids were recorded more frequently than the other two predatory families, with an average of 5 individuals/100 m^2. The average density of the subfamily Epinephelinae was 60% lower than Lutjanids. Carangids had the lowest average density of these three families, with 2 individuals/100 m^2.

Lutjanid density peaked at three islands; Tuvuca, Vanua Vatu and Mago (11, 9 and 8 individuals/100 m^2 respectively), with 3-6 individuals/100 m^2 off other islands. Epinephelinae density ranged from 1- 3 individuals/100 m^2 (Nayau and Kabara, respectively). Carangids were recorded on transects at just 6 of the islands, with the greatest densities at Vanua Balavu (12.5 individuals/100 m^2) and Nayau (6 individuals/100 m^2). The remaining 4 islands recorded less than 2 individuals/100 m^2.

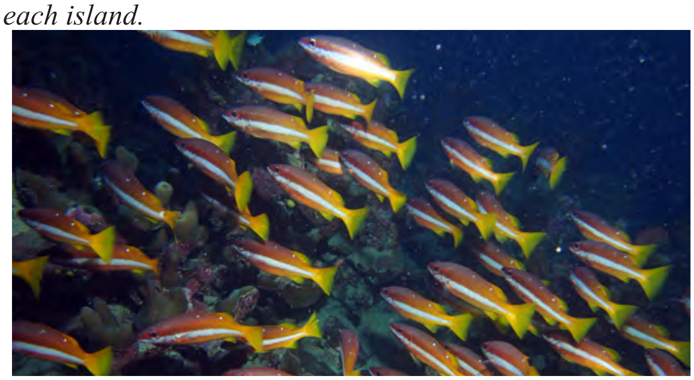


Fig. 96. A school of two-spot banded snapper, Lutjanus biguttatus.

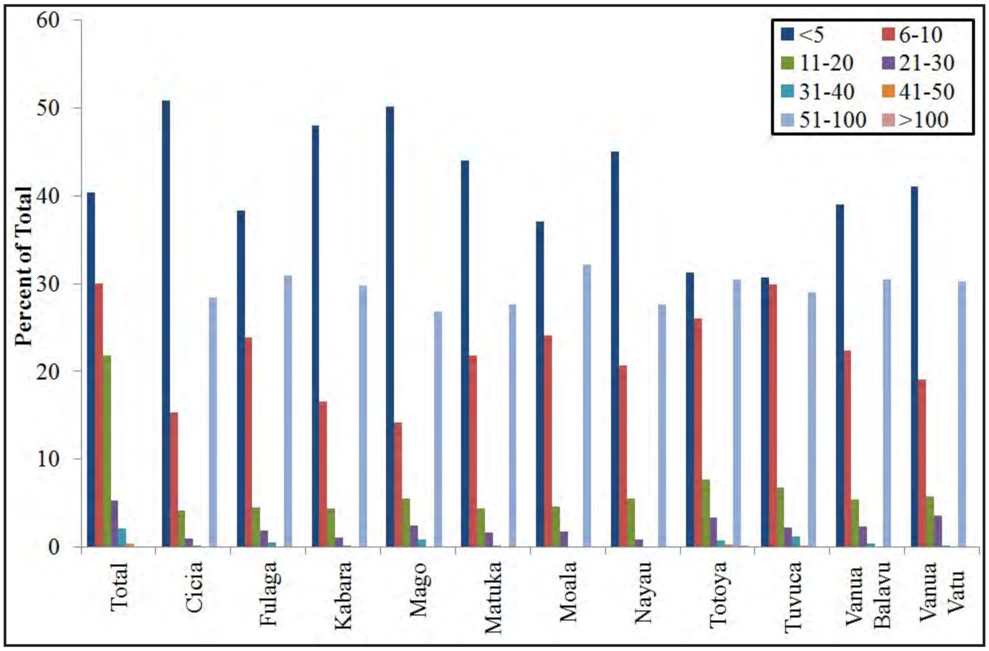


Fig. 97. The relative abundance (percentage of total) of all reef fish size classes recorded in each island.

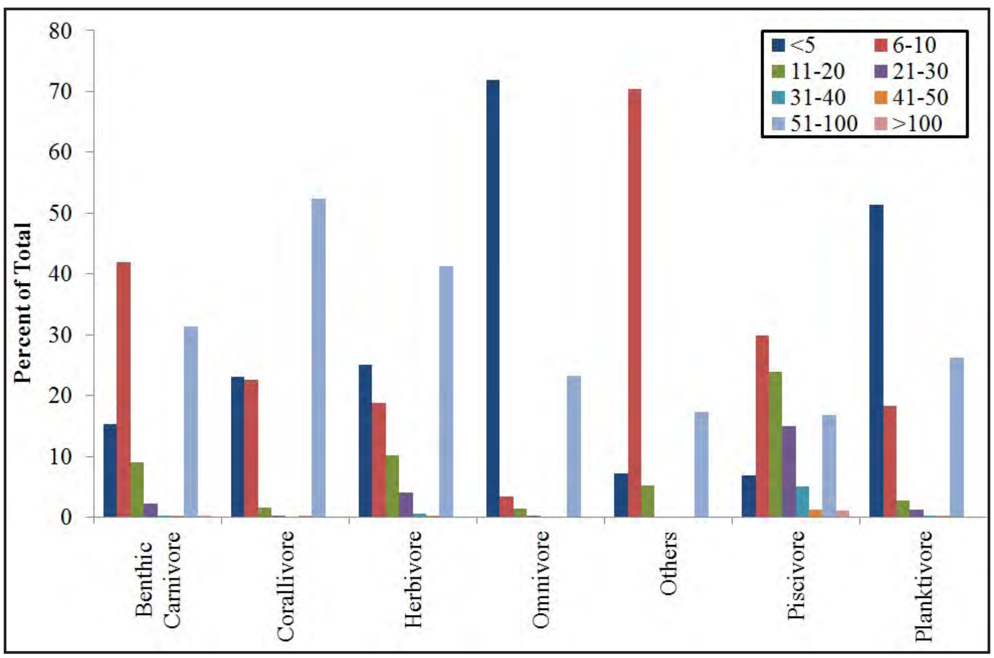


Fig. 98. The relative abundance (percentage of total) of reef fish size classes by feeding guild.

Size Class

Overall, the fish assemblage was dominated by fish less than 20 cm total length (92% of fish; Fig. 97). The larger size classes (i.e. above 41 cm) represented a small component of the total percentage of fish size (0.5%) and overall 7% of fish were between 21 and 40 cm.

Several islands were dominated a fish assemblage where individuals were less than 5 cm (Cicia 51%, Kabara 48% and Mago 51%). Vanua Vatu and Totoya had more fish within the 31 to 40 cm class than the other islands. This was probably due to the presence of large, schooling species at these islands (e.g., *Caesio teres, M. niger and Caesio lunaris*). Relative abundance of fish rarely exceeded 100 cm, with several islands recording no individuals within this class. Totoya had a slightly higher representation of fish over 100 cm, due to a higher abundance of sharks at this site.

Over 95% of omnivorous fish were under 10 cm in length and none exceeded 40 cm (Fig. 98). Of all feeding guilds, the largest proportion of fish greater than 51 cm in length belonged to the piscivores (2%). Almost half of the planktivores were between 6 and 20 cm, with 78% under 10 cm. Benthic carnivores were not particularly large with 89% under 20 cm and just 0.3% of fish recorded exceeding 41 cm in length. As expected, almost all corallivores were under 20 cm length. Just over a quarter of herbivorous fish were between 11 and 30 cm, with the majority of herbivores between 6 and 10 cm in length.

Fig. 99. Most groupers were 11-30 cm total length.

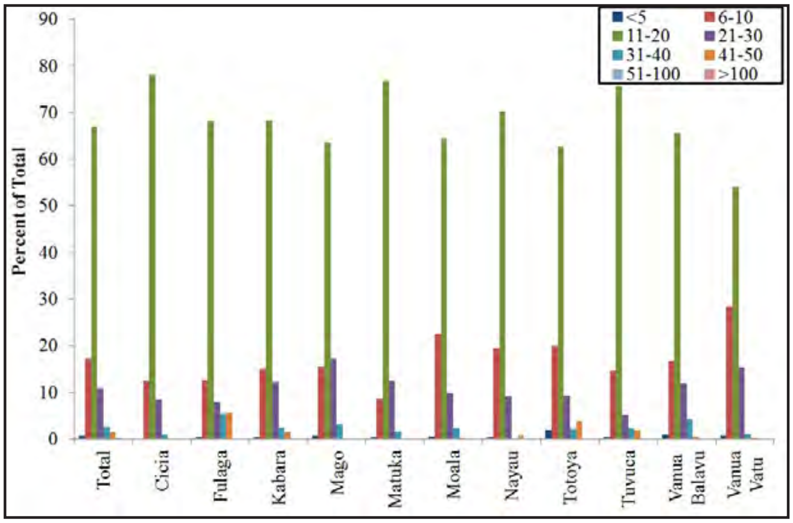


Fig. 100. The relative abundance (percentage of total) of reef fish size classes for Scaridae.

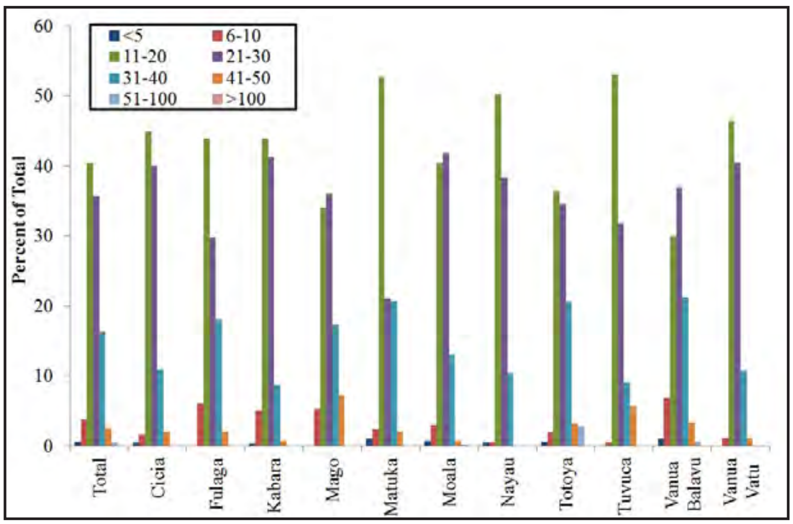


Fig. 101. The relative abundance (percentage of total) of reef fish size classes for Acanthuridae.

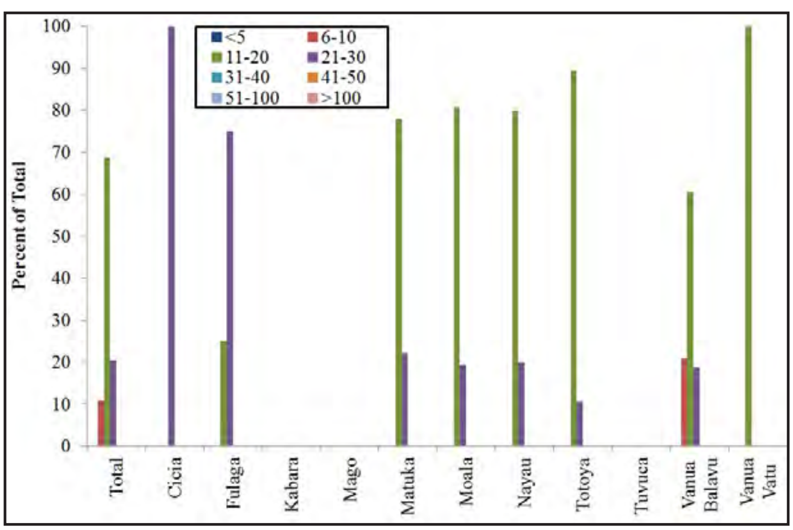


Fig. 102. The relative abundance (percentage of total) of reef fish size classes for Siganidae.

The three main groups of herbivores were mostly <30 cm in length. Scarids tended to fit within the larger size classes, with 92% ranging from 11 to 40 cm, and 3% exceeding 41 cm (Fig. 100). Overall, less than 1% of Scarids recorded were under 5 cm in length. The larger Scarids (e.g., *Chlorurus microhinos, Cetoscarus bicolor, Scarus forsteni* and *Hipposcarus longiceps*) were observed more frequently in Mago and Totoya. Acanthurids tended to be mid-sized, with the majority between 11 and 30 cm in length and less than 1% under 5 cm (Fig. 101). Fulaga's reefs comprised the greatest relative abundance of Acanthurids over 41 cm (6%). This was due to several larger unicornfish, *Naso hexacanthus* and *Naso lopezi*. Siganids tended to be primarily within the 11 to 20 cm size class, however at several islands, including Cicia, most or all individuals were larger in size (Fig. 102). Only in Vanua Balavu were individuals under 10 cm in length.

Fig. 103. A small school of acanthurids.

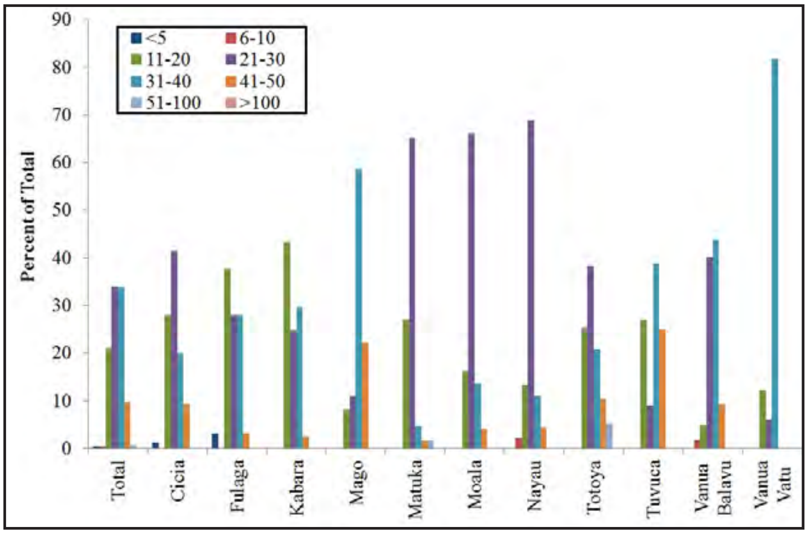


Fig. 104. The relative abundance (percentage of total) of reef fish size classes for Lutjanidae.

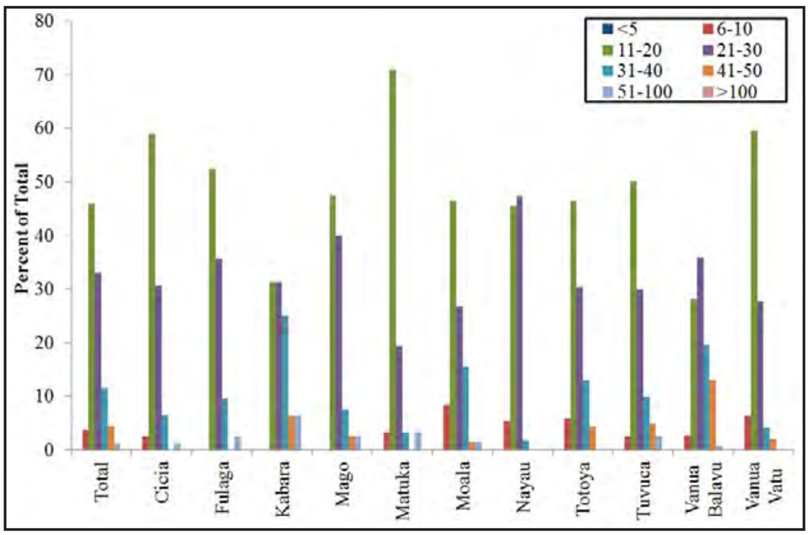


Fig. 105. The relative abundance (percentage of total) of reef fish size classes for Epinephelinae

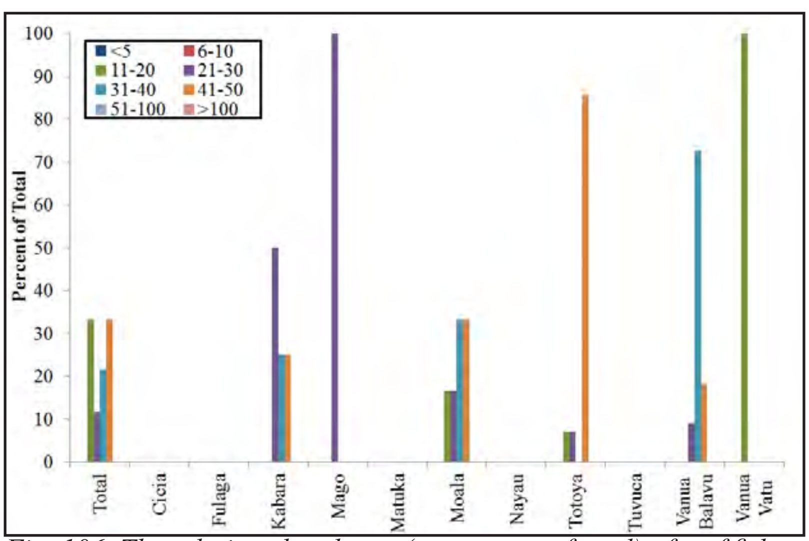


Fig. 106. The relative abundance (percentage of total) of reef fish size classes for Carangidae.

Lutjanids were mid to large body sizes, with two thirds of this family between 21 and 40 cm length (Fig. 104). Less than 1% of Lutjanids were under 10 cm, and no individuals exceeded 100 cm.
A quarter of Lutjanids in Tuvuca were between 41 and 50 cm length, and in Totoya over 5% were larger than 51 cm.

Over 90% of all individuals from the subfamily Epinephelinae were within the middle of the size distribution and approximately 4% of individuals were at either end of the scale (Fig. 105). Groupers between 41 and 50 cm were most commonly observed at Vanua Balavu and Mago. No groupers under 5 cm were recorded at any island.
All Carangids recorded throughout the islands were between 11 and 50 cm (Fig. 106). A third of all Carangids were between both 11 and 20 cm and 41 and 50 cm. The greatest variability of sizes was observed in Moala, with many other islands recording Carangids within just one or two size categories.

Sharks

Three species of sharks were recorded throughout the Mission; *Carcharhinus amblyrhynchos, Triaenodon obesus* and *Carcharhinus melanopterus*. *T. obesus* was the most commonly observed species. Totoya was the only site where all three species were observed and where individuals were recorded most frequently. Individuals recorded on transects ranged from 31 cm to over 100 cm, with the majority exceeding 100 cm.

Fig. 107. A white tip shark from Totoya.

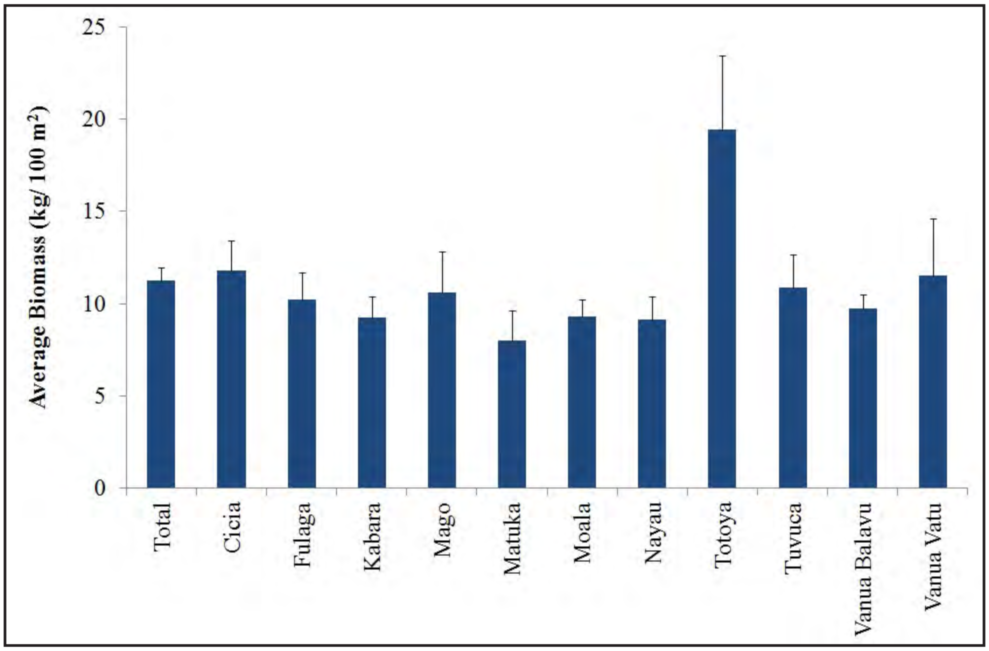


Fig. 108. The average total biomass (kg/ 100 m² ±SE) recorded by island.

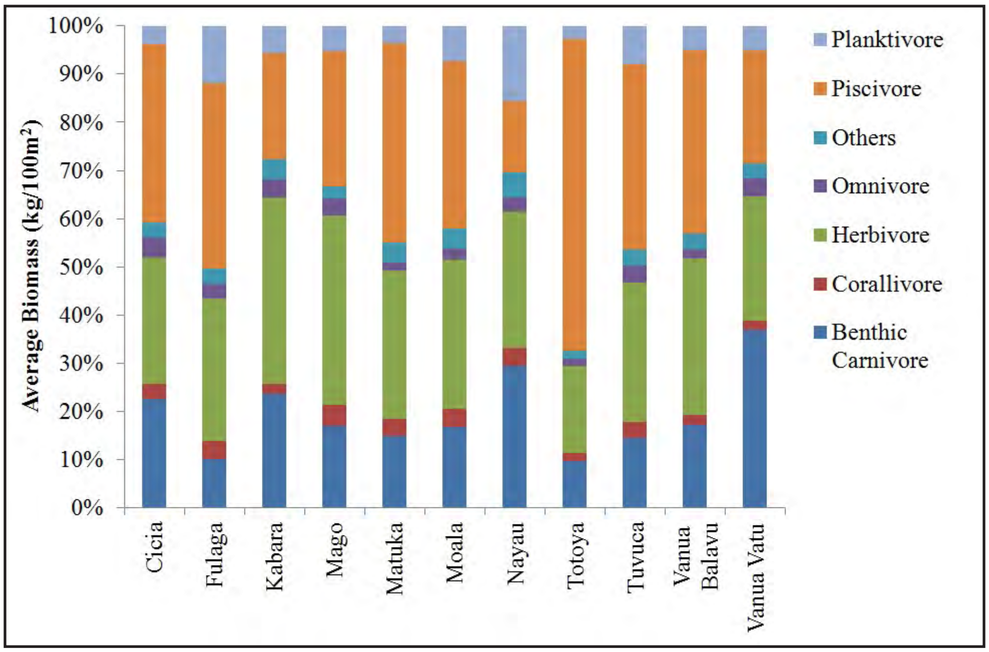


Fig. 109. The average total biomass (kg/ 100 m² ±SE) recorded by functional group for each island.

Biomass

Average biomass at these islands was 11.27 kg/100 m² (Fig. 108). Biomass was fairly consistent among islands, ranging between 8-12 kg/100 m²). The only exception was Totoya, where biomass was far higher (19.4 kg/100 m²). The lowest average biomass was recorded at Matuka (8 kg/100 m²).

Overall, the larger-bodied genera contributed the most towards total biomass in Fiji. *Triaenodon* was the largest contributor of total biomass (18%), followed by two parrotfish genera; *Scarus* (13%) and *Chlorurus* (7%).

Piscivores and herbivores also contributed towards large proportions of overall biomass in each island. In Totoya, piscivores had the greatest biomass of all guilds which was due to the greater abundance of sharks at this location. *Triaenodon* and *Carcharhinus* contributed 85% of piscivore biomass in Totoya and over 55% of total biomass at this island.

Benthic carnivores contributed more towards total biomass in Vanua Vatu and Nayau than at other islands. In Vanuau Vatu, *Chelinus* contributed almost 60% of the biomass of benthic carnivores. The proportion of corallivores was greater in Mago and Nayau and very low in Totoya and Kabara.

Fig. 110. Goatfish are important benthic carnivores that often occurred in schools of 20-50 fish, but most were small in size.

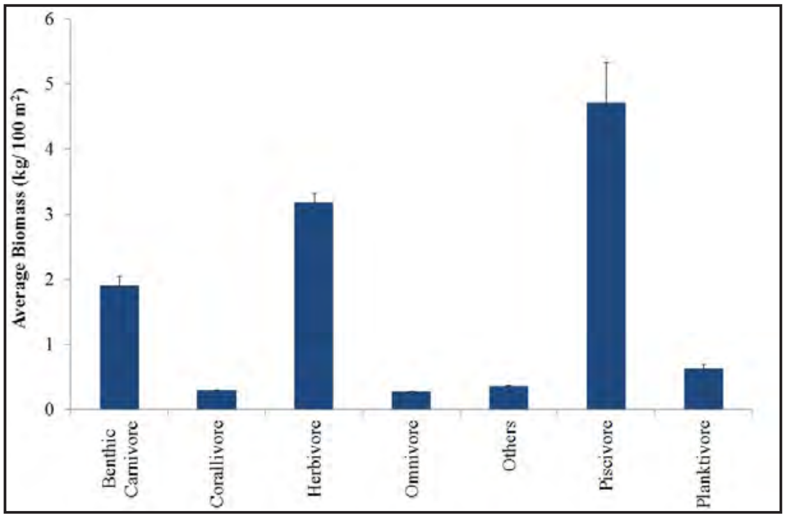


Fig. 111. The average total biomass (kg/ 100 m² ±SE) recorded by feeding guild.

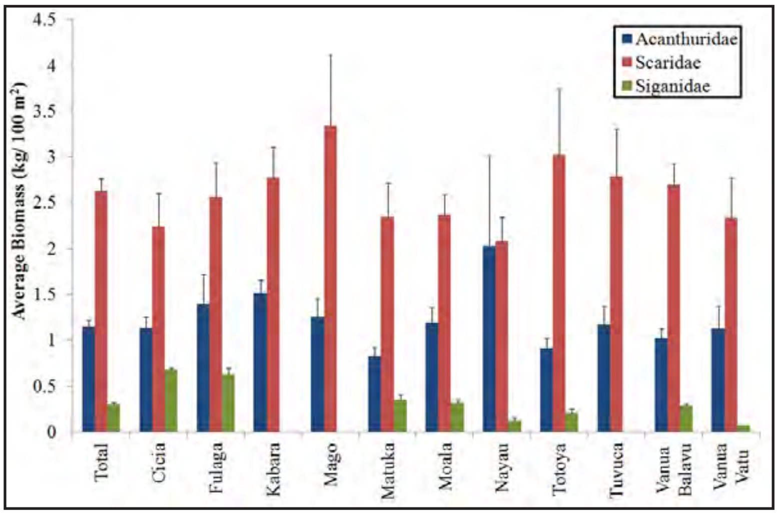


Fig. 112. The total average biomass (kg/ 100 m² ±SE) recorded for Acanthuridae, Scaridae and Siganidae families in each island.

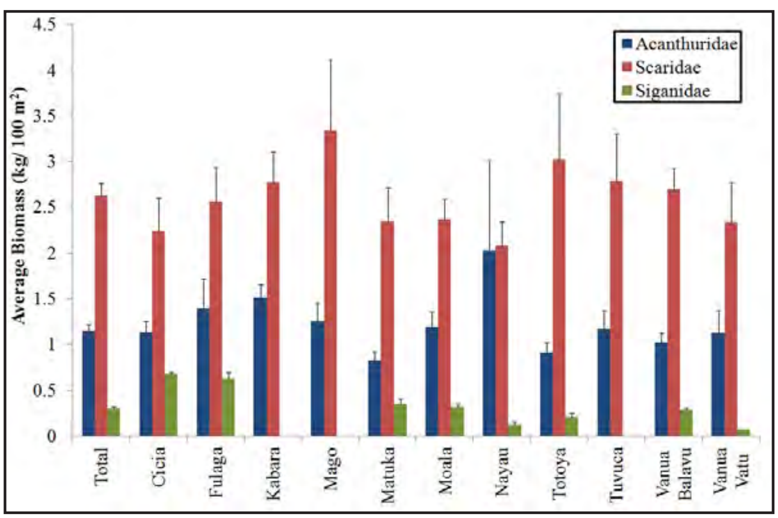


Fig. 113. The total average biomass (kg/ 100 m² ±SE) recorded for Carangidae, Lutjanidae and Epinephelinae families in each island.

Two of the feeding guilds recorded an average biomass that exceeded 1 kg/100 m²; piscivores (4.7 kg/100 m²), herbivores (3.2 kg/100 m²), benthic carnivores (1.9 kg/100 m²; Fig. 111). Omnivores and corallivores contained the lowest average biomass of all feeding guilds, with just 0.3 kg/100 m² in each guild.

Herbivore biomass was dominated by Scarids (total average; 2.6 kg/100 m²) and Acanthurid and Siganid biomass were lower, with an average of just 1.15 kg/100 m² and 0.3 kg/100 m² respectively (Fig. 112). The largest biomass of Scarids was recorded at Mago (3.34 kg/100 m²) and Totoya (3.02 kg/100 m²). Scarid biomass at the remaining islands ranged was very consistent, ranging between 2.79 and 2.1 kg/100 m². Acanthurid biomass was also consistent throughout the islands, with a maximum recorded in Nayau (2.1 kg/100 m²) and the lowest biomass at Matuka (0.8 kg/100 m²). Siganid biomass was extremely low throughout the islands and never exceeded 1 kg/100 m².

Lutjanids dominated the biomass of predatory families at most islands, with an overall average of 1.6 kg/100 m² (Fig. 113). Epinephelinae and Carangidae had an average of approximately 0.8 kg/100 m². Mago recorded a higher biomass of Lutjanids (2.27 kg/100 m²), which is most likely due to the presence of larger schools and individuals of *Lutjanus gibbus, Lutjanus bohar, Lutjanus monostigma* and *Macolor niger*. The lowest Lutjanid biomass of 1 kg/100 m² was recorded at Nayau. Grouper biomass was greatest at Kabara (1.26 kg/100 m²), followed by Vanua Balavu (1.16 kg/100 m²). The lowest biomass was observed at Vanua Vatu (0.47 kg/100 m²). Due to large *Carangoides orthogrammus* and *Caranx melampygus* individuals, Carangid biomass was surprisingly high at Kabara (1.93 kg/100 m²), compared with the other islands (range: 0.9 to 0.06 kg/100 m²).

Conclusions

Coral communities throughout the Lau Province have shown progressive recovery from damage from coral bleaching, outbreaks of corallivores and storms sustained in the early part of the new millennium. In particular, acroporid corals have rebounded and are once again the dominant coral in terms of cover. Most corals were in fairly good shape, although some reefs had a low to medium prevalence of coral diseases (especially white syndrome). Bleaching was not observed during the mission. Signs of predation were predominantly limited to fish bites, with localized impacts from *Drupella* gastropods and a single outbreak of crown of thorns starfish documented on the fore reef at Cicia. It is interesting to note that these reefs also had the highest live coral cover and the most Acropora recorded in the Lau Province.

In general, benthic communities could support continued recruitment and growth of corals, as the cover of macroalgae was relatively low. The only exceptions were some deeper reef communities, lagoonal reefs and vertical walls. The main pest species having a negative impact on the quality of benthic substrates was cyanobacteria, which formed dense mats on the sediment, rubble and often adjacent to corals in many locations. One reason for the notable presence of this algae may be the localized depletion of sea cucumbers, which are key detritivores that play a critical role in maintaining clean, aerated sediments. *Xenia* soft corals were also notably abundant on some deeper reefs in areas where stony coral had been damaged. Most reefs had high cover of crustose coralline algae, but a high prevalence of lethal orange disease was observed on many reefs. Considerable damage to fore reef and lagoonal reef communities was also attributed to *P. lacrymatus* damselfish algal lawns.

Traditional management and a lack of commercial fisheries within Lau Province have resulted in reef environments that sustain healthy reef fish assemblages. A high number of reef fish species (482 species) was recorded throughout this mission. Species richness was slightly higher than previously documented in another Fijian District (approx. 340 species, Kubulau District; Goetze, 2009; Jupiter et al., 2010).

Total mean biomass was moderately high (1126 kg/ha, range 1941-801 kg/ha) and surpassed other locations both in the Pacific Ocean (e.g., PNG 378-301 kg/ha, Cinner et al., 2006) and in Fiji (e.g., Vatu-i-Ra, $\bar{x}$ 730 kg/ha, Marnane et al., 2003). Our result was similar to those found in areas closed to fishing around Kubulau District, Bua Province (see Jupiter and Egli, 2010).

The size distribution of reef fish was skewed towards those under 20 cm total length, with few exceeding 50 cm. Fish assemblage was dominated by smaller bodied genera, primarily pomacentrids. This result was surprising as human population and fishing pressure have both declined throughout this province (Turner et al., 2007). However the notably high algal cover may explain part of this trend, by supporting the large aggregations and abundance of herbivorous farming damselfish throughout the islands.

Results from other studies in Lau Province identified a temporal and spatial decline in the abundance of small fish species, mostly in coral-associated species (Wilson et al., 2008, Wilson et al., 2010). The reduced abundance was attributed to declines in live coral cover (primarily Acroporids), which decreased habitat complexity and food availability, and reduced fishing pressure which altered predator-prey dynamics. Our surveys suggest that recovery of branching corals may have occurred between these previous studies. This may have resulted in an increase in abundance of small-bodied species as habitat rugosity improved (Pratchett et al., 2012; Graham and Nash, 2013). Although fishing in Lau is for subsistence, net fishing does occur and our results suggest that this method favors the larger bodied and slow growing species. Hence, very few large surgeonfish, parrotfish, groupers or snapper were recorded which is concerning as smaller individuals generally produce fewer and weaker offspring.

Wilson et al. (2008) identified a 50-70% decline in coral cover at both Matuka and Totoya, with a maximum of 24% coral cover in 2006. In 2013, coral cover was still lower at these islands compared with other locations in our surveys. This corresponded with the two lowest total mean densities of reef fish, particularly corallivores. However, total mean biomass was greatest in Totoya which indicates that fish assemblage here is dominated by large, roving species and not smaller species that depend on coral for refuge or food. Sharks, large parrotfish, jobfish and unicornfish were commonly observed around this area.

Many of these reefs are traditionally managed, but would perhaps benefit from additional fisheries management, particularly to increase the size structure of assemblages. Despite having low biomass, Totoya had remarkably high biomass and large individuals from key predatory and herbivorous families. Hence these reefs would benefit from additional protection to continue sustaining high biomass. Interestingly, the greatest abundance of fish over 30 cm in length occurred around Moala, which also had the greatest human population. The protection of larger-bodied fish appears to be working in Moala and should be continued in order to maintain current assemblages. Of all the islands surveyed, Matuka supported the lowest overall biomass and density of reef fish.

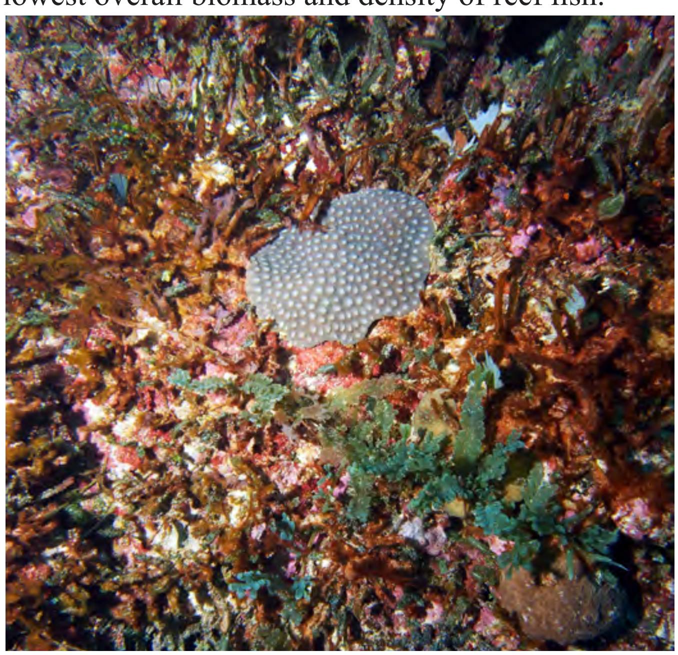


Fig. 114. Macroalgae overgrowing a Diploastrea colony.

Although, several large (>50 cm) sharks, snappers, unicornfish and parrotfish were recorded. Although human population is not exceptionally high for the area, fishing intensity is amongst the greatest of Lau's islands and this may contribute to reduced density and biomass of fish (Dulvy et al., 2004).

Fig. 115. Crown of thorns starfish were seen throughout the Lau Province at low densities, with a single outbreak documented at Cicia.

Fig. 116. A damselfish within its territory of algae.

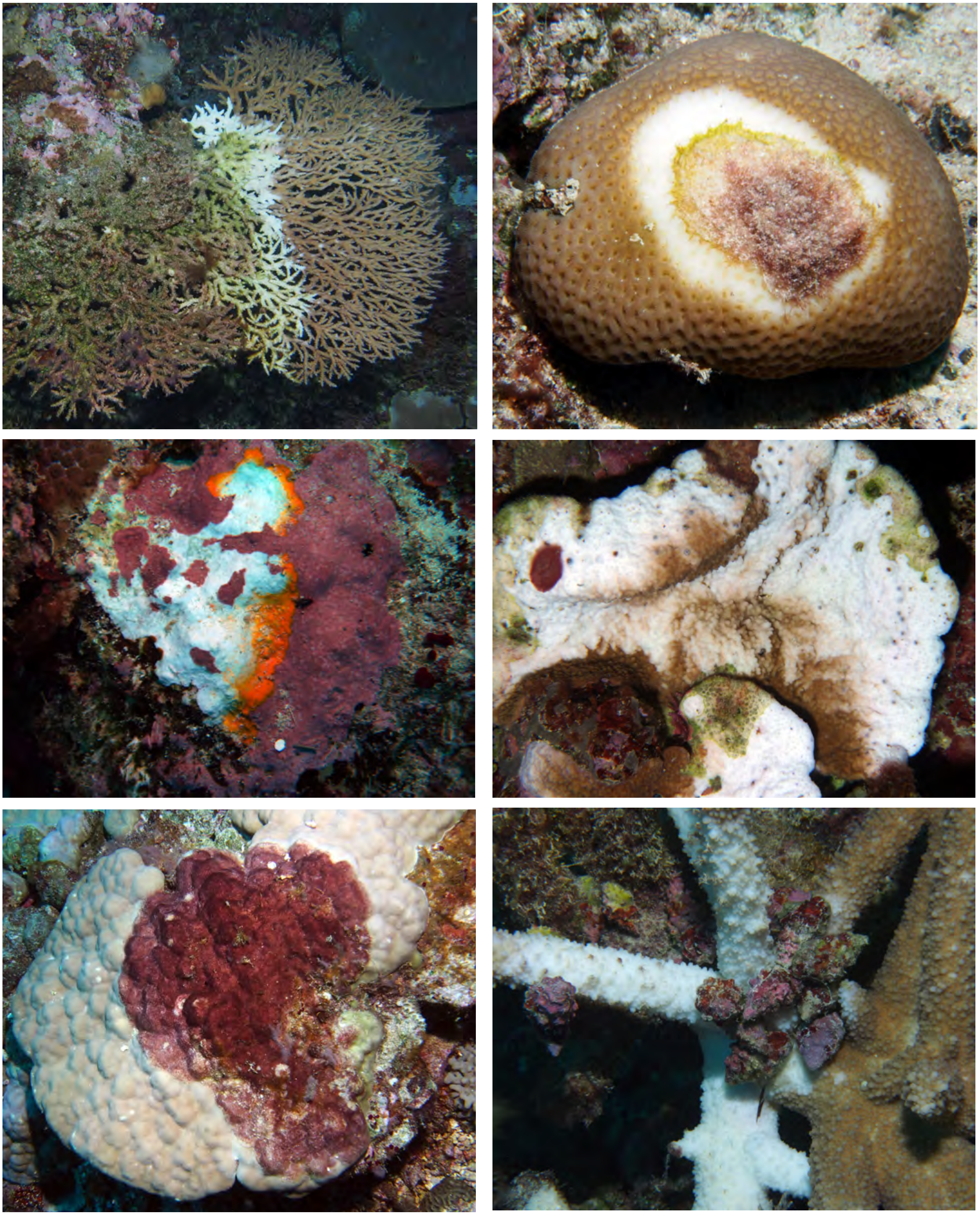


Fig. 117. Signs of stress on coral reefs in the Lau Province. White syndrome on a table acroporid (top left). yellow band disease on Goniastrea (top right). Lethal orange disease on CCA (center left). Bleached colony of Montipora (center right). Cyanobacteria overgrowing Porites (bottom left). Drupella snails on Acropora (bottom right).

Appendix I: Participants

Name	Institution	Function
Phil Renaud	Khaled bin Sultan Living Oceans Foundation	Executive Director
Andy Bruckner	Khaled bin Sultan Living Oceans Foundation	Chief Scientist
Amy Heemsoth	Khaled bin Sultan Living Oceans Foundation	Director of Education
Badi Samaniego	University of the Philippines KSLOF Fellow	Fish surveyor
Joao Monteiro	University of Azores, KSLOF Fellow	Coral fluorescence
Jeremy Kerr	Nova Southeastern University, KSLOF Fellow	Groundtruthing / habitat mapping
Anderson Mayfield	National Museum of Marine Biology and Aquarium of Taiwan, KSLOF Fellow	Coral genetics
Gwilym Rowlands	Nova Southeastern University National Coral Reef Institute	Groundtruthing / habitat mapping
Steve Saul	Nova Southeastern University National Coral Reef Institute	Groundtruthing / habitat mapping
Roko Sau Joesefa Cinavilakeba	Pacific Blue Foundation and Vice Chairman of the Lau Provincial Council	Traditional Leaders and community representative
Stacy Jupiter	Wildlife Conservation Society of Fiji	Local Scientist
Laitia Raloa	Lau Provincial Office	Protocol Officer
Ron Vave	University of the South Pacific	Scientific Diver
William Saladrau	Fiji Department of Fisheries	Scientific Diver
Ken Marks	Atlantic and Gulf Rapid Reef Assessment Program (AGRRA)	Photo transects
Alex Dempsey	Nova Southeastern University National Coral Reef Institute	Benthic surveyor
Dawn Bailey	Dive-In OCEAN foundation	Coral surveyor
Janet Eyre	Reef Environmental Education Foundation (REEF)	Fish surveyor
Derek Manzello	NOAA	Ocean acidification
Katie Hillyer	Victoria University, Wellington New Zealand	Benthic surveyor
Nick Cautin	Dive Safety Officer	Diving operations

Appendix II. Species of planktivores recorded in transects

Scientific Name	No reefs	Scientific Name	No reefs
Acanthurus albipectoralis	11	*Genicanthus melanospilos*	12
Acanthurus nubilus	1	*Genicanthus watanabei*	4
Acanthurus sp.	1	*Abudefduf sexfasciatus*	23
Acanthurus thompsoni	30	*Abudefduf vaigiensis*	9
Naso annulatus	3	*Amblyglyphidodon aureus*	18
Naso brachycentron	1	*Amblyglyphidodon curacao*	6
Naso brevirostris	26	*Amblyglyphidodon leucogaster*	1
Naso caesius	2	*Amblyglyphidodon orbicularis*	28
Naso hexacanthus	15	*Chromis acares*	3
Naso lopezi	3	*Chromis agilis*	6
Naso minor	1	*Chromis alpha*	30
Naso thynnoides	1	*Chromis amboinensis*	50
Naso tonganus	6	*Chromis atripectoralis*	16
Naso vlamingii	34	*Chromis atripes*	60
Caesio caerulaurea	25	*Chromis cf. leucura*	1
Caesio lunaris	6	*Chromis chrysura*	19
Caesio teres	15	*Chromis iomelas*	62
Pterocaesio digramma	4	*Chromis lepidolepis*	36
Pterocaesio lativittata	1	*Chromis margaritifer*	52
Pterocaesio pisang	14	*Chromis retrofasciata*	48
Pterocaesio tile	42	*Chromis ternatensis*	52
Pterocaesio trilineata	38	*Chromis vanderbilti*	16
Decapterus macarellus	2	*Chromis viridis*	32
Decapterus sp.	1	*Chromis weberi*	22
Hemitaurichthys polylepis	27	*Chromis xanthura*	60
Heniochus acuminatus	19	*Neopomacentrus metallicus*	1
Platax pinnatus	1	*Pomacentrus callainus*	63
Myripristis adusta	2	*Pomacentrus cf. adelus*	1
Myripristis berndti	31	*Pomacentrus opisthostigma*	1
Myripristis kuntee	41	*Pomacentrus pavo*	6
Myripristis murdjan	2	*Pomachromis richardsoni*	5
Myripristis sp.	1	*Nemateleotris magnifica*	26
Myripristis violacea	26	*Ptereleotris evides*	41
Myripristis vittata	9	*Ptereleotris heteroptera*	3
Cirrhilabrus exquisitus	13	*Ptereleotris microlepis*	3
Cirrhilabrus punctatus	48	*Ptereleotris zebra*	3
Cirrhilabrus scottorum	15	*Grammatorhyncus bilineatus*	1
Cirrhilabrus sp.	3	*Rastrelliger kanagurta*	1
Pseudocoris yamashiroi	8	*Pseudanthias pascalus*	40
Thalassoma amblycephalum	22	*Pseudanthias squamipinnis*	8
Hoplolatilus starcki	7	*Serranocirrhitus latus*	35
Malacanthus brevirostris	6		
Malacanthus latovittatus	4		

Appendix III. Species of benthic carnivores recorded in transects

Scientific Name	No reefs	Scientific Name	No reefs
Apogon angustatus	**2**	*Eviota dorsogilva*	**2**
Apogon kallopterus	**2**	*Eviota guttata*	**14**
Apogon nigrofasciatus	**3**	*Eviota parasites*	**3**
Archamia biguttata	**1**	*Eviota sebreei*	**14**
Archamia fucata	**1**	*Eviota sigillata*	**5**
Cheilodipterus quinquelineatus	**12**	*Eviota smaragdus*	**1**
Nectamia savayensis	**1**	*Exyrias bellisimus*	**1**
Aulostomus chinensis	**29**	*Fusigobius duospilus*	**1**
Balistoides conspicillum	**10**	*Fusigobius melacron*	**1**
Balistoides viridescens	**16**	*Fusigobius signipinnis*	**3**
Odonus niger	**1**	*Gnatholepis cauerensis*	**3**
Pseudobalistes flavimarginatus	**7**	*Gobiodon sp.*	**8**
Rhinecanthus aculeatus	**1**	*Istigobius rigilius*	**1**
Rhinecanthus lunula	**3**	*Koumansetta rainfordi*	**9**
Rhinecanthus rectangulus	**1**	*Trimma annosum*	**1**
Sufflamen bursa	**55**	*Trimma benjamini*	**1**
Sufflamen chrysopterus	**23**	*Trimma caesiura*	**1**
Sufflamen fraenatum	**1**	*Trimma cf. tevegae*	**5**
Xanthichthys auromarginatus	**1**	*Trimma sp.*	**3**
Ecsenius bicolor	**3**	*Trimma taylori*	**1**
Ecsenius fijiensis	**8**	*Valenciennea helsdingenii*	**18**
Ecsenius sp. (checkered)	**1**	*Valenciennea parva*	**1**
Meiacanthus bundoon	**30**	*Valenciennea puellaris*	**1**
Meiacanthus oualanensis	**21**	*Valenciennea strigata*	**10**
Diplogrammus goramensis	**1**	*Plectorhinchus chaetodonoides*	**6**
Synchiropus morrisoni	**1**	*Plectorhinchus gibbosus*	**1**
Caracanthus maculatus	**1**	*Plectorhinchus picus*	**3**
Selaroides leptolepis	**1**	*Plectorhinchus vittatus*	**1**
Chaetodon flavirostris	**3**	*Neoniphon argenteus*	**1**
Chaetodon lunula	**14**	*Neoniphon opercularis*	**5**
Heniochus monoceros	**41**	*Neoniphon sammara*	**31**
Neocirrhitus armatus	**3**	*Sargocentron caudimaculatum*	**33**
Gorgasia maculata	**3**	*Sargocentron cornutum*	**1**
Heteroconger sp.	**1**	*Sargocentron diadema*	**3**
Dasyatis kuhlii	**2**	*Sargocentron ittodai*	**1**
Amblyeleotris guttata	**19**	*Sargocentron rubrum*	**3**
Amblyeleotris steinitzi	**9**	*Sargocentron spiniferum*	**22**
Amblyeleotris wheeleri	**3**	*Sargocentron tiere*	**4**
Amblygobius phalaena	**5**	*Anampses caeruleopunctatus*	**13**
Amblygobius sp.	**2**	*Anampses melanurus*	**1**
Bryaninops natans	**4**	*Anampses neoguinaicus*	**34**
Bryaninops yongei	**1**	*Anampses twistii*	**59**
Ctenogobiops crocineus	**1**	*Bodianus anthioides*	**17**

Appendix III. Species of benthic carnivores in transects (cont.)

Scientific Name	No reefs	Scientific Name	No reefs
Bodianus axillaris	**57**	*Thalassoma purpureum*	**1**
Bodianus dictynna	**4**	*Thalassoma quinquevittatum*	**26**
Bodianus loxozonus	**43**	*Thalassoma trilobatum*	**1**
Bodianus mesothorax	**29**	*Gnathodentex aureolineatus*	**24**
Cheilinus chlorourus	**15**	*Lethrinus obsoletus*	**10**
Cheilinus fasciatus	**25**	*Monotaxis grandoculis*	**29**
Cheilinus oxycephalus	**52**	*Monotaxis heterodon*	**66**
Cheilinus trilobatus	**39**	*Cantherhines longicaudus*	**1**
Cheilinus undulatus	**14**	*Cantherhines pardalis*	**21**
Choerodon jordani	**5**	*Mulloidichthys flavolineatus*	**5**
Coris batuensis	**6**	*Mulloidichthys vanicolensis*	**9**
Coris dorsomacula	**10**	*Parupeneus barberinoides*	**3**
Coris gaimard	**31**	*Parupeneus barberinus*	**33**
Coris sp. (3 stripes) (C. notialis)	**1**	*Parupeneus ciliatus*	**3**
Zanclus cornutus	**63**	*Parupeneus crassilabris*	**48**
Gomphosus varius	**66**	*Parupeneus cyclostomus*	**61**
Halichoeres biocellatus	**59**	*Parupeneus multifasciatus*	**67**
Halichoeres claudia	**22**	*Parupeneus pleurostigma*	**33**
Halichoeres hortulanus	**62**	*Gymnothorax javanicus*	**1**
Halichoeres margaritaceus	**4**	*Aetobatus narinari*	**1**
Halichoeres marginatus	**19**	*Manta birostris*	**1**
Halichoeres prosopeion	**15**	*Scolopsis bilineatus*	**50**
Halichoeres richmondi	**4**	*Scolopsis trilineatus*	**1**
Halichoeres trimaculatus	**6**	*Opistognathus sp.*	**1**
Hemigymnus fasciatus	**53**	*Ostracion meleagris*	**21**
Hemigymnus melapterus	**14**	*Ostracion solorensis*	**23**
Hologymnosus annulatus	**11**	*Heteropriacanthus cruentatus*	**1**
Hologymnosus doliatus	**6**	*Pempheris oualensis*	**11**
Macropharyngodon meleagris	**26**	*Parapercis clathrata*	**15**
Macropharyngodon negrosensis	**3**	*Parapercis hexophthalma*	**26**
Novaculichthys taeniourus	**9**	*Parapercis sp. (Allen)*	**2**
Oxycheilinus rhodochrous	**3**	*Pempheris schwenkii*	**1**
Pseudocheilinus evanidus	**51**	*Apolemichthys trimaculatus*	**2**
Pseudocheilinus hexataenia	**65**	*Centropyge bicolor*	**36**
Pseudocheilinus octotaenia	**35**	*Pygoplites diacanthus*	**58**
Pseudocheilinus tetrataenia	**1**	*Cypho purpurascens*	**8**
Stethojulis bandanensis	**40**	*Pictichromis porphyreus*	**3**
Stethojulis notialis	**2**	*Solenostomus paegnius*	**1**
Stethojulis trilineata	**4**	*Arothron cf. caeruleopunctatus*	**1**
Thalassoma hardwicke	**44**	*Arothron hispidus*	**3**
Thalassoma jansenii	**10**	*Arothron meleagris*	**1**
Thalassoma lunare	**33**	*Arothron nigropunctatus*	**23**
Thalassoma lutescens	**54**	*Arothron stellatus*	**2**

Appendix IV. Species of corallivores, omnivores, and other species recorded in transects

Corallivores

Scientific Name	No reefs
Exallias brevis	**3**
Chaetodon baronessa	**44**
Chaetodon bennetti	**24**
Chaetodon citrinellus	**42**
Chaetodon ephippium	**52**
Chaetodon kleinii	**14**
Chaetodon lineolatus	**8**
Chaetodon lunulatus	**66**
Chaetodon melannotus	**10**
Chaetodon mertensii	**49**
Chaetodon ornatissimus	**10**
Chaetodon pelewensis	**65**
Chaetodon plebeius	**29**
Chaetodon rafflesi	**47**
Chaetodon reticulatus	**63**
Chaetodon trifascialis	**41**
Chaetodon ulietensis	**45**
Chaetodon unimaculatus	**24**
Chaetodon vagabundus	**55**
Forcipiger flavissimus	**61**
Forcipiger longirostris	**37**
Heniochus chrysostomus	**58**
Heniochus singularis	**6**
Heniochus varius	**32**
Coris aygula	**14**
Labrichthys unilineatus	**30**
Labropsis australis	**30**
Labropsis xanthonota	**49**
Cantherhines dumerilii	**18**
Oxymonacanthus longirostris	**30**
Plectroglyphidodon dickii	**30**
Plectroglyphidodon johnstonianus	**44**

Omnivores

Scientific Name	No reefs
Balistapus undulatus	**64**
Melichthys vidua	**38**
Chaetodon auriga	**31**
Chaetodon semeion	**2**
Kyphosus cinerascens	**5**
Aluterus scriptus	**1**
Pervagor janthinosoma	**6**
Pervagor melanocephalus	**1**
Ostracion cubicus	**4**
Pomacanthus imperator	**9**
Amphiprion barberi	**11**
Amphiprion chrysopterus	**47**
Amphiprion clarkii	**4**
Amphiprion fijiensis	**8**
Amphiprion perideraion	**19**
Dascyllus aruanus	**14**
Dascyllus reticulatus	**54**
Neoglyphidodon carlsoni	**17**
Pomacentrus brachialis	**1**
Pomacentrus imitator	**67**
Pomacentrus vaiuli	**67**
Priacanthus hamrur	**7**

Other species

Scientific Name	No reefs
Canthigaster solandri	**11**
Canthigaster valentini	**20**
Ctenochaetus binotatus	**38**
Ctenochaetus cyanocheilus	**43**
Ctenochaetus striatus	**67**
Aspidontus taeniatus	**1**
Plagiotremus flavus	**34**
Plagiotremus rhinorhynchos	**4**
Plagiotremus tapeinosoma	**9**
Labroides bicolor	**41**
Labroides dimidiatus	**67**
Labroides rubrolabiatus	**2**

Appendix V. Species of herbivores recorded in transects

Scientific Name	No reefs	Scientific Name	No reefs
Acanthurus blochii	**8**	*Pomacentrus nigromanus*	**2**
Acanthurus grammoptilus	**1**	*Pomacentrus nigromarginatus*	**11**
Acanthurus guttatus	**3**	*Pomacentrus spilotoceps*	**19**
Acanthurus lineatus	**45**	*Stegastes fasciolatus*	**38**
Acanthurus mata	**7**	*Stegastes nigricans*	**21**
Acanthurus nigricans	**22**	*Calotomus carolinus*	**14**
Acanthurus nigricauda	**56**	*Cetoscarus bicolor*	**42**
Acanthurus nigrofuscus	**57**	*Chlorurus bleekeri*	**11**
Acanthurus olivaceus	**8**	*Chlorurus frontalis*	**5**
Acanthurus pyroferus	**62**	*Chlorurus microrhinos*	**51**
Acanthurus triostegus	**12**	*Chlorurus sordidus*	**66**
Naso lituratus	**59**	*Hipposcarus longiceps*	**30**
Naso unicornis	**19**	*Scarus altipinnis*	**40**
Zebrasoma scopas	**65**	*Scarus chameleon*	**43**
Zebrasoma veliferum	**50**	*Scarus dimidiatus*	**10**
Cirripectes castaneus	**9**	*Scarus forsteni*	**39**
Cirripectes stigmaticus	**38**	*Scarus frenatus*	**33**
Cirripectes variolosus	**1**	*Scarus ghobban*	**7**
Kyphosus vaigiensis	**6**	*Scarus globiceps*	**36**
Pseudodax moluccanus	**10**	*Scarus longipinnis*	**6**
Pseudojuloides cerasinus	**7**	*Scarus niger*	**62**
Amanses scopas	**6**	*Scarus oviceps*	**10**
Paraluteres prionurus	**4**	*Scarus psittacus*	**52**
Centropyge bispinosus	**65**	*Scarus rivulatus*	**2**
Centropyge flavissimus	**62**	*Scarus rubroviolaceus*	**16**
Centropyge heraldi	**10**	*Scarus schlegeli*	**64**
Paracentropyge multifasciata	**6**	*Scarus sp.*	**1**
Chrysiptera rollandi	**2**	*Scarus spinus*	**33**
Chrysiptera sp. (brown)	**1**	*Siganus argenteus*	**16**
Chrysiptera talboti	**51**	*Siganus cf. javus*	**1**
Chrysiptera taupou	**47**	*Siganus doliatus*	**6**
Dascyllus trimaculatus	**54**	*Siganus punctatissimus*	**18**
Dischistodus sp.	**1**	*Siganus punctatus*	**10**
Plectroglyphidodon lacrymatus	**63**	*Siganus spinus*	**1**
Pomacentrus bankanensis	**5**	*Siganus stellatus*	**1**
Pomacentrus coelestis	**6**	*Siganus uspi*	**22**
Pomacentrus maafu	**27**	*Canthigaster amboinensis*	
Pomacentrus microspilus	**5**		

Appendix VI. Species of piscivores in transects

Scientific Name	No reefs	Scientific Name	No reefs
Cheilodipterus artus	**3**	*Lutjanus kasmira*	**23**
Cheilodipterus isostigmus	**1**	*Lutjanus monostigma*	**27**
Cheilodipterus macrodon	**14**	*Lutjanus semicinctus*	**10**
Tylosurus crocodilus	**1**	*Macolor macularis*	**28**
Carangoides ferdau	**2**	*Macolor niger*	**30**
Carangoides orthogrammus	**20**	*Gymnothorax flavimarginatus*	**2**
Carangoides plagiotaenia	**1**	*Gymnosarda unicolor*	**14**
Caranx ignobilis	**1**	*Sarda orientalis*	**2**
Caranx melampygus	**7**	*Sarda sp.*	**1**
Elagatis bipinnulata	**3**	*Scomberomorus commerson*	**5**
Scomberoides lysan	**4**	*Pterois antennata*	**1**
Carcharhinus amblyrhynchos	**6**	*Anyperodon leucogrammicus*	**9**
Carcharhinus melanopterus	**1**	*Belonoperca chabanaudi*	**11**
Negaprion acutidens	**1**	*Cephalopholis argus*	**52**
Triaenodon obesus	**23**	*Cephalopholis leopardus*	**17**
Chanos chanos	**1**	*Cephalopholis miniata*	**1**
Cirrhitichthys falco	**17**	*Cephalopholis sexmaculata*	**2**
Paracirrhites arcatus	**55**	*Cephalopholis spiloparaea*	**15**
Paracirrhites forsteri	**47**	*Cephalopholis urodeta*	**55**
Paracirrhites hemistictus	**1**	*Epinephelus caeruleopunctatus*	**1**
Echeneis naucrates	**11**	*Epinephelus cyanopodus*	**1**
Fistularia commersonii	**4**	*Epinephelus fasciatus*	**4**
Epibulus brevis	**9**	*Epinephelus howlandi*	**1**
Epibulus insidiator	**59**	*Epinephelus maculatus*	**1**
Oxycheilinus bimaculatus	**3**	*Epinephelus merra*	**22**
Oxycheilinus digrammus	**67**	*Epinephelus microspilos*	**1**
Oxycheilinus unifasciatus	**11**	*Epinephelus ongus*	**1**
Gymnocranius microdon	**4**	*Epinephelus polyphekadion*	**14**
Lethrinus atkinsoni	**6**	*Epinephelus tauvina*	**2**
Lethrinus erythracanthus	**6**	*Gracila albomarginata*	**16**
Lethrinus erythropterus	**3**	*Plectropomus laevis*	**28**
Lethrinus harak	**1**	*Plectropomus leopardus*	**13**
Lethrinus olivaceus	**3**	*Variola albimarginata*	**1**
Lethrinus rivulatus	**1**	*Variola louti*	**16**
Lethrinus sp.	**1**	*Sphyraena barracuda*	**3**
Lethrinus xanthochilus	**4**	*Sphyraena flavicauda*	**1**
Aphareus furca	**55**	*Sphyraena helleri*	**24**
Aprion virescens	**10**	*Sphyraena jello*	**1**
Lutjanus bohar	**41**	*Saurida gracilis*	**2**
Lutjanus fulvus	**17**	*Synodus dermatogenys*	**2**
Lutjanus gibbus	**40**	*Synodus variegatus*	**21**

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