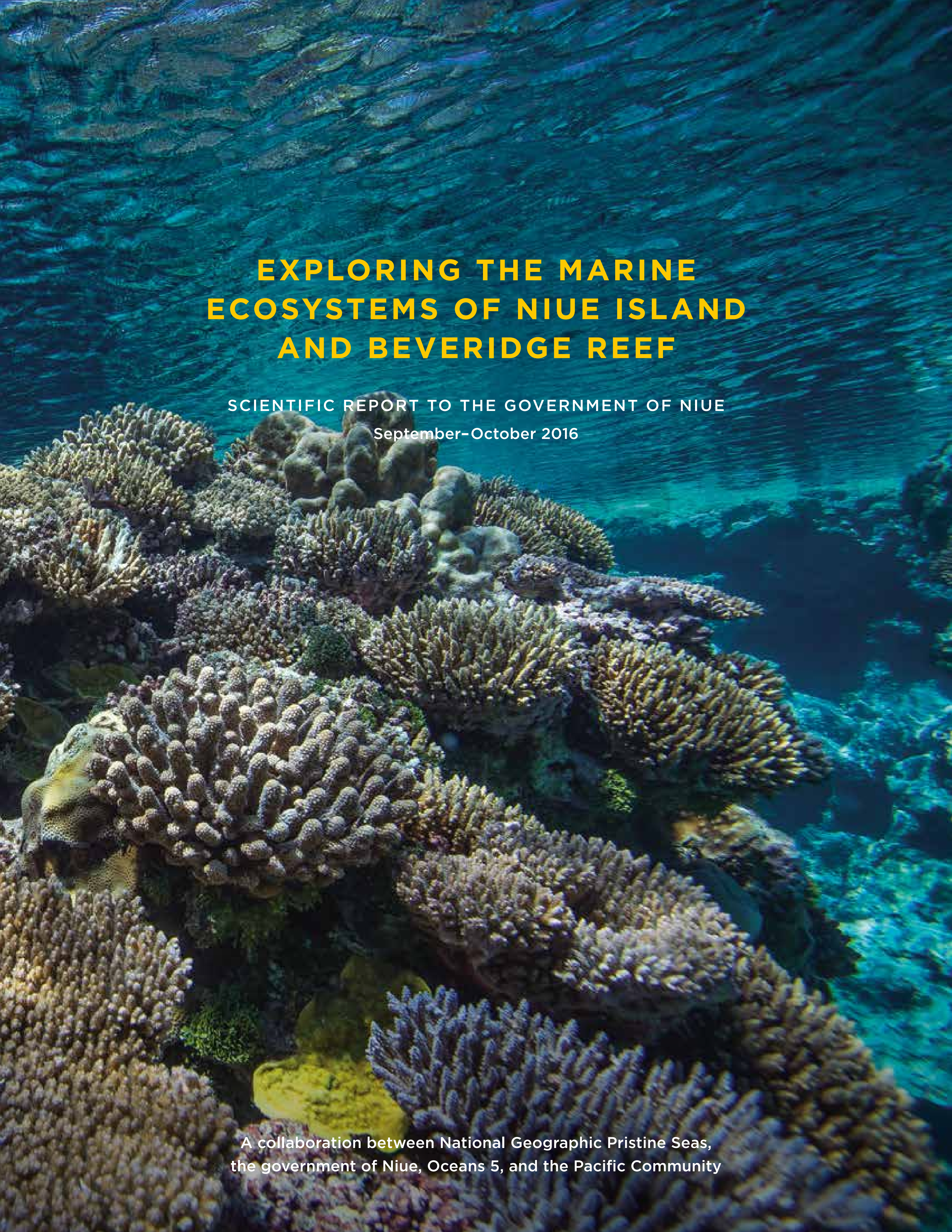

EXPLORING THE MARINE ECOSYSTEMS OF NIUE ISLAND AND BEVERIDGE REEF

SCIENTIFIC REPORT TO THE GOVERNMENT OF NIUE

September–October 2016

A collaboration between National Geographic Pristine Seas,
the government of Niue, Oceans 5, and the Pacific Community

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

National Geographic Pristine Seas, in collaboration with the government of Niue, Oceans 5, and the Pacific Community, conducted an 18-day expedition to Niue in October 2016 to perform comprehensive quantitative surveys of the health of its marine environment, including the largely unknown Beveridge Reef. The goals of the expedition were to assess the biodiversity of the marine environment, build capacity of Niue's fisheries department in survey methodologies, and inform the island's ongoing marine spatial planning process. Prior to our expedition, there had not been a comprehensive survey of Niue's marine ecosystems.

We conducted in situ surveys of fishes (N = 370), corals and other components of the shallow-water marine ecosystem (N = 70) at 34 locations around Niue and Beveridge Reef. Baited Remote Underwater Video Systems (BRUVS) were deployed at 50 stations around each island to assess sharks and other predators. We explored open ocean communities using baited stereocameras at 10 sites each around Niue and Beveridge Reef with a total of 100 individual camera drops. National Geographic's deep-sea dropcameras were deployed at 11 stations between 276 and 2,447 m depth. Macro-invertebrates were assessed using manta tows at Niue (N = 6; 10.8 km total) and Beveridge Reef (N = 4; 7.2 km total).

During the expedition, we recorded a total of 300 species of fishes. Fish biomass was more than twice as large at Beveridge Reef than at Niue. In addition, biomass of piscivores was 7.5 times larger at Beveridge Reef than at Niue. Fish biomass around Niue was some of the lowest that we have observed in the Pacific. We found no differences in fish biomass between the MPA and adjacent areas at Niue despite 20+ years of protection. Fishing line was evident throughout the MPA, suggesting a lack of compliance with the no-take area.

Relative to other sites sampled during Pristine Seas expeditions, the open ocean fish assemblage at Niue and Beveridge Reef was found to be depauperate. This low species richness and abundance may reflect the low natural productivity of the region and/or the result of overfishing. The little known Blainville's beaked whale (*Mesoplodon densirostris*) was observed at Beveridge Reef, which is the first record of this species from Niue's waters. Previous studies suggest strong site fidelity for this species, thus this may be a resident population. Despite our sampling late in the season, humpback whales were commonly observed close to the reef at Beveridge Reef. We observed mothers with calves, and males were heard singing on several dives.

Four species of sharks and rays were observed on Baited Remote Underwater Video Systems: grey reef shark (*Carcharhinus amblyrhynchos*), whitetip reef shark (*Triaenodon obesus*), spotted eagle ray (*Aetobatus narinari*), and marbled stingray (*Himantura oxyrhyncha*). Densities of grey reef sharks at Beveridge Reef were much greater than recorded elsewhere around the world to date using BRUVS. Relative to Beveridge Reef, a lower abundance of sharks and large predatory fishes was recorded on Niue, which likely suggests overfishing of these socioeconomically important species. Three species of globally endangered marine turtles were also recorded on BRUVS: loggerhead sea turtle (*Caretta caretta*), green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*).

Our deep-sea video camera footage revealed a relatively diverse assemblage of species, with at least 23 taxa of deepwater fishes from 14 families observed. We identified a smalltooth sand tiger shark (*Odontaspis ferox*) at 506 m depth, representing the first record of this species at Niue.

We recorded 121 species of coral on the expedition. Percent coral cover was relatively low overall (Niue = 19% and Beveridge Reef = 15%), with the lowest values at windward locations on the south and east coastlines at both locations. Higher coral cover on the leeward side of Niue (26% vs. 8% on the windward side) and similar size structure of coral colonies reflect growth since Cyclone Heta in 2004. The algal assemblage was depauperate on both reef ecosystems, likely due to high herbivory and low productivity.

High densities of giant clams at Beveridge Reef suggest a healthy population with low fishing pressure. In contrast, Niue had low densities of giant clams even on the windward side of the reef, which receives less fishing pressure than the leeward coast.

Our results highlight both the global importance of Beveridge Reef as a shark refuge and the low standing stock of nearshore fishes around Niue. Grey reef sharks, a globally threatened species, were observed on nearly every dive at Beveridge Reef and accounted for more than one-third of the total fish biomass at this remote atoll. These results indicate the extraordinary natural value of Beveridge Reef, and the importance of protecting this resource in the longterm.

Our results also indicate that due to the low productivity and isolation of the region, Niue's marine ecosystems are highly vulnerable to both human and natural impacts, including fishing activity, storm events, and climate change. Therefore, local marine resources require careful management and effective enforcement to provide food security for the people of Niue into the future. Measures should include establishing small no-take areas around Niue with surrounding well-managed fishing areas. In addition, our results strongly suggest the need to establish a world-class no-take marine reserve in and around Beveridge Reef. These actions will raise Niue's global profile as a pristine ecotourism destination, as will its contribution to global marine conservation.

INTRODUCTION

INTRODUCTION

Niue is one of the world's largest single raised coral atolls (259 km^2) with its highest peak 68 m above sea level and an Exclusive Economic Zone (EEZ) of 318,144 km^2 (Terry and Nunn 2003, FMI 2016). Sea-level changes during the Quaternary (2.6 MYBP–present) produced a "staircase" of marine terraces at several distinct heights around the coast, with steep-walled coastal chasms and extensive cave networks (Figure 1, Terry and Nunn 2003). Unlike other raised atolls in the Pacific (e.g., Nauru, Line and Phoenix Islands), Niue lacks the thick phosphate rock formed from guano deposition of pre-human seabird rookeries, owing to the absence of nutrient-rich upwelling currents to support fish stocks large enough to sustain significant seabird populations (Stoddard and Scoffin 1983).

FIGURE 1.

Niue is one of the world's largest raised atoll with extensive marine terraces at distinct heights around the coast.

Niue was colonized ~ 1900 YBP (Bell et al. 2015), most likely with people coming from Tonga and Samoa (Clark 2010). In 2011, the population of Niue was 1,611, with 20,200 Niueans living in New Zealand, and an additional 1–2,000 in Australia. Niue is a self-governing parliamentary democracy (Fono ekupule) in free association with New Zealand.

Niue's EEZ contains a number of seamounts and at least three outlying coral reefs, which are at or near the surface (Beveridge, Antipode, and Haran). Of these, Beveridge Reef, 240 km to the southeast of Niue, is the largest with a total area of ~ 56 km^2, although it is a submerged atoll with no emergent land. Beveridge Reef is a culturally significant area to the people of Niue. Oral history from Rarotonga, Cook Islands, suggests the reef was once covered in coconut palms until a cyclone swept the trees and the soil away (Best 1922). In 1847 the British Captain Lower-Tinger, commander of the brig Beveridge Reef cited the atoll and reported his discovery to the Admiralty in London. Since much of the reef is visible only at low tide, it has been the site of numerous shipwrecks over the years.

One of the most iconic marine species in Niue is the katuali or flat-tail sea snake (*Laticauda schistorhynchus*), which is found only in Niue and is listed as Vulnerable by the International Union for Conservation of Nature (IUCN) due to its restricted range and habitat requirements (Figure 2). However, much of Niue's marine environment has not been extensively studied due to its remoteness and lack of a safe harbor. Relatively few scientific surveys have taken place in its EEZ, and Beveridge Reef has never undergone a thorough scientific investigation.

FIGURE 2.

The katuali or flat-tail sea snake (*Laticauda schistorhynchus*) is found only in Niue's waters.

In early 2015, the Niuean government approached Oceans 5 (an international funders' collaborative comprised of new and experienced philanthropists dedicated to protecting the world's five oceans) to propose the development of a sustainable and integrated approach to ocean conservation and management. Oceans 5 is supporting the local nonprofit Tofia Niue, in partnership with the government of Niue in the Niue Ocean Wide (NOW) project to conserve and sustainably manage Niue's waters. Niue has begun a three-year planning process to create a Marine Management Plan that will define a EEZ-wide network of resource use zones.

The intended goals of NOW are to

- improve fisheries management, both near-shore and pelagic;
- ensure long-term food security;
- increase the value of tourism;
- establish a large marine protected area in the EEZ;
- ensure that Niue's environment remains as pristine as possible; and
- increase Niue's global stature as a leader in conservation and tourism

OBJECTIVES OF THE EXPEDITION

The goals of the Pristine Seas project are to find, survey, and help protect the last wild places in the ocean. It is essential that we let the world know that these places exist, that they are threatened, and that they deserve to be protected. In Niue, there is strong support for the creation of a large-scale, "globally significant Marine Protected Area." To this end, National Geographic Pristine Seas, in collaboration with the Niuean government, Oceans 5, and the Pacific Community conducted an expedition to Niue Island and Beveridge Reef in September–October 2016 to conduct the first-ever, comprehensive baseline survey of these largely unknown marine ecosystems.

RESULTS

RESULTS

Benthos

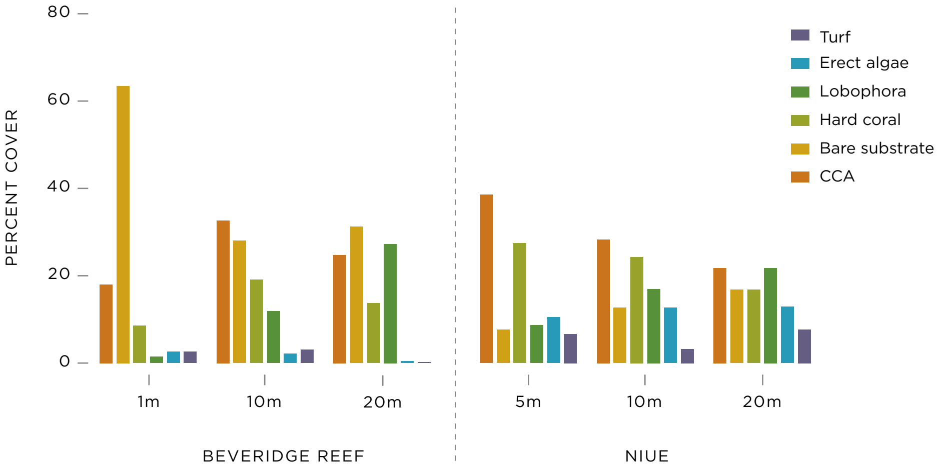
Prior to our expedition, there had not been a comprehensive survey of Niue's marine ecosystems. We provide the first checklists for corals, algae, and fishes for the waters surrounding Niue and Beveridge Reef, as well as comparisons of benthic community composition between islands, depths, and wind exposures (i.e., windward, east-facing shores and leeward, west-facing shores).

BENTHIC COMMUNITY COMPOSITION

Benthic taxa were organized into functional groups as follows: hard corals, CCA (crustose coralline algae), *Lobophora* (taxa within this genus of thalloid brown alga), erect algae (taxa > 2 cm height except for *Lobophora*), turf algae, bare substrate, and other invertebrates (including soft corals). CCA accounted for 28% of the cover at Niue, followed by hard coral (19%), *Lobophora* (17%), bare substrate (13%), and erect algae (12%). At Beveridge Reef, bare substrate comprised 35% of benthic functional group cover, followed by CCA (27%), *Lobophora* (17%), and hard coral (15%). There were stark differences in cover by depth and habitat (Figure 3). The shallow (1 m) backreef sites at Beveridge Reef were dominated by bare substrate. Hard coral cover and CCA were highest at 5 m sites at Niue and decreased with depth, whereas *Lobophora* showed the opposite trend. *Lobophora* also showed an increase with depth at Beveridge Reef.

FIGURE 3.

Benthic functional group cover by island and depth.

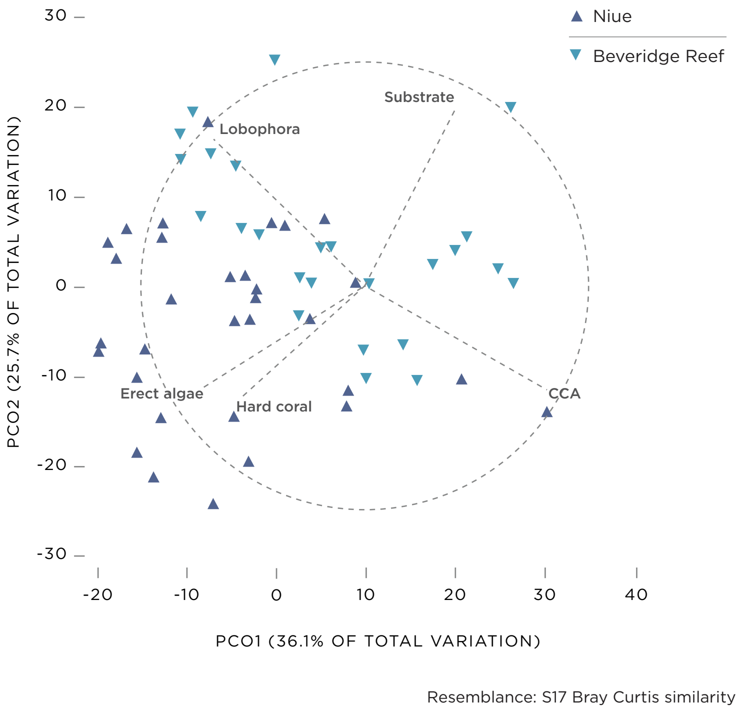


Comparisons of benthic functional groups between islands and depths (10 and 20 m only) showed a significant difference between islands (Pseudo-$F_{1,70}$ – 11.5, p = 0.001), but not between depths or their interaction (both p > 0.05). The first two axes of the multivariate principal coordinates analysis (PCO) plot explained nearly 62% of the variation in benthic functional groups (Figure 4). Hard coral and erect algae explained much of the variation for Niue, while bare substrate was responsible for explaining much of the benthic composition at Beveridge Reef.

There were significant differences in the benthic communities between Niue and Beveridge Reef and between windward and leeward sides of both reef systems, with the differences much more pronounced around Beveridge Reef compared with Niue (PERMANOVAs: all p < 0.001, Figure 5, 6). At Beveridge Reef, CCA was nearly two times higher at windward compared to leeward exposures, and bare substrate was ~ 39% higher at windward exposures (Table 1). Conversely, the cover of *Lobophora* at Beveridge Reef was 5.7 times higher at leeward areas compared to windward locations, while hard coral cover was nearly two times higher at leeward exposures (Figure 7). Similar to Beveridge Reef, CCA also contributed the most to the dissimilarity between windward and leeward areas at Niue with cover 2.7 times higher at windward locations. Hard coral cover at Niue was 3.3 times higher at leeward compared to windward areas and contributed more to the dissimilarity between wind exposures compared to Beveridge Reef. Erect algae showed the largest difference in cover between wind exposures at Niue with cover 4.7 times higher at leeward vs. windward areas.

FIGURE 4.

Comparison of benthic functional groups between Niue and Beveridge Reef using principal coordinates analysis (10 and 20 m stations only). Vector direction and length indicate the relative importance of specific functional groups.



Resemblance: S17 Bray Curtis similarity

FIGURE 5.

A. Leeward Niue,
B. Windward Niue,
C. Leeward Beveridge Reef,
D. Windward Beveridge Reef.

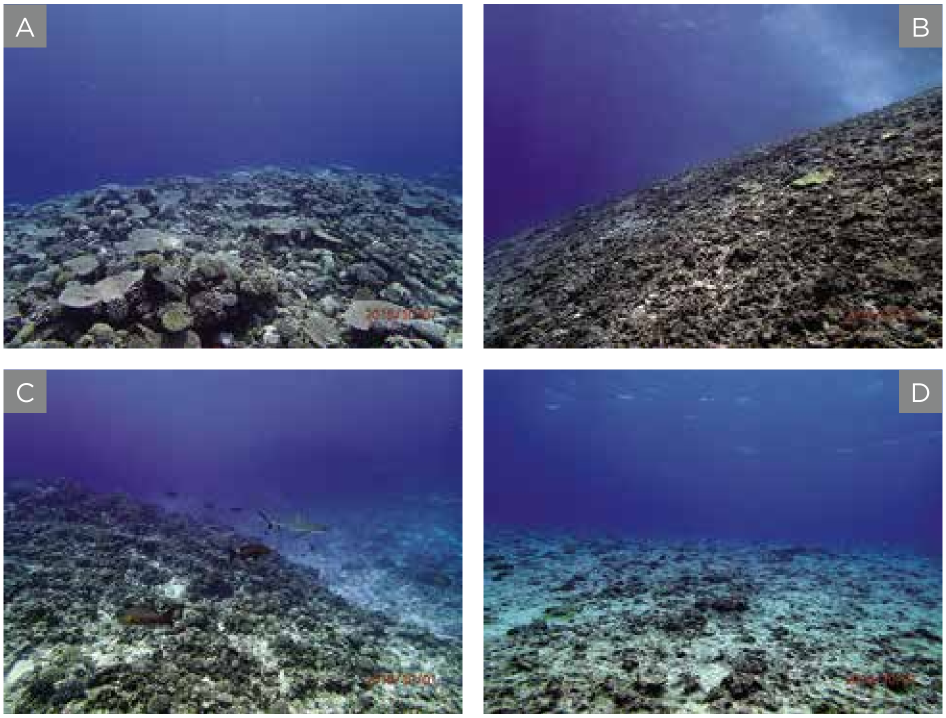


FIGURE 6.

Percent cover of major benthic functional groups around A. Niue and B. Beveridge Reef.

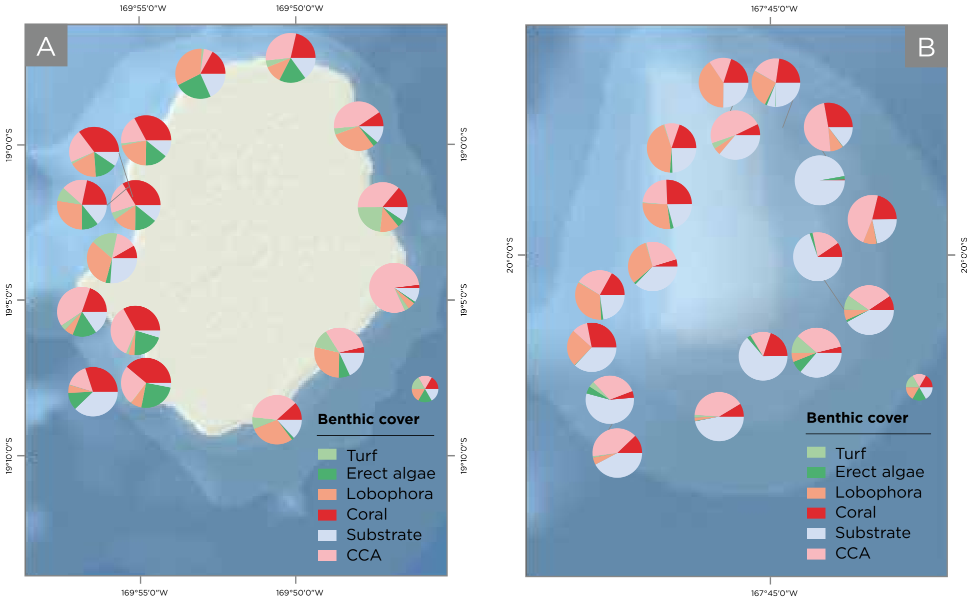


TABLE 1.

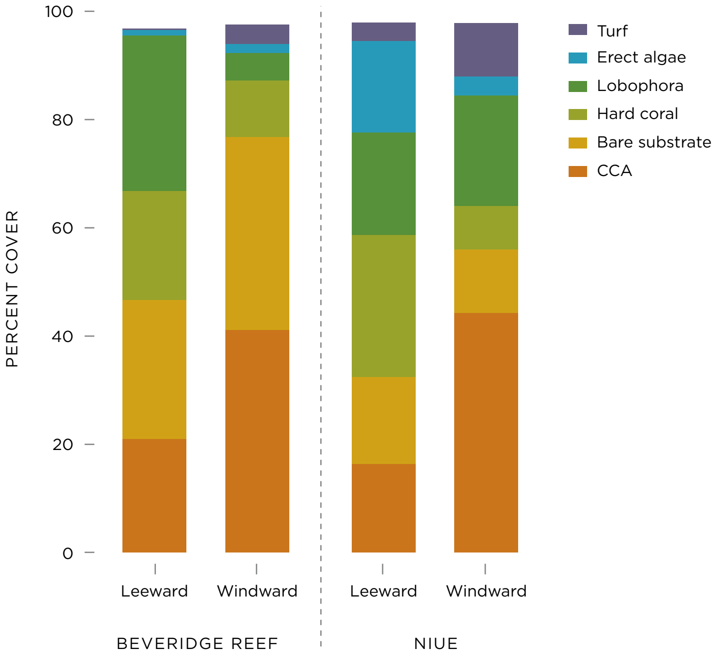
Benthic functional groups contributing most to the dissimilarity between wind exposures (windward vs. leeward) for each island. Dissimilarities were calculated using SIMPER (similarity percentage analysis).

Beveridge Reef	Leeward	Windward	Dissimilarity	% Contribution
CCA	20.95	41.08	12.61	28.46
Lobophora	28.65	5.04	12.11	27.32
Bare substrate	25.75	35.72	9.26	20.90
Hard coral	20.13	10.40	6.06	13.66

Niue	Leeward	Windward	Dissimilarity	% Contribution
CCA	16.33	44.20	14.76	30.66
Hard coral	26.27	8.00	9.53	19.80
Lobophora	18.89	20.40	7.08	14.70
Erect algae	16.91	3.60	6.87	14.26
Bare substrate	16.07	11.80	4.89	10.16

FIGURE 7.

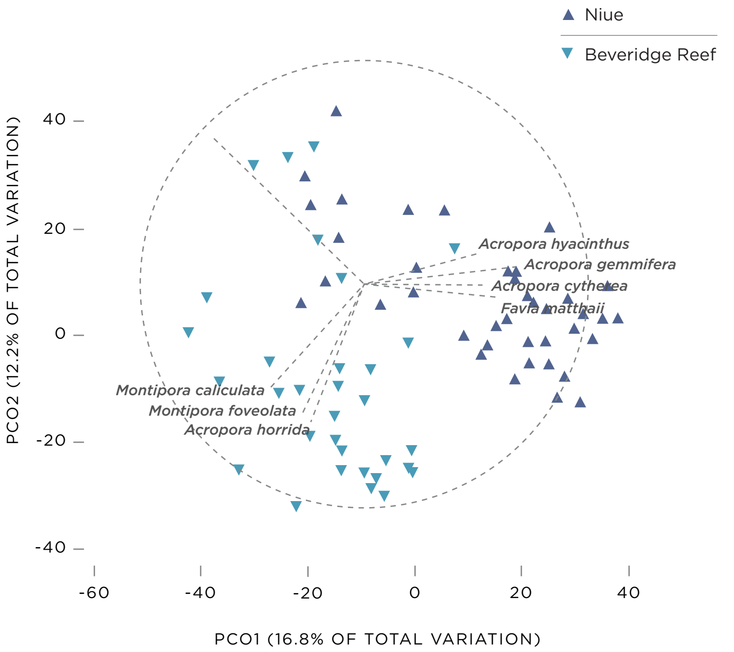
Comparisons of benthic functional group cover between islands and wind exposures.



Corals

We recorded a total of 121 taxa of scleractinian (hard) corals from 12 families during our expedition (Appendix II). The most specious family was Acroporidae (n = 42), followed by Faviidae (n = 23), Poritidae (n = 11), and Agariciidae (n = 9). There were 102 coral taxa recorded from Niue (90 on transect and 12 rare species observed, but not recorded on transect), and 78 from Beveridge Reef (72 on transect, 6 rare species).

The coral species composition between Niue and Beveridge Reef showed a 82.7% dissimilarity and was well separated in ordination space (Figure 8). The top three species by percent cover at Niue were *Acropora gemmifera* (= 3.3 ± 3.9 SD), *Acropora cytherea* (= 2.4 ± 4.2 SD), and *Acropora nasuta* (= 1.9 ± 4.2 SD), while the top three at Beveridge Reef were *Acropora globiceps* (= 1.6 ± 2.0 SD), *Montastrea curta* (= 1.4 ± 1.4 SD), and *Porites lobata* (= 1.1 ± 1.4 SD).



Transform: Square root
Resemblance: S17 Bray Curtis similarity

FIGURE 8.

Comparison of coral species between Niue and Beveridge Reef using principal coordinates analysis. Vector direction and length indicate the relative importance of specific functional groups.

Algae

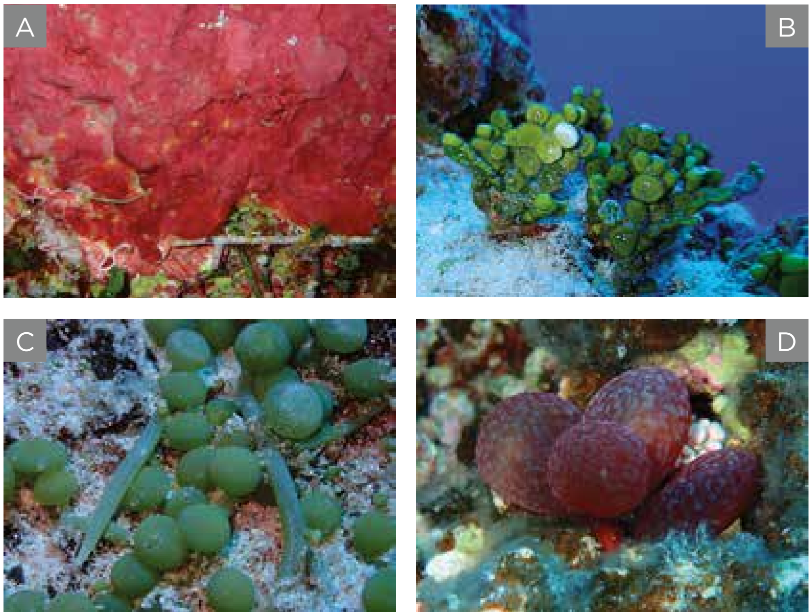
A total of 59 algal taxa were identified during the expedition, with a composition typical of the southwest tropical Pacific (Appendix III). Rhodophyta (red algae) accounted for 49% of the taxa, followed by Chlorophyta (green algae, 37%), Ochrophyta (brown algae, 8%), and Cyanophyta (blue-green algae, 5%).

A total of 56 algal taxa were recorded from Niue, while less than half as many (n = 27) were found at Beveridge Reef. Distributions among algal divisions were similar between reef systems. Rhodophyta comprised 50% of the algal taxa at Niue and 44% at Beveridge Reef. Chlorophyta accounted for 36% of the algal taxa at Niue and 44% at Beveridge Reef. Ochrophyta and Cyanophyta were minor components of the assemblages at both locations.

Encrusting coralline algae were comprised of several species of *Peyssonnelia, Porolithon*, *Neogoniolithon*, and *Haematocelis* (Figure 9). The thalloid brown alga *Lobophora variegata* was mainly found in the encrusting form down to 20 m and the non-encrusting form below 30 m. Erect algae consisted of several species of *Halimeda*, and to a less extent *Caulerpa*, *Microdictyon*, and a mix of other genera. The dominant species of *Halimeda* included *Halimeda opuntia*, *H. micronesica*, and *Halimeda lacunalis f. lata*. We found two interesting algal taxa: *Halimeda pygmaea*, recently described from Fiji, which was found attached to overhangs below 25 m, and *Erythrymenia* sp., an undescribed species also reported from Fiji.

FIGURE 9.

A. Encrusting coralline algae *Peyssonnelia* sp., B. *Halimeda lacunalis f. lata*, C. *Caulerpa macrophysa*, D. *Erythrymenia* sp., an undescribed algae species also reported from Fiji.



Echinoderms

Sea urchins were the most abundant echinoderm (Phylum Echinodermata: e.g., sea urchins, sea stars, sea cucumbers, sea lilies, brittle stars) found on Niue's reefs. Densities of sea urchins were more than one order of magnitude higher overall at Beveridge Reef compared with Niue. *Echinostrephus aciculatus*, a filter feeding sea urchin that collects drift algae, and the grazer *Echinometra mathaei* were the most abundant sea urchins at Beveridge Reef; however, they showed different depth distributions, with *E. aciculatus* most abundant at 10 m and *E. mathaei* most abundant in the shallow backreef (Figure 10, 11). *Echinothrix diadema* was the next most abundant sea urchin at Beveridge Reef and was twice as abundant in the shallow backreef compared with the 10 m forereef sites. This species was the most abundant sea urchin found at Niue with densities two times higher at 5 vs. 10 m. Sea urchins were uncommon at the 20 m sites at both islands, although an unidentified *Echinothrix* was observed in moderate densities (= 0.1 m^{-2}) at Beveridge Reef at this deeper depth.

The sea lily *Comaster* sp. was common at some 20 m sites around Niue but not observed anywhere else during the expedition. Two sea cucumbers (*Thelenota ananas* and *Holothuria atra*) were observed on transects at Beveridge Reef but not around Niue. *H. atra* was observed only along the shallow backreef sites (= 0.27 m^{-2}) and *T. ananas* was found in similarly low densities at both the 10 and 20 m sites (= 0.02 m^{-2}).

FIGURE 10.

Densities (number 10 m^{-2}) of the most common sea urchins observed at Beveridge Reef and Niue by depth.

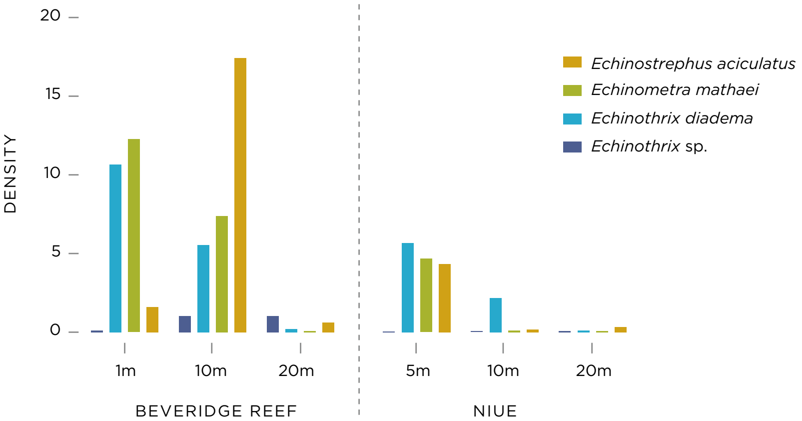
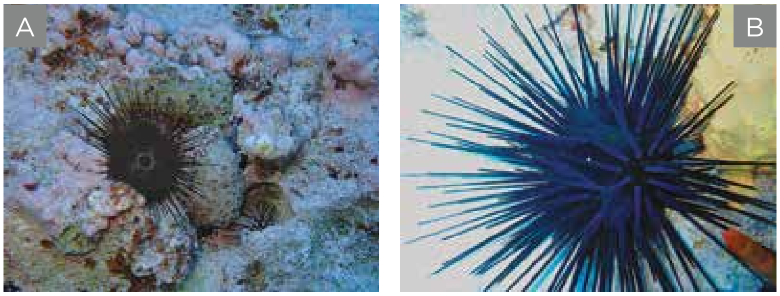


FIGURE 11.

A. The most abundant sea urchin at Beveridge Reef was the filter feeder *Echinostrephus aciculatus*. B. The grazer *Echinothrix diadema* was most common at Niue.



Commercially important invertebrates

Populations of commercially important macro-invertebrates were surveyed using manta tows and reef benthos transects (RBT) (Appendix IV). Macro-invertebrate densities were relatively low overall except for a few species such as giant clams (*Tridacna* spp.) and sea urchins (*Echinothrix* spp. and *Heterocentrotus mammillatus*, Table 2). Although generally abundant, these species showed great spatial variation at each of the sites surveyed. Densities of macro-invertebrates were likely influenced by wind and swell, with higher densities of *Tridacna* spp. observed at leeward locations, both at Niue and Beveridge Reef (Figure 12). *Tridacna* spp. averaged ~ 2000 individual ha^{-1} at leeward sites around Beveridge Reef, and an order of magnitude lower than that on the windward side as well as around the entire island of Niue.

RBTs were conducted only at Beveridge Reef, hence results regarding macro-invertebrate abundance should be treated with caution. However, densities tended to follow the same pattern as those found with manta tow surveys, with relatively high densities of sea urchins and giant clams at the leeward site of the lagoon. *Tridacna maxima* densities at Beveridge Reef approximated the regional reference densities for healthy stocks (750 ha^{-1}, Table 2). Other macro-invertebrate species were found at relatively low densities.

TABLE 2.

Densities (individuals ha^{-1}) of common macro-invertebrate species (i.e. those observed in at least two of the three stations surveyed) in Beveridge Reef lagoon. na = no regional reference density available.

Species	Average ± SE	Regional reference density for healthy stocks (Pakoa et al. 2014)
Echinothrix diadema	9,250.00 ± 2,752.21	na
Echinometra mathaei	1,555.56 ± 527.78	na
Tridacna maxima	1,375.00 ± 674.86	750
***Diadema* sp.**	1,013.89 ± 972.52	
Holothuria atra	930.56 ± 222.22	5,600
Heterocentrotus mammillatus	736.11 ± 427.86	na
Echinothrix calamaris	194.44 ± 174.03	na
Turbo argyrostomus	180.56 ± 160.17	na
Tridacna* sp.	41.67 ± 24.06	na
Reishia armigera	41.67 ± 24.06	na
Holothuria whitmaei	41.67 ± 24.06	50

* *Tridacna* sp. showed shell details that may not be consistent with *Tridacna maxima*.

A total of 99 *Tridacna maxima* were measured during the survey at Beveridge Reef. Measured individuals ranged from 20 to 400 mm, with a modal length class of 111–120 mm (Figure 13). Eighty-six percent of the measured population was below the minimum legal harvest sale of 180 mm in effect for Niue.

FIGURE 12.

Densities of macro-invertebrates from manta tows.

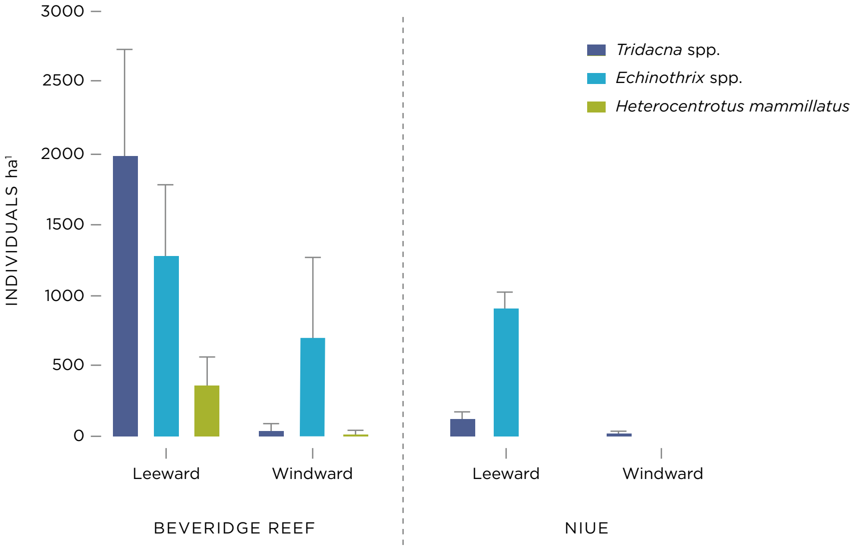
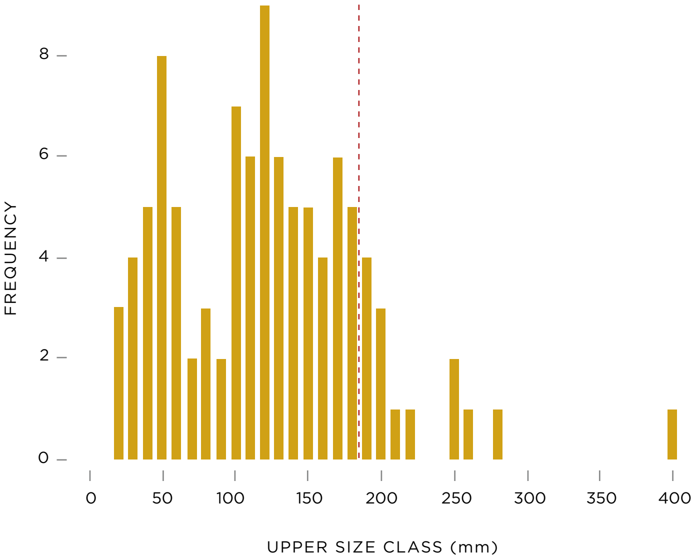


FIGURE 13.

Size frequency distribution of *Tridacna maxima* at Beveridge Reef lagoon (n = 99). The red line represents the minimum legal size for harvest at Niue.



Connectivity studies

Overall, a total of 175 samples, from two species of invertebrate and three fish species, were collected from Beveridge Reef lagoon for genetic analysis (Table 3). Pending collection of comparable genetic tissue from Niue by the Department of Agriculture, Forestry and Fisheries, these tissues will be examined to assess connectivity between Beveridge Reef and Niue.

TABLE 3.

Summary of samples collected from Beveridge Reef for genetic analysis.

Species	No. of individual sampled	Tissue sampled
Tridacna* spp.	89	Mantle
Acanthurus nigrofuscus	25	Muscle
Acanthurus triostegus	21	Muscle
Cephalopholis argus	20	Muscle
Echinometra mathaei	20	Gonad

* Samples of *Tridacna* individuals collected might not have been only composed of the species *Tridacna maxima*.

Fishes

SHALLOW WATER FISHES

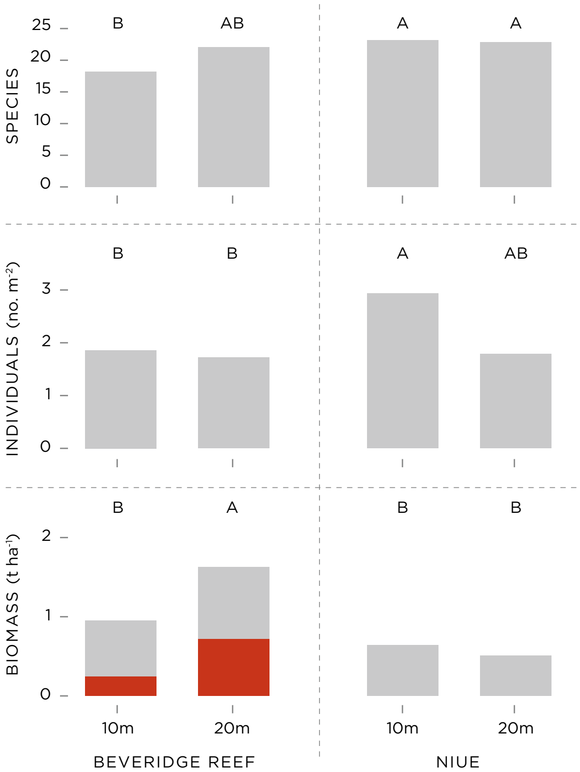
A total of 295 shallow-water fish species from 41 families were observed during our survey (Figure 14, Appendix V). Fish assemblage characteristics (e.g., species richness, numerical abundance, and biomass) were all significantly different among island/depth (10 and 20 m only) combinations (Figure 15). Species richness was lowest at the 10 m sites at Beveridge Reef but similar among all other island/depth combinations. Numerical abundance was highest at the 10 m Niue sites and similar among all others. Biomass showed large differences, with biomass 2.3 times higher at Beveridge Reef compared with Niue, and highest at the 20 m Beveridge Reef sites. At Beveridge Reef, sharks (primarily grey reefs—*Carcharhinus amblyrhynchos*) accounted for 28% of the biomass at 10 m and 44% at 20 m. If sharks are excluded from the analysis, then biomass is not significantly different between islands ($F_{1,173} = 1.8$, $p = 0.17$) or depth strata ($F_{1,173} = 0.6$, $p = 0.56$), although there is a significant interaction ($F_{1,173} = 3.1$, $p = 0.002$).

Comparison of 10 m, 20 m, and shallow (~ 1–2 m) backreef habitats at Beveridge Reef showed significant differences in fish assemblage characteristics (Figure 16). Species richness was significantly higher at the 20 m sites compared with 10 m and shallow backreef. The number of individuals was significantly lower in the backreef compared with the two forereef depth strata. Biomass was significantly higher at 20 m sites compared with either 10 m forereef sites or backreef locations. If sharks are excluded, there is no significant difference in biomass among depth strata at Beveridge Reef ($F_{2,97}$ – 2.7, $p = 0.07$)

FIGURE 14.

A. The dwarf hawkfish (*Cirrhitichthys falco*) and B. Fire dartfish (*Nemateleotris magnifica*) are common species found on Niue's coral reefs.

FIGURE 15.



Fish assemblage characteristics between islands and depths. Red bars denote biomass of sharks. Species richness – $F_{3,173}$ – 4.6, $p = 0.004$. Numerical abundance (number m^{-2}) – $F_{3,173}$ – 7.8, $p < 0.001$. Biomass (t ha^{-1}) – $F_{3,173}$ – 8.4, $p < 0.001$. Letters above bars represent island-depth combinations that are not significantly different from one another based on pair-wise Tukey HSD multiple comparison tests.

Comparisons of fish assemblage characteristics among depth strata at Niue also revealed significant differences (Figure 16). Species richness was similar among depth strata, while number of individuals was highest in the 5 m depth strata and lowest at 20 m. Biomass at Niue was lowest at 20 m and not significantly different between 5 and 10 m. No sharks were enumerated on quantitative transects at Niue, although we did observe both grey reef and whitetip reef (*Triaenodon obesus*) sharks during our dives.

Fish assemblage characteristics varied by wind exposure, with most characteristics typically higher in leeward compared with windward locations between islands and within an island (Figure 17, Table 4). Biomass of sharks was two times higher at leeward areas of Beveridge Reef compared with windward locations, although the relative percentage of shark biomass was similar between exposures (38% leeward vs. 40% windward).

FIGURE 16.

Fish assemblage characteristics between depths within an island. A. Beveridge Reef: Species richness (number transect^{-1}) – $F^{2,97}$ – 11.0, $p < 0.001$, Numerical abundance (number m^{-2}) - $F_{2,97}$ – 7.9, $p < 0.001$, Biomass (t ha^{-1}) - $F_{2,97}$ – 3.4, $p = 0.037$. B. Niue: Species richness (number transect^{-1}) – $F^{2,129}$ – 2.1, $p < 0.123$, Numerical abundance (number m^{-2}) - $F_{2,129}$ – 4.0, $p = 0.022$, Biomass (t ha^{-1}) - $F_{2,129}$ – 9.3, $p < 0.001$. Red bars denote biomass of sharks. Letters above bars represent island-depth combinations that are not significantly different from one another based on pair-wise Tukey HSD multiple comparison tests.

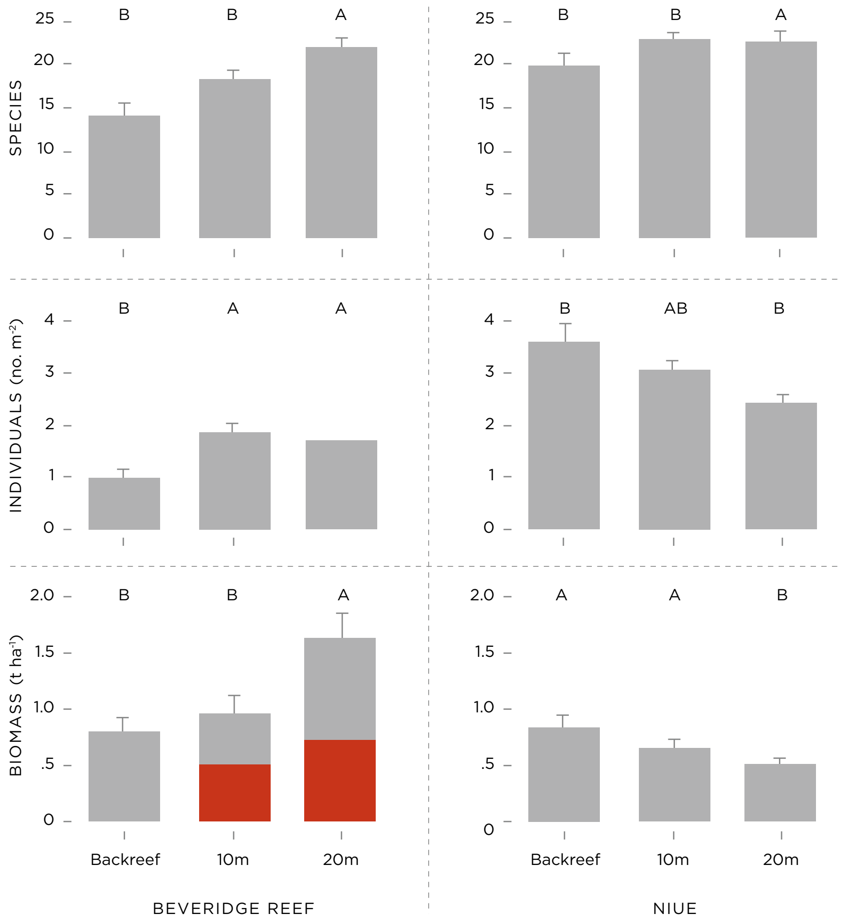


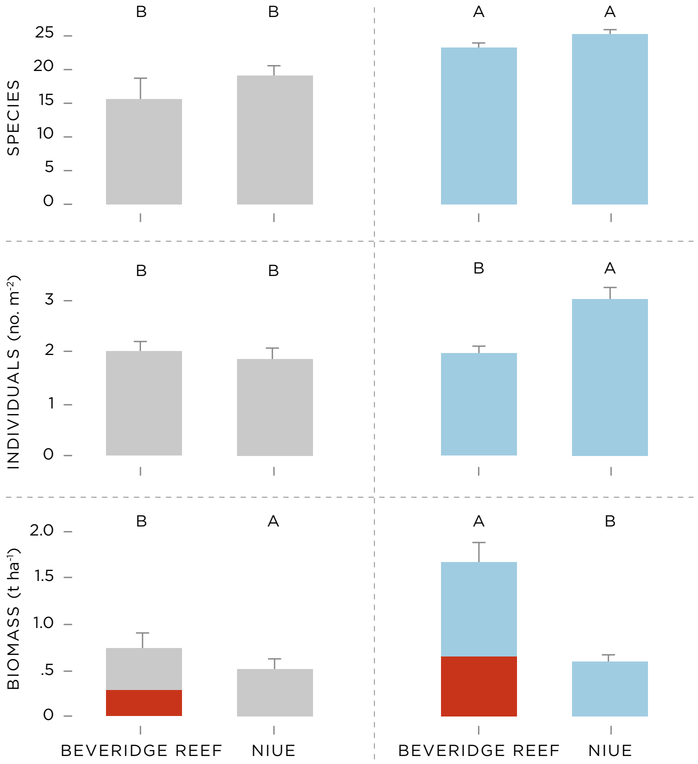
TABLE 4.

Fish assemblage characteristics (Assem. char.) by island (Niue and Beveridge Reef = Bev) and wind exposure. Leeward = lee, windward = wind. Statistical results of two-way analysis of variance (ANOVA). Multiple comparison results of Tukey's HSD pair-wise tests.

Assem. char.	$F_{3,173}$	p	Island	Exposure	Multiple comparisons
Species	20.7	< 0.001	Niue > Bev	lee > wind	Niue_lee = Bev_lee > Niue_wind = Bev_wind
Number	10.7	< 0.001	Niue > Bev	lee > wind	Niue_lee > Bev_lee = Niue_wind = Bev_wind
Biomass	15.6	< 0.001	Bev > Niue	lee > wind	Bev_lee > Niue_lee = Bev_wind = Niue_wind
Biomass w/o sharks	11.5	< 0.001	Bev = Niue	lee > wind	Bev_lee > Niue_lee = Niue_wind > Bev_wind

FIGURE 17.

Fish assemblage characteristics between wind exposures and islands. Red bars denote biomass of sharks. Letters above bars represent island-shore combinations that are not significantly different from one another based on pair-wise Tukey HSD multiple comparison tests.



EFFICACY OF MARINE PROTECTED AREA

Fish biomass in the no-take Alofi North Marine Protected Area (MPA) was not significantly different from fish biomass at comparable leeward locations around Niue ($F_{1,99}$ – 0.92, p = 0.34). In fact, fish biomass was higher, although not significantly so, in every depth stratum sampled outside vs. inside the no-take MPA (Table 5). There was no significant interaction between management (MPA vs. open) and depth strata ($F_{2,99}$ – 0.90, p = 0.41).

FISH TROPHIC COMPARISONS

Piscivores (primarily sharks) made up 57% and 41% of the fish biomass in the 20 and 10 m depth strata at Beveridge Reef, respectively (Figure 18), and were 7.5 times higher at Beveridge Reef compared with Niue. Biomass of this trophic group was low in all other island/depth strata combinations. Herbivores were the dominant trophic group by weight overall, with the highest values and highest percentages of total biomass present in the shallow backreef at Beveridge Reef and the 5 m depth strata at Niue. Carnivores were relatively evenly represented across all depth strata and planktivores had notably low abundance overall.

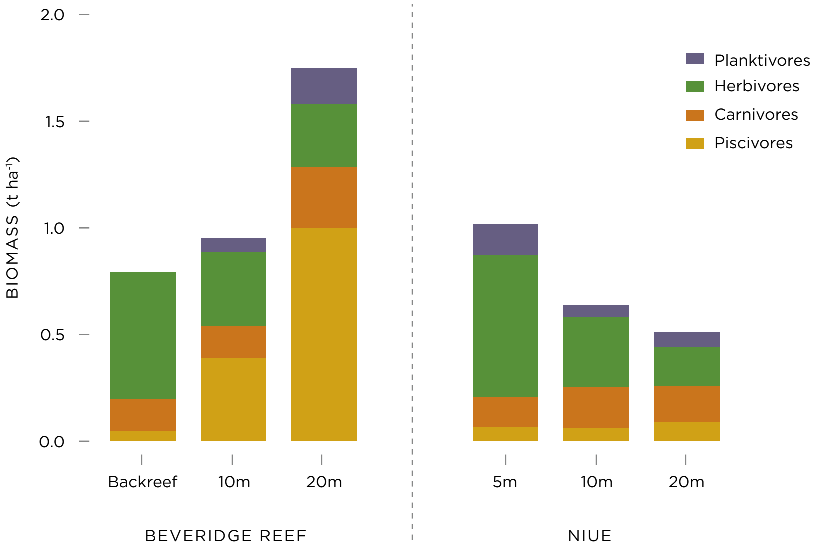
TABLE 5.

Fish biomass in the Alofi marine protected area Alofi North MPA and leeward locations at Niue by depth strata. Values are mean fish biomass (g m^{-2}) with standard deviations in parentheses. Statistical results (F) of least squares means planned comparisons.

Depth (m)	Alofi MPA	Open	% diff.	F	p
5	83.1 (49.1)	84.8 (57.7)	-2.0	0.11	0.74
10	55.1 (36.5)	72.6 (36.0)	-24.0	2.23	0.14
20	47.6 (34.9)	52.4 (35.2)	-9.0	0.16	0.69

FIGURE 18.

Trophic fish biomass by island and depth strata.



FISH SPECIES COMPOSITION

The dominant species by weight at Beveridge Reef was the grey reef shark (*Carcharhinus amblyrhynchos*, = 40.8 ± 96.3 g m^{-2}), which represented 33% of the total fish biomass at Beveridge Reef (Figure 19). This species was followed by bluelined surgeonfish (*Acanthurus nigroris*, = 6.8 ± 18.7 g m^{-2}), bristletooth tang (*Ctenochaetus striatus*, = 5.4 ± 7.0 g m^{-2}), and bullethead parrotfish (*Chlorurus sordidus*, = 4.1 ± 6.4 g m^{-2}). At Niue, the most abundant species by weight were the bristletooth tang (= 3.7 ± 5.4 g m^{-2}), followed by Forsten's parrotfish (*Scarus forsteni*, = 3.2 ± 6.3 g m^{-2}), and peacock grouper (*Cephalopholis argus*, = 3.1 ± 5.7 g m^{-2}).

The fish assemblages between Niue and Beveridge Reef were highly dissimilar (SIMPER – 90.9% dissimilar). The species accounting for most of the dissimilarity were grey reef sharks (11%), bluelined surgeonfish (6%), bristletooth tang (5%), and peacock grouper (3%) (Table 6). The Niue and Beveridge Reef 10 and 20 m forereef sites were well separated from one another in ordination space (Figure 20). Grey reef sharks and blacktip grouper (*Epinephelus fasciatus*) explained much of the separation at Beveridge Reef, while darkfin grouper (*Cephalopholis urodeta*) and agile chromis (*Chromis agilis*) explained the separation at Niue. The 5 m forereef sites at Niue and the shallow backreef sites at Beveridge Reef showed a great deal of overlap, with fivestripe wrasse (*Thalassoma quinquevittatum*) and brighteye damselfish (*Plectroglyphidodon imparipennis*) driving this concordance.

FIGURE 19.

Grey reef sharks were the dominant fish biomass at Beveridge Reef but were rarely observed at Niue.

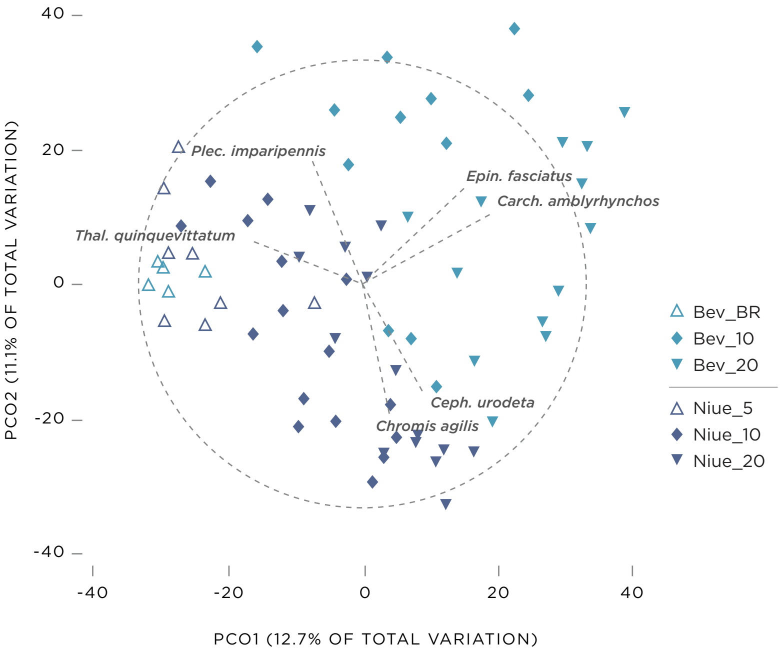
TABLE 6.

Fish species most responsible for the dissimilarity between Niue and Beveridge Reef based on Similarity of Percentages based on SIMPER analysis. Values are biomass ($g\ m^{-2}$) Avg. diss. = average dissimilarity, Cum. % diss. = cumulative percent dissimilarity.

Species	Common Name	Beveridge Reef biomass	Niue biomass	Avg. diss.	Cum. % diss.
Carcharhinus amblyrhynchos	grey reef shark	40.82	0.00	10.80	11.89
Acanthurus nigroris	bluelined surgeonfish	6.83	2.39	5.52	17.96
Ctenochaetus striatus	bristletooth tang	5.36	3.70	4.63	23.05
Cephalopholis argus	peacock grouper	2.88	3.15	3.01	26.37
Chlorurus sordidus	bullethead parrotfish	4.15	0.40	2.88	29.54
Scarus forsteni	Forsten's parrotfish	1.23	3.23	2.65	32.46
Lutjanus bohar	red snapper	2.62	2.82	2.64	35.37
Parupeneus crassilabris	double-bar goatfish	2.87	2.13	2.20	37.79
Melichthys vidua	pinktail triggerfish	2.22	2.10	2.15	40.16
Acanthurus nigrofuscus	brown surgeonfish	1.22	2.76	2.12	42.49

FIGURE 20.

Comparison of fish assemblage structure based on species biomass between Niue and Beveridge Reef and among depth strata using principal coordinates analysis. Vector direction and length indicate the relative importance of the primary species.



Transform: Log(X+1)
Resemblance: S17 Bray Curtis similarity

NEARSHORE PREDATORS

We deployed Baited Remote Underwater Video Systems (BRUVS) on the bottom in ~ 20 m of water to survey the presence and relative abundance of sharks and other fish predators of the nearshore environment. Four species of elasmobranchs (sharks and rays) were observed on benthic BRUVS: grey reef shark (*Carcharhinus amblyrhynchos*), whitetip reef shark (*Triaenodon obesus*), spotted eagle ray (*Aetobatus narinari*), and marbled stingray (*Himantura oxyrhyncha*) (Figure 21). Elasmobranchs were present in 66% of the drops, with a 34% occurrence around Niue and a 98% occurrence at Beveridge Reef (Figure 22). The highest number of individuals per frame (MaxN = 15) was for grey reef sharks at Beveridge Reef. This species was present at 98% of all deployments at Beveridge Reef and 30% of all deployments at Niue. The highest abundance of whitetip reef sharks was only two sharks per frame per hour at Beveridge Reef and was present in 49% of all deployments at Beveridge Reef but only 6% at Niue. Spotted eagle rays were observed only at Beveridge Reef, where they occurred in 18% of the samples. Marbled stingrays were also observed only at Beveridge Reef, with two single observation out of the 49 deployments. The mean number of elasmobranchs per frame per hour was nearly 12 times higher at Beveridge Reef (= 6.0) than at Niue (= 0.50). The MaxN of grey reef sharks was 2.5 times higher than all other elasmobranchs combined. Densities of grey reef sharks from BRUVS at Beveridge Reef were an order of magnitude higher than recorded elsewhere around the world (Table 7).

TABLE 7.

Mean MaxN for grey reef and Caribbean reef sharks from various studies around the world.

Location	Reef Shark Species	Mean MaxN	Reference
Beveridge Reef	***Carcharhinus amblyrhynchos***	**5.10**	**This study**
Palmyra Atoll	*Carcharhinus amblyrhynchos*	1.08	Bradley et al. In press
Raja Ampat	*Carcharhinus amblyrhynchos*	0.50	Jaiteh et al. 2016
Niue	***Carcharhinus amblyrhynchos***	**0.44**	**This study**
GBR = Great Barrier Reef	*Carcharhinus amblyrhynchos*	0.26	Espinoza et al. 2014
Belize	*Carcharhinus perezi*	0.23	Bond et al. 2012
Fiji	*Carcharhinus amblyrhynchos*	0.20	Goetze & Fullwood 2013

In addition to sharks and rays, the relative abundance of several other key species was noted on our BRUVS. These included red snapper (*Lutjanus bohar*), black jack (*Caranx lugubris*), dogtooth tuna (*Gymnosarda unicolor*), and the katuali (sea krait – *Laticauda schystorhyncha*), which is endemic to Niue. Red snapper abundance, a species present in 76% of all deployments (62% at Niue and 90% at Beveridge Reef, respectively) was nearly three times higher at Beveridge Reef (MaxN = 4.45 ± 0.09 SE) compared to Niue (1.66 ± 0.03 SE). Similarly, black jacks were abundant at Beveridge Reef (3.65 ± 0.45 SE) and were virtually absent from Niue.

FIGURE 21.

Maximum number of individuals per frame (MaxN) for dominant predatory species observed on BRUVS.

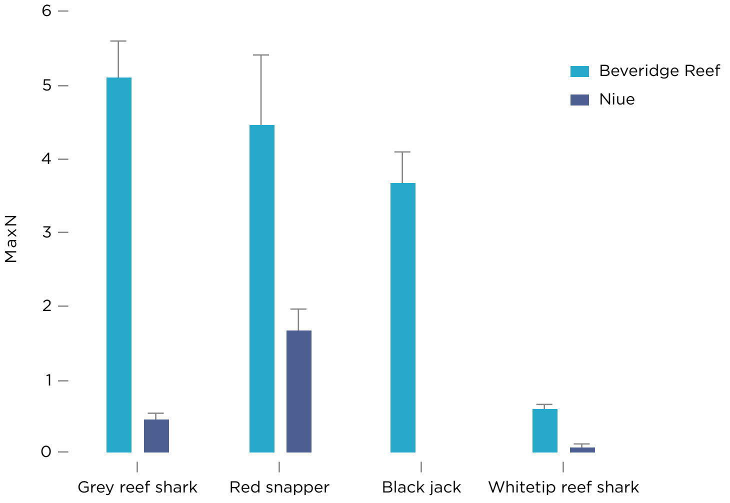


FIGURE 22.

Distribution of dominant predatory fishes observed on BRUVS around A. Niue and B. Beveridge Reef. Values for pie sizes at MaxN per station.

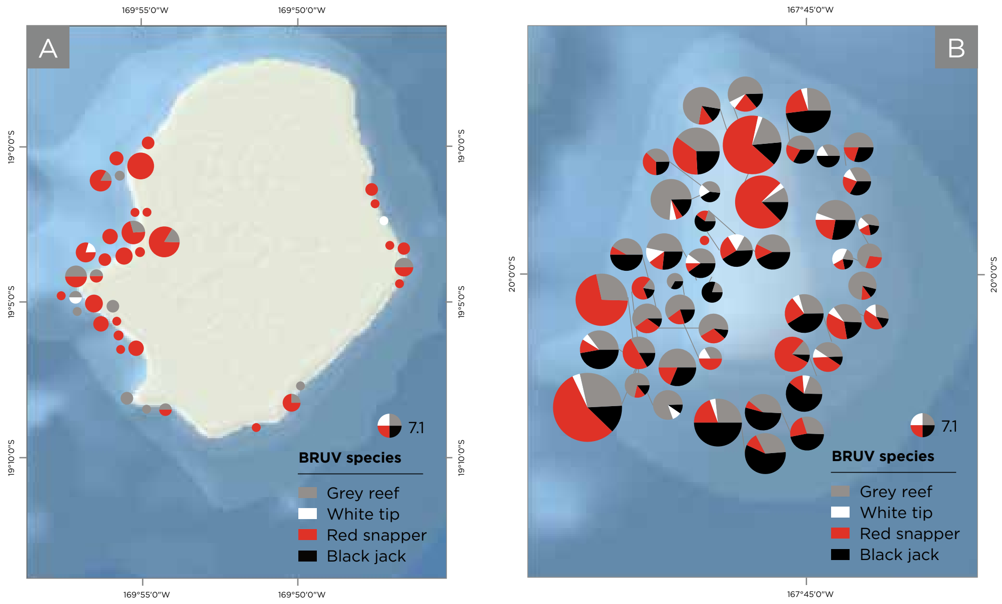


FIGURE 23.

Elasmobranchs (sharks and rays) observed on benthic BRUVs. A. Grey reef shark (*Carcharhinus amblyrhynchos*), B. Whitetip reef shark (*Triaenodon obesus*), and C. Marbled stingray (*Himantura oxyrhyncha*).

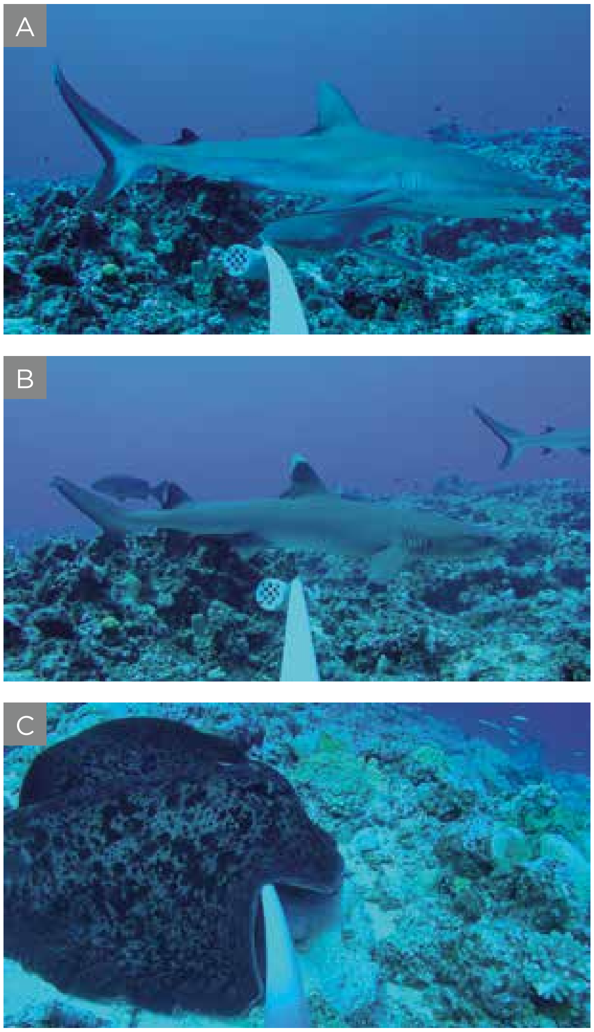


FIGURE 24.

Other reef fish predators recorded included A. Red snapper (*Lutjanus bohar*) and B. Giant trevally (*Caranx ignobilis*).

The presence of several other predators was recorded but not included in the analysis including several giant trevally (*Caranx ignobilis*), humphead (Maori) wrasse (*Cheilinus undulatus*) and large schools of Heller's barracuda (*Sphyraena helleri*). Notably, three species of endangered marine turtles were also recorded: loggerhead sea turtle (*Caretta caretta*), green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*).

FIGURE 25.

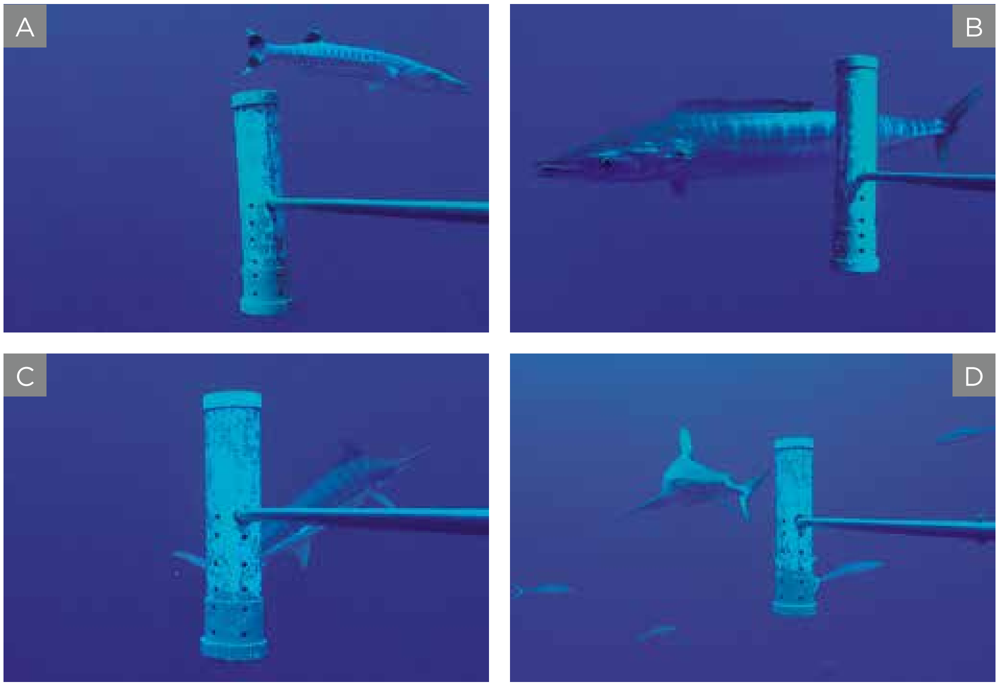
Three species of marine turtles were recorded at Beveridge Reef. A. Loggerhead (*Caretta caretta*), B. Green (*Chelonia mydas*), and C. Hawksbill (*Eretmochelys imbricata*).

PELAGIC ASSEMBLAGES

Mid-water BRUVS were deployed at 10 sites each around Niue and Beveridge Reef with a total of 100 individual camera drops (there were five stereo camera pairs on each longline). We recorded 112 individual pelagic fishes and marine mammals, representing 16 species from nine families with some indicative and rare species shown in (Figure 26).

Overall, total abundance per sample was nearly six times higher at Beveridge Reef compared with Niue and species richness was two times higher at Beveridge Reef. However, these differences were driven by a single sampling site to the west of Beveridge Reef when 50 individuals from nine species were observed. If this one sample is excluded, then abundance and species richness between the two islands is nearly identical (abundance: 1.7 vs. 1.1, richness: 1.0 vs. 0.9, Beveridge Reef vs. Niue, respectively). More sampling is needed to distinguish whether this area is a relative hotspot or an artifact of the patchy distribution of pelagic wildlife.

FIGURE 26.



Species observed on mid-water BRUVS.
A. Great barracuda (*Sphyraena barracuda*),
B. Wahoo (*Acanthocybium solandri*),
C. Striped marlin (*Kajikia audax*),
D. Grey reef shark (*Carcharhinus amblyrhynchos*) and rainbow runners (*Elagatis bipinnulata*).

The most abundant species was the mackerel scad (*Decapterus macarellus*) with 25 individuals observed, but this species was observed only at 5% of the sites (Table 8). The freckled driftfish (*Psenes cyanophrys*) was the most frequently observed species, occurring at 35% of the sites, but only eight individuals in total were sighted. Flying fish (*Cheilopogon* spp.) were observed at 20% of the sites and were frequently seen from the vessel. A variety of pelagic predators including three species of shark, two species of tuna, wahoo (*Acanthocybium solandri*), striped marlin (*Kajikia audax*) and Blainville's beaked whale (*Mesoplodon densirostris*) were observed on camera drops; however, all were in low abundance, and present ≤ 10% of the sites.

The mean length of mackerel scads was 43.5 cm (Table 9), which is the largest mean recorded size for this species at any of our Pristine Seas locations to date. Mean length for flying fish was 32.6 cm (max = 39.3 cm), which is in the upper size range for the family Exocoetidae. Measurements of individuals of *Psenes cyanophrys, Caranx sexfasciatus*, and *Naucrates ductor* suggest they were all predominantly juveniles.

TABLE 8.

Species observed on mid-water BRUVS at Niue and Beveridge Reef ranked by Index of Relative Dominance (IRD). Maximum number of individuals (MaxN) by longline (camera), mean MaxN per site (sd), percentage of sites where species was present, and (IRD = MaxN site x % sites).

Common Name	Species	MaxN longline (camera)	Mean MaxN site	% sites	IRD
Freckled driftfish	*Psenes cyanophrys*	8 (8)	0.08 (0.12)	35	280
Flying fish	*Cheilopogon* spp.	11 (13)	0.13 (0.33)	20	220
Mackerel scad	*Decapterus macarellus*	25 (46)	0.46 (2.06)	5	125
Rainbow runner	*Elagatis bipinnulata*	9 (21)	0.21 (0.94)	5	45
Skipjack tuna	*Katsuwonus pelamis*	7 (7)	0.07 (0.31)	5	35
Wahoo	*Acanthocybium solandri*	3 (3)	0.03 (0.01)	10	30
Silky shark	*Carcharhinus falciformis*	2 (2)	0.02 (0.06)	10	20
Yellowfin tuna	*Thunnus albacares*	3 (3)	0.03 (0.13)	5	15
Trumpetfish	*Aulostomus chinensis*	1 (1)	0.01 (0.04)	5	5
Bigeye trevally (juv.)	*Caranx sexfasciatus*	2 (1)	0.01 (0.04)	5	5
Grey reef shark	*Carcharhinus amblyrhynchos*	3 (2)	0.02 (0.09)	5	5
Oceanic whitetip shark	*Carcharhinus longimanus*	4 (1)	0.01 (0.04)	5	5
Flutemouth	*Fistularia* sp.	5 (1)	0.01 (0.04)	5	5
Striped marlin	*Kajikia audax*	6 (1)	0.01 (0.04)	5	5
Blainville's beaked whale	*Mesoplodon densirostris*	7 (1)	0.01 (0.04)	5	5
Pilot fish	*Naucrates ductor*	8 (1)	0.01 (0.04)	5	5

TABLE 9.

Measurements of species observed in mid-water BRUVS surveys. Total number of individuals measured (N), mean length for each species (cm), and standard deviation (sd) of length.

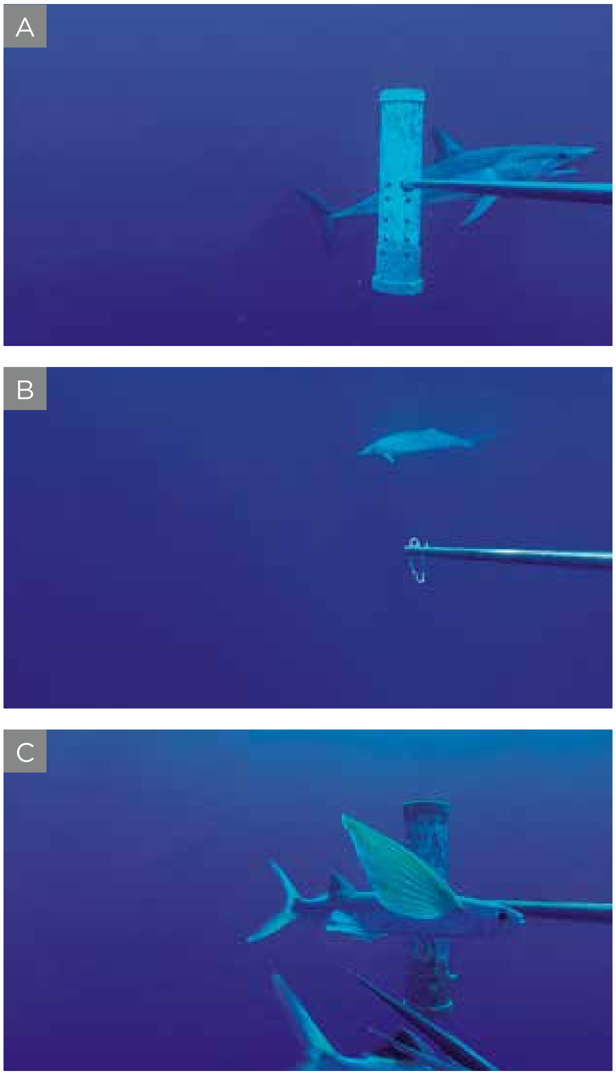
Common Name	Species	N	Mean length - cm (sd)
Wahoo	*Acanthocybium solandri*	2	101.3 (2.1)
Bigeye trevally (juv.)	*Caranx sexfasciatus*	1	5.8
Grey reef shark	*Carcharhinus amblyrhynchos*	2	145.5 (14.5)
Silky shark	*Carcharhinus falciformis*	1	165.1
Flying fish	*Cheilopogon spp.*	11	32.6 (5.4)
Mackerel scad	*Decapterus macarellus*	26	43.5 (6.5)
Rainbow runner	*Elagatis bipinnulata*	17	63.9 (15.8)
Striped marlin	*Kajikia audax*	1	331.8
Skipjack tuna	*Katsuwonus pelamis*	5	59.8 (10.2)
Pilot fish	*Naucrates ductor*	1	9.5
Freckled driftfish	*Psenes cyanophrys*	4	7.0 (5.1)
Yellowfin tuna	*Thunnus albacares*	1	98.6

Due to the low number of fishes observed, the entire video, beyond the standardized two-hour sampling period, was scanned for additional species. This effort yielded five additional individuals, four of which belonged to species previously recorded. The extended sampling yielded a single shortfin mako shark (*Isurus oxyrhynchus*) south of Beveridge Reef (318.6 cm TL, Figure 27). Additionally, the wahoo measured within the two-hour survey periods were relatively small (= 101.3 cm), compared to the two individuals documented outside the survey period, which were much larger (185.6 and 199.0 cm).

Additional observations were made during time on the water while deploying and retrieving mid-water BRUVS. A pod of Blainville's beaked whales, consisting of at least four individuals, was observed and opportunistically filmed to the west of Beveridge Reef on October 1, 2016 (Figure 27), and one individual was observed on a deployment to the east of the atoll four days later. Humpback whales were commonly observed close to the reef, with mother and calf pairs and singing males. Flying fish, of at least three taxa, were seen from the surface on all trips outside the reef both at Niue and Beveridge Reef and were observed in abundances greater than have been observed during previous Pristine Seas expeditions (Figure 27). Few seabirds were noted overall compared with other locations sampled as part of the Pristine Seas program.

FIGURE 27.

A. Shortfin mako shark (*Isurus oxyrhynchos*), B. Blainville's beaked whale (*Mesoplodon densirostris*), C. Flying fish (*Cheilopogon* spp). All species were observed at Beveridge Reef.



Deep sea

We conducted 11 dropcamera deployments at Niue and Beveridge Reef from September 27–October 8, 2016. Deployments ranged from 276–2,447 m in depth (mean = 1,115 ± sd 796 m) (Table 10). The deep (1,094–2,447 m) seafloor was comprised largely of sand and cobble habitat, while the most common substrata-type overall was sand. Three deployments at mid-depths (276, 274, and 407 m) were classified as diagonal rock ridge.

Thirty-two species from 21 families were observed and six classes from five phyla were represented in the video footage (Table 11, Figure 28). The grey cutthroat eel (*Synaphobranchus affinis*, Family Synaphobranchidae) was the most frequently counted of the fishes (45% frequency of occurrence), followed by the cusk eel (*Lamprogrammus brunswigi*, Family Ophidiidae, 36% frequency of occurrence), and their sightings ranged from 2,447 to 1,188 m depth. The deepwater red snapper (*Etelis carbunculus*, Family Lutjanidae, 27% frequency of occurrence) and the rusty jobfish (*Aphareus rutilans*, Family Lutjanidae, 18% frequency of occurrence) were observed in mid-depth surveys (276–506 m).

TABLE 10.

Drop camera deployments and predominant habitats: mud (M), sand (S), pebble (P), cobble (C), boulder (B), continuous flat rock (F), diagonal rock ridge (R), and vertical rock-pinnacle top (T).

Drop	Location	Date	Lat.	Long.	Depth (m)	Habitat > 50%	Habitat > 30%
N1	S Niue	9/27/2016	-19.1186	-169.973	1,825	S	C
N2	NE Niue	9/28/2016	-18.9949	-169.744	2,447	S	C
N3	NW Niue	9/29/2016	-18.9896	-169.980	1,761	S	F
N4	NW Niue	9/30/2016	-18.9279	-169.926	2,053	S	S
N5	W Beveridge Reef	10/1/2016	-19.9919	-167.792	1,094	S	S
N6	S Beveridge Reef	10/2/2016	-20.0543	-167.783	1,188	S	C
N7	W Beveridge Reef	10/3/2016	-20.0114	-167.796	506	S	R
N8	NW Beveridge Reef	10/4/2016	-19.9819	-167.778	276	R	S
N9	NE Beveridge Reef	10/5/2016	-19.9929	-167.729	434	S	S
N10	Alofi Ridge, Niue	10/7/2016	-19.0736	-169.961	274	R	S
N11	Alofi Seamount, Niue	10/8/2016	-19.0838	-169.999	407	R	R

Of the sharks, the grey reef shark (*Carcharhinus amblyrhynchos*) and the Galapagos shark (*Carcharhinus galapagensis*) were each observed on one deployment, at 276 and 506 m depth, respectively. The purple chimaera (*Hydrolagus purpurescens*, Family Chimaeridae) was observed at 1,761 m and the lanternshark (*Etmopterus* sp., Family Etmopteridae) was observed at 1,188 m. The first observation of a smalltooth sand tiger (*Odontaspis ferox*, Family Odontaspididae) in Niue was noted at 506 m depth.

Only one Echinoderm was observed: a sea star (Family Astropectinidae) at 506 m depth. Arthropods were abundant. Gamba shrimp (Family Aristeidae) were the most numerous and frequently encountered invertebrates, as they were sighted on 91% of the deployments. Amphipod shrimps were also frequently encountered (sighted on 64% of deployments). Sponges (Family Porifera) were underrepresented, with only one species observed (glass sponge, Family Euplectellidae) at 1,761 m depth. Cnidarians were represented by three families: a sea anemone (Family Liponematidae) at 506 m depth, two Gorgonids (*Leptogorgia* sp. Family Liponematidae), and a black coral (Family Antipathidae) at 274 m depth.

FIGURE 28.

Fishes observed on dropcam deployments. A. *Epinephelus morrhua* (276 m), B. *Odontaspis ferox* (506 m), C. *Paracaesio kusakarii* (274 m), D. *Synaphobranchus affinis* (2447 m).

TABLE 11.

Phylogenetic listing of taxa observed on dropcam videos with maximum number of individuals (MaxN) by site and frequency of occurrence (Freq. occ. %).

Order	Family	Species	Common Name	MaxN	Freq. occ. (%)
Lyssacinosa	Euplectellidae		Glass sponge	0.09	9.1
Actiniaria	Liponematidae	*Liponema* sp.	Sea anemone	0.09	9.1
Alcyonacea	Gorgoniidae	*Leptogorgia*	Gorgonid	0.64	9.1
Antipatharia	Antipathidae		Black coral	0.09	9.1
Amphipoda			Amphipod shrimp	11.64	63.6
			Decapod shrimp	0.09	9.1
	Aristeidae		Gamba shrimp	2.27	90.9
	Pandalidae		Pandalid shrimp	0.09	9.1
Decapoda			Hermit crab	0.09	9.1
Paxillosida	Astropectinidae		Sea star	0.09	9.1
Anguilliformes	Muraenidae	*Gymnothorax berndti*	Y-patterned moray	0.09	9.1
			Eel	0.18	18.2
	Synaphobranchidae	*Synaphobranchus affinis*	Grey cutthroat eel	0.73	45.4
Gadiformes	Macrouridae	*Gadamus* sp.	Grenadier	0.36	18.2
	Moridae	*Antimora rostrata*	Blue antimora	0.18	9.1
		Guttigadus sp.	Morid cod	0.09	9.1
Ophidiiformes	Ophidiidae	*Lamprogrammus brunswigi*	Cusk eel	0.36	36.4
		Lepophidium negropinna	Specklefin cusk eel	0.09	9.1
Perciformes	Carangidae	*Caranx lugubris*	Black jack	0.18	9.1
		Seriola rivoliana	Almaco jack	0.18	9.1
	Lutjanidae	*Aphareus rutilans*	Rusty jobfish	0.18	18.2
		Etelis carbunculus	Deepwater red snapper	0.27	27.3
			Snapper	0.09	9.1
		Paracaesio kusakarii	Saddle-back snapper	1.64	9.1
		Pristipomoides zonatus	Oblique-banded snapper	0.09	9.1
	Serranidae	*Epinephelus morrhua*	Comet grouper	0.09	9.1
	Trichiuridae	*Benthodesmus* sp.	Frostfish	0.09	9.1
Carcharhiniformes	Carcharhinidae	*Carcharhinus amblyrhynchos*	Grey reef shark	0.09	9.1
	Carcharhinidae	*Carcharhinus galapagensis*	Galapagos shark	0.09	9.1
Chimaeriformes	Chimaeridae	*Hydrolagus purpurescens*	Purple chimaera	0.09	9.1
Lamniformes	Odontaspididae	*Odontaspis ferox*	Smalltooth sand tiger	0.09	9.1
Squaliformes	Etmopteridae	*Etmopterus* sp.	Velvet belly dogfish	0.09	9.1

Fishing effort in and around Niue’s EEZ

We examined the magnitude and spatial distribution of fishing effort inside and around Niue's EEZ from 2013 to 2016 using data from Global Fishing Watch (GFW). GFW uses machine-learning algorithms to classify vessels based of their movement patterns. This classification is used when official data are not available; for Niue’s analysis we used a minimum classification accuracy of 80%, which minimizes the possibility that we include cargo or shipping vessels. SPC data for 2015 shows that fishing effort days as reported by GFW are about 36% of those reported to SPC CES database. Although GFW data for Niue’s EEZ are limited, they do provide important insights into the spatial and temporal dynamics of fisheries, especially when other data are nonexistent or not available.

Over this four-year period, 16 unique fishing vessels from seven flagged states (Kiribati, Fiji, Vanuatu, United States, Japan, Taiwan, and China) were observed fishing inside Niue's EEZ from GFW. Total fishing effort has increased inside Niue's EEZ from zero vessels and zero fishing days in 2013 to 12 vessels and 467 fishing days in 2016 (Table 12). This apparent drastic increase is likely a result of increasing coverage in GFW data and more widespread use of the automated identification system (AIS) by fishing vessels. A notable exception to this overall increase is the sharp decrease in Taiwanese fishing effort from 40 fishing days in 2014 to only one fishing day in 2016 (Figure 29). Total fishing effort was predominantly by long-liners from Fiji (39%), Vanuatu (35%), and Taiwan (10%), and vessels from Kiribati of unknown gear type (9%, Table 13). Maps of vessel tracks and fishing effort reveal that fishing activity is more intense to the northwest, and to a lesser extent, the southwest portions of the EEZ (Figure 30, 31). These data are conservative and underestimate the number of fishing vessels operating in Niue’s EEZ because many fishing vessels either do not carry AIS or turn it off when fishing illegally. From our work in other areas, we have concluded that AIS tracking accounts for only 30–50% of the fishing effort.

TABLE 12.

Fishing vessels and fishing effort inside Niue’s EEZ (2013–2016).

Year	Fishing vessels	Days in EEZ	Fishing days in EEZ	Hours in EEZ	Fishing hours in EEZ
2013	0	23	0	381	0
2014	1	82	40	1,494	593
2015	6	123	45	2,149	544
2016	12	619	467	13,238	6,895

FIGURE 29.

Fishing effort (days) by flag state inside Niue's EEZ (2014–2016).

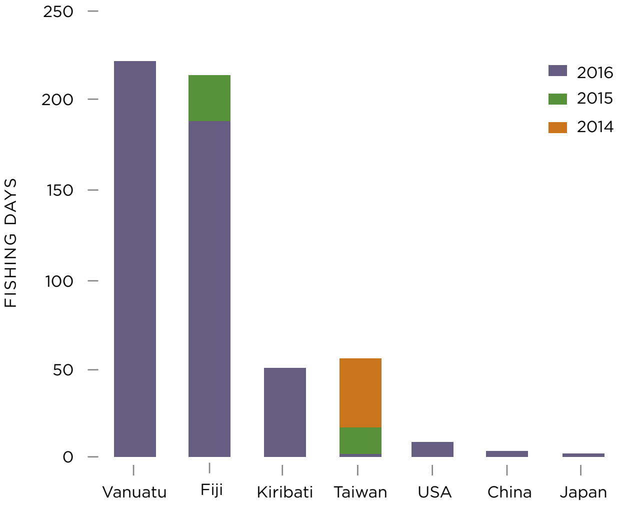


TABLE 13.

Number of vessels (percentage of the total number [%]) and fishing days (percentage of the total number of days [%]) by gear type and flag state inside Niue's EEZ (2013–2016).

Flag state	Gear type	Vessels	Fishing days
Fiji	Drifting_longlines	2 (12%)	213 (39%)
Vanuatu	Drifting_longlines	3 (19%)	194 (35%)
Taiwan	Drifting_longlines	1 (6%)	55 (10%)
Kiribati	Unknown	1 (6%)	49 (9%)
Vanuatu	Unknown	1 (6%)	27 (5%)
United States	Drifting_longlines	2 (12%)	8 (1%)
Taiwan	Unknown	2 (12%)	2 (0%)
China	Drifting_longlines	1 (6%)	1 (0%)
	Pole_and_line	1 (6%)	1 (0%)
	Unknown	1 (6%)	1 (0%)
Japan	Unknown	1 (6%)	1 (0%)

FIGURE 30.

Tracks of fishing vessels inside and around Niue's EEZ (2013–2016).

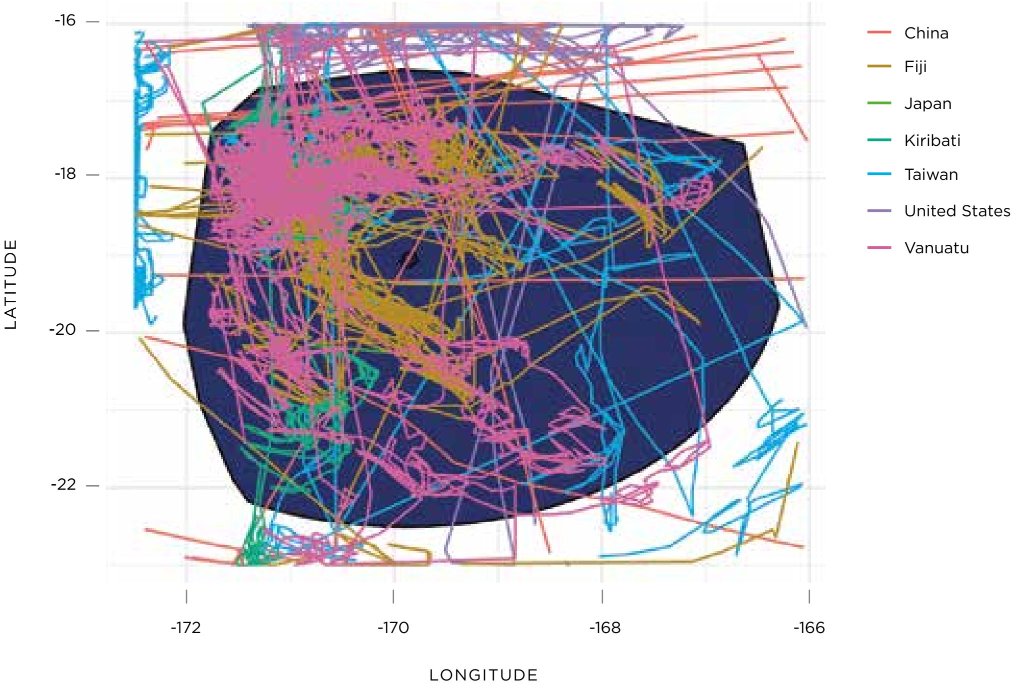
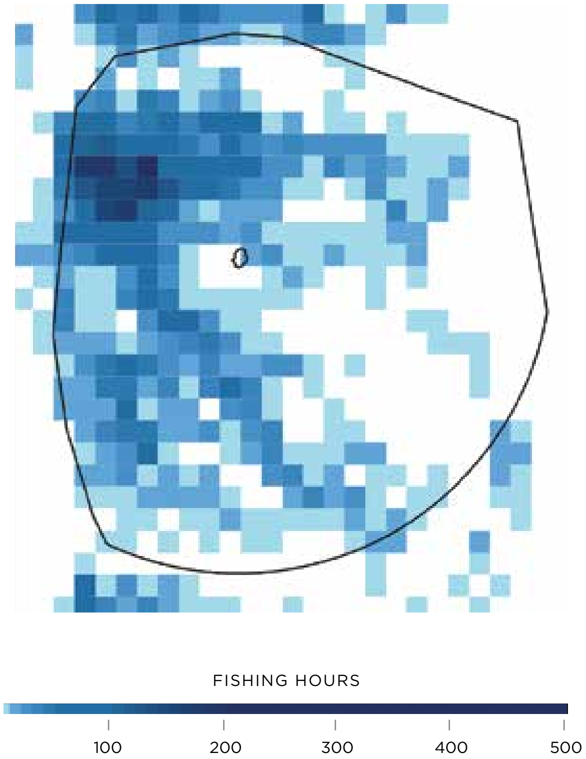


FIGURE 31.

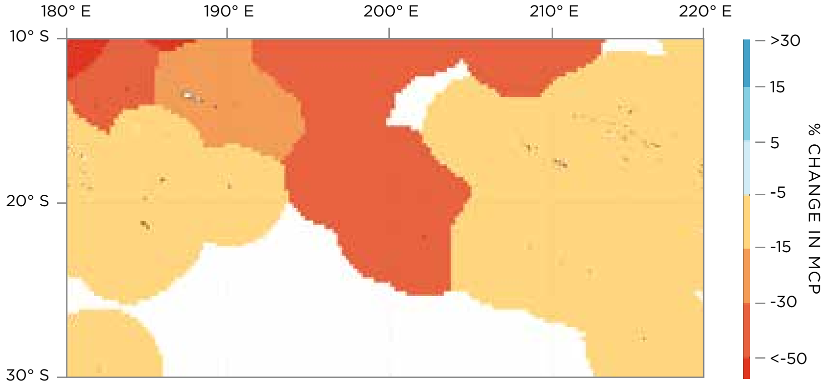
Spatial distribution of fishing effort in and around Niue's EEZ (2013–2016). Grid size = 0.25º.



Understanding how climate change is likely to alter the fisheries revenues of maritime countries is a crucial next step towards the development of effective socioeconomic policy and food sustainability strategies to mitigate and adapt to climate change (Lam et al. 2016). Maximum fisheries catch potential (MCP) is projected to decrease globally by nearly 8% by 2050 relative to 2000 under the business-as-usual scenario (Representative Concentration Pathways [RCP] 8.5). While the decline in MCP in Niue's EEZ is not as low as that for other nations in the region, there is still projected to be a 5–15% decline in maximum catch potential in Niue's waters under conservative climate change projections (Lam et al. 2016, Figure 32).

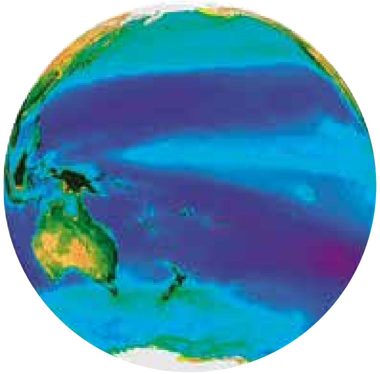
The ocean's least productive waters (oligotrophic) are expanding due to climate change (Polovina et al. 2008). Niue is located in the center of the oligotrophic South Pacific gyre (Figure 33). This area is expanding at 245,766 km²/year or 1.4% of the total per annum (Polovina et al. 2008). The expansion of the low chlorophyll waters is consistent with global warming scenarios based on increased vertical stratification in the midlatitudes, but the rates of expansion already greatly exceed recent model predictions. This means that Niue's already low productivity waters will likely decrease even further in the future.

FIGURE 32.



Change in projected maximum catch potential of Niue and surrounding nations' EEZs in 2050 relative to 2000 levels under Representative Concentration Pathways 8.5 scenario (Lam et al. 2016).

FIGURE 33.



Primary productivity in austral summer from NASA SeaWiFS. Approximate position of Niue's EEZ represented by red circle.

Microplastics

Given the increasing levels of plastic pollution of the oceans, it is important to better understand the impact of microplastics in the ocean food web. We partnered with National Geographic Emerging Explorer Gregg Treinish from Adventurers and Scientists for Conservation (ASC), to sample microplastics during our expedition. We collected samples of seawater in one-liter bottles at 20 locations during the expedition.

Microplastics averaged only 0.37 pieces per liter and were present in 35% of our samples, which is lower than we have seen in most of the other locations we have sampled. Abundance and max number were slightly higher at Beveridge Reef compared with Niue but the differences were small (Table 14). None of the samples taken in the lagoon at Beveridge Reef (n = 3) had any microplastics present. Blue and black filaments were the most abundant microplastics observed.

TABLE 14.

Summary of microplastics found in water samples at Niue.

Location	Samples	Samples w/o plastics	Pieces/L (sd)	Max Pieces/L
Beveridge Reef	8	62.50%	0.46 (0.78)	2.22
Niue	12	66.67%	0.30 (0.49)	1.45
Total	**20**	**65.00%**	**0.37 (0.61)**	**2.22**

Type of microplastic	N
Blue filament < 1.5 mm	4
Black filament < 1.5 mm	3
Red filament 1.6–3.1 mm	1
Transparent filament < 1.5 mm	1
Black other shape < 1.5 mm	1

Micropaleontology

Microfossils are excellent indicators of general environmental conditions such as temperature, salinity and organic enrichment. While some species are cosmopolitan and found worldwide, others are unique to certain geographic locations. We sampled at 20 locations for microfossils during the expedition.

Analysis of the 20 samples is pending, but two samples from Beveridge Reef were selected to represent the lagoon and forereef habitats and picked for foraminifera (> 125 um). The samples were dyed with rose bengal and treated with ethanol when collected, and 10 ml of a sample was wet sieved with > 125 um (63–125 um fraction was archived) for foraminifer analysis. Both samples are mostly biogenic and contained benthic foraminifera almost exclusively (Figure 34, Table 15).

TABLE 15.

Micropaleontology samples sorted from Beveridge Reef.

Picked sample	A16 - forereef	A17 - lagoon
Stained/living foraminifers	None	None
Number of foraminifers per 10 ml	~300	~240
Number of species	~30	~14
Size	≥ 500µ: 56%, < 500µ: 44%	≥ 500µ: 77%, < 500µ: 23%
Breakage	40%	60%
Erosion	50%	80%
Foraminifer dominant	Textulariina	Textulariina
Suborder	(Agglutinated): 55%	(Agglutinated): 33.3%
	Miliolina: 20%	
	Rotaliina: 25%	

FIGURE 34.

Foraminifera sorted from the forereef at Beveridge Reef.

DISCUSSION

DISCUSSION

Our expedition was a collaborative effort between the government of Niue, National Geographic Pristine Seas, Oceans 5, and the Pacific Community. This integrated assessment highlights both the global importance of Beveridge Reef as a shark hotspot and the low standing stock of nearshore fishes around Niue. By creating well-managed resource use zones and a world-class marine reserve, Niue's global profile as a pristine ecotourism destination would increase, as would its contribution to global marine conservation. In addition, effectively managing the nearshore resources would provide sustainable food security for the people of Niue into the future.

Benthic communities

The windward (east) sides of both islands had low structural complexity and limited biotic cover. Compared with Beveridge Reef, Niue had higher cover of coral and erect algae, with less bare substrate. The topographic relief of the uplifted island of Niue provides a more sheltered leeward shore compared with Beveridge Reef, which is emergent only at low tide. This shelter likely provides a more favorable environment for the growth of coral and erect algae. Beveridge Reef has been impacted by a number of cyclones in recent years, which would make the recovery of coral and the growth of erect algae more difficult. The low cover of turf algae at both islands likely reflects high grazing intensities by herbivorous fishes, as well as low productivity.

Cyclone Heta, a category 5 tropical cyclone, struck Niue in 2004, generating waves in excess of 30 m and significantly impacting on marine, as well as terrestrial environments. The cyclone's center passed within 15 km of the Niuean capital, Alofi, and produced a sea surge of over 50 m, which overtopped the sea cliffs and pushed inland more than 100 m, devastating all in its path. Damage from Cyclone Heta was estimated at more than NZ$37 million. Many of the coral colonies on the leeward side of Niue, particularly those of the genus Acropora, were very similar in size structure, likely reflecting the decade of growth following Cyclone Heta (Figure 35).

Nearly 50% of the coral reefs across the Pacific are classified as threatened (Burke et al. 2011, Bruno and Selig 2007). The mean coral values reported at Niue (19%) and Beveridge Reef (15%) are slightly lower than the regional average, around 20%, for the Central Pacific (Bruno and Selig 2007). This might reflect the multiple cyclone impacts over the last few decades, coupled with low productivity and recruitment limitation due to the islands' isolation. Protecting the remaining living corals should be a conservation priority.

Except for sea urchins and giant clams, densities of invertebrates were relatively low in Beveridge Reef and Niue compared with other locations around the Pacific suggesting that isolation of the two locations may play important roles in the presence and abundance of these species. Results from manta tows on the forereef at both reef systems indicate that strong wind and swell exposure likely play an important role in the distribution and replenishment of species and may strongly affect the settlement of individuals.

Observed densities of giant clams were relatively high at Beveridge Reef, close to the regional reference density considered for healthy stocks of 750 individuals ha^{-1}. Densities observed on the leeward side of Beveridge Reef and inside the lagoon tend to suggest a healthy population with low fishing pressure, whereas Niue had low densities even on the leeward part of the reef, which receives less fishing pressure than the leeward coast. Cyclone Heta is likely to have strongly affected the population in both locations. The relatively small size of individuals observed in Beveridge Reef lagoon (shallow depth) may be a consequence of the cyclone, which may have wiped out the older and larger individuals. Moreover, the lack of mature individuals after the cyclone combined with the isolation of the locations may have affected subsequent recruitment to the area.

FIGURE 35.

Many coral species, like this table coral (*Acropora cytherea*), showed similar size structure, likely resulting from regrowth following Cyclone Heta in 2004.

Shallow water fishes

Fish biomass was more than two times greater at Beveridge Reef than at Niue, and the biomass of piscivores was 7.5 times greater. Several large blacksaddled coral grouper (*Plectropomus laevis*) were observed at Beveridge Reef (Figure 37). Planktivores were in notably low abundance at all locations. Fish biomass was not significantly different between the Alofi no-take MPA and other locations along the leeward coast of Niue, regardless of depth.

The fish biomass at Beveridge Reef, based on visual surveys, was dominated by grey reef sharks. In addition, our BRUV results indicate a large abundance of grey reef sharks at Beveridge Reef when compared with other global locations where BRUVs have been deployed to quantify sharks. Sharks and other predatory fish abundance at Niue was low, very likely due to continuous overfishing and fishing for sharks.

Sharks are globally threatened and extirpation of these species from fished coral-reef systems is an imminent likelihood in the absence of substantial changes to coral reef management (Robins et al. 2006, Ferritti et al. 2010). High exploitation rates coupled with low resilience to fishing pressure have resulted in shark population declines worldwide (Dulvy et al. 2014). The landings of sharks and rays, reported to the United Nations Food and Agriculture Organization (FAO), increased steadily to a peak in 2003 (> 900,000 tons) and have declined by 20% since (Dulvy et al. 2014). True total catch, however, is likely to be three to four times greater than reported (Clarke et al. 2006, Worm et al. 2013). Over one-third of sharks and rays in the southwest Pacific region are threatened with extinction (Jupiter et al. 2014), and immediate and substantial reductions in shark fishing will be required to reverse their ongoing collapse.

FIGURE 36.

Grey reef sharks are globally threatened.

The fish assemblage at Niue and Beveridge Reef has affinities to the central Pacific. It is depauperate relative to nearby Tonga, where 1162 species have been recorded (Randall et al. 2003). This difference is most likely due to the limited amount of habitat available around Niue for colonization. *Ecsenius niue* is a small blenny endemic to Niue (Figure 38). This species is locally abundant and while it has a very limited range, it has no known threats and is considered of Least Concern by the IUCN Red List of Threatened Species.

FIGURE 37.

We observed several large blacksaddled coral grouper (*Plectropomus laevis*) at Beveridge Reef.

FIGURE 38.

Ecsenius niue is a small blenny endemic to Niue but locally abundant in shallow subtidal habitats with living coral.

Pelagic ecosystem

Relative to other locations sampled within the Pristine Seas program, there were few scad (*Decapterus* spp.), which are a common pelagic prey species. This raises the question as to what the primary prey are for large pelagic predators such as the wahoo, tuna, and marlin we observed. Since flying fish were observed in large numbers, it may be that they replace scad as the primary prey in Niue's EEZ.

Few sharks were recorded on the pelagic cameras, which is striking given the remoteness of Beveridge Reef and the high number of reef sharks that we observed there. Relative to other sites sampled during the Pristine Seas program, the pelagic fish assemblage at Niue and Beveridge Reef is depauperate. The low richness and abundance may reflect the low natural productivity of the region and/or the result of overfishing. The primary productivity of Niue's EEZ is 159 mg C m^{-2} day^{-1}, with a total shelf area (284 km^2) < 0.1% of its EEZ (Zylich 2012). This level of primary productivity is lower than that reported for nearby Tonga (217 mg C m^{-2} day^{-1}) and the Cook Islands (198 mg C m^{-2} day^{-1}), and much lower than New Zealand to the south (493 mg C m^{-2} day^{-1}). Total fisheries extraction from Niue is low (1,400 t in 2010, Zylich 2012). However, given the low productivity of these waters and the small shelf area, it may be that even low levels of exploitation can deplete this remote and isolated area. However, we also note that our surveys are a snapshot in time and higher levels of sampling throughout the year could yield different results.

Deepwater ecosystems

Our deep (276–2,447 m) video camera footage provided an important contribution to our understanding of the marine fauna of Niue. Despite Niue's isolation, we observed a relatively diverse assemblage of species compared with other populated areas in the Pacific (Dalzell et al. 1993). At least 23 taxa of deepwater fishes from 14 families were observed. We observed a smalltooth sand tiger shark (*Odontaspis ferox*) at 506 m depth, representing the first record of this species at Niue. Important resource fishes were observed at mid-depths, including the comet grouper (*Epinephelus morrhua*), and several species of jacks (Carangidae) and snappers (Lutjanidae). During an early assessment of marine resources at Niue (Dalzell et al. 1993), concluded that fish stocks were abundant and under-exploited. Our video footage shows that while important food fishes were noted, abundances were low relative to other areas we have surveyed in the Pacific. For example, only one species of fish was observed schooling in high density: the saddle-back snapper (*Paracaesio kusakarii*) at 274 m, and only on one occasion. Other food fishes averaged less than one individual per frame.

Rare and unique species

Blainville's beaked whales (*Mesoplodon densirostris*) were observed at Beveridge Reef, which is the first record of this species from Niue's EEZ. There is limited information on global abundance and none on trends in abundance for this species. It is not believed to be uncommon but it is potentially vulnerable to low-level threats and a 30% global reduction over three generations cannot be ruled out. For these reseasons, it is listed as Data Deficient by IUCN. Previous studies of movement patterns on this species suggest strong site fidelity (Schorr et al. 2009), so these individuals may represent a resident population. Despite our sampling period being late in the season, humpback whales were commonly observed close to the reef at Beveridge Reef. We observed mothers with calves and males engaged in singing behavior.

The flat-tail sea snake or katuali (*Laticauda schistorhynchus*) has a very restricted range and is known only from Niue, where it has an extent of occurrence estimated to be less than 300 km^2. This species is listed as Vulnerable by the IUCN and needs to reproduce on land. Its current threats include habitat degradation from coastal development and extreme weather events such as cyclones. Future threats include sea level rise due to climate change.

As noted earlier, we made the first observation of a smalltooth sand tiger (*Odontaspis ferox*, Family Odontaspididae) in Niue. Although *O. ferox* is not specifically targeted by commercial fishing activities, its likely very low fecundity make it susceptible to local extirpation, even at seemingly small capture rates (Fergusson et al. 2008). This species is considered Vulnerable globally by the IUCN.

Management implications

Our results indicate that due to the low productivity and isolation of the region, Niue's marine ecosystems are highly vulnerable to anthropogenic and natural forcing factors, including fishing activity, storm events, and prospective climate change.

HUMAN-CAUSED

The sensitivity of the region to human activity is especially apparent when comparing Niue and Beveridge Reef. Fish biomass is more than twice as high in Beveridge Reef, an area of no fishing, as compared with Niue, which has relatively high fishing pressure. The disparity in biomass is even greater in piscivore biomass, particularly sharks, which were abundant at Beveridge Reef but uncommon on our surveys at Niue. Indeed, fish biomass around Niue is some of the lowest we have witnessed in the Pacific and is consistent with previous work that showed similar results (Labrosse et al. 1999). This indicates that even relatively little fishing activity can significantly impact such a vulnerable ecosystem.

Anecdotally, older fishermen shared that marine resources are in poorer condition compared with the past. Niue's fishing culture is strong and many on the island depend on local catch for their food security. However, there is a huge demand for fresh Niue fish from off-island Niueans, who represent > 90% of the country's population. Exportation of coconut crabs from Niue to New Zealand was banned in 2015 because export numbers had exceeded the suggested harvest levels for the size of Niue. However, there are currently no regulations, or estimates, of the amount of fish that are exported to New Zealand by individuals via plane. Nearshore fisheries resources cannot sustain this level of fishing pressure.

We found no differences in fish biomass between the MPA and adjacent areas despite 20+ years of protection. Fishing line was evident throughout the MPA and poaching inside the MPA likely has contributed to its ineffectiveness. Our deepwater surveys recorded a number of important food fish species; however with low abundances and the ease of overfishing, these stocks likely cannot withstand intensive exploitation and are in need of increased protection.

NATURAL

A major contributor to resource depletions around Niue is the limited natural carrying capacity of the coastal habitats, which are also under constant pressure from high harvest levels (Fisk 2007). As a result of natural disturbances (cyclones, storms, bleaching) and large variations in species replenishment (due to the isolation of Niue from other similar reef systems), the island likely experiences wide fluctuations in resource availability and abundance, on both spatial and temporal scales. These patterns coupled with limited habitat and future climate change scenarios indicate that fish assemblages around Niue are depleted at some level and may not recover under current management activities and future environmental conditions.

MANAGEMENT OPTIONS

Our results suggest Beveridge Reef still has relatively healthy shark populations compared with most places around the world and protecting this remote atoll and its surrounding area should be a top priority for the conservation of Niue's natural heritage. For inshore fisheries, the 2008 Pacific Islands Regional Coastal Fisheries Management Policy (Apia Policy) recognized the need for better management to improve sustainable fisheries yields and maintain ecosystem function (Jupiter et al. 2014a). Fisheries management relies on controlling fishing effort (e.g. seasonal and area closures, gear restrictions, limited entry) and/or catch (e.g. bag and size limits, catch quotas), and many of these measures have been practiced in various forms for thousands of years by indigenous peoples in the Pacific, including Niue (Friedlander 2015). The lack of even the most basic knowledge on catch and effort among most nearshore fisheries in the Pacific makes harvest controls impractical except for a small number of select and valuable single species fisheries. Spatial management, in the form of MPAs; customary marine tenure; more comprehensive marine zoning; and restrictions on destructive and overly efficient fishing gear holds the greatest promise for reversing the decline in coral reef fisheries and the associated ecosystem in the region.

Identifying areas that significantly contribute to fisheries sustainability via a series of strategically selected, long-term, and highly restrictive MPAs would enhance fisheries and preserve biodiversity (Gaines et al. 2010). The establishment of no-take protected areas that are effectively enforced has proven to be a valuable fisheries management tool through adult spillover and enhanced reproductive output (Sladek Nowlis and Friedlander 2005, Edgar et al. 2014), and should be a priority to sustainably manage marine resources in Niue.

The traditional system in many Pacific Islands emphasized social and cultural controls on fishing with a code of conduct that was strictly enforced (Johannes 1978, 1982, Ruddle 1988, Veitayaki 1997, Poepoe et al. 2007). Integrating traditional ecological knowledge and customary management practices into contemporary marine management has shown promise in a number of locations through revitalization of local traditions and resource knowledge (Berkes et al. 2000, Cinner et al. 2005, Aswani & Hamilton 2004, Friedlander et al. 2013). Today hundreds of Pacific Island communities engage in bottom-up management of their coastal and marine resources, with technical support and resources provided by the Locally Managed Marine Area network (Jupiter et al. 2014b).

In summary, our results suggest the need to create small no-take areas around Niue and well-managed fishing areas around those, to stop the depletion of reef fish around Niue. In addition, our results strongly suggest the need to establish a world-class no-take marine reserve in and around Beveridge Reef.

ENFORCEMENT

Any future marine spatial plan will require improved enforcement of existing regulations. Our surveys found no differences in fish biomass between the existing Alofi MPA and adjacent areas despite 20+ years of protection. The discovery of fishing line throughout the MPA suggests low adherence to existing regulations. To ensure efficacy of a future marine spatial plan and long-term food security, Niuen officials should seek to improve enforcement of existing and future regulations.

ECOSYSTEM-BASED MANAGEMENT

To conserve marine biodiversity, maintain fisheries, and deliver a broad suite of ecosystem services over a long-term timeframe, an ecosystem-based fisheries management (EBFM) approach is necessary (Pikitch et al. 2004, Rosenberg & McLeod 2005). Integrated island management offers considerable cost-effectiveness and efficient ways to simultaneously manage biodiversity, climate adaptation, disaster risk reduction and health services (Jupiter et al. 2014b). By creating well-managed resource use zones and a world-class marine reserve, Niue's global profile as a pristine ecotourism destination would rise, as would its contribution to global marine conservation, and its ability to provide food security into the future.

Pristine Seas’ recommendations

BEVERIDGE REEF NO-TAKE MARINE PROTECTED AREA

Beveridge Reef is of extraordinary natural and cultural value to the people of Niue. Our results also suggest it is an important refuge for the grey reef shark, a globally threatened species, and potentially Blainville’s beaked whale, whose life history and population status are virtually unknown. As such, we recommend the creation of a no-take marine reserve at Beveridge Reef and its surrounding pelagic zone. This area would protect the entire Beveridge Reef and surrounding waters frequently used by pelagic species with large habitat use range like sharks, tunas, cetaceans, and sea turtles.

The proposed Beveridge Reef no-take marine protected area (Figure 39) would cover at least six seamounts, ecosystems know for their high levels of endemism and importance as stepping stones for highly migratory species. The proposed polygon would have a minimal impact on current industrial fishing effort (as per Global Fishing Watch effort data) and ongoing artisanal fishing around Niue Island.

The reserve could benefit Niue in several ways:

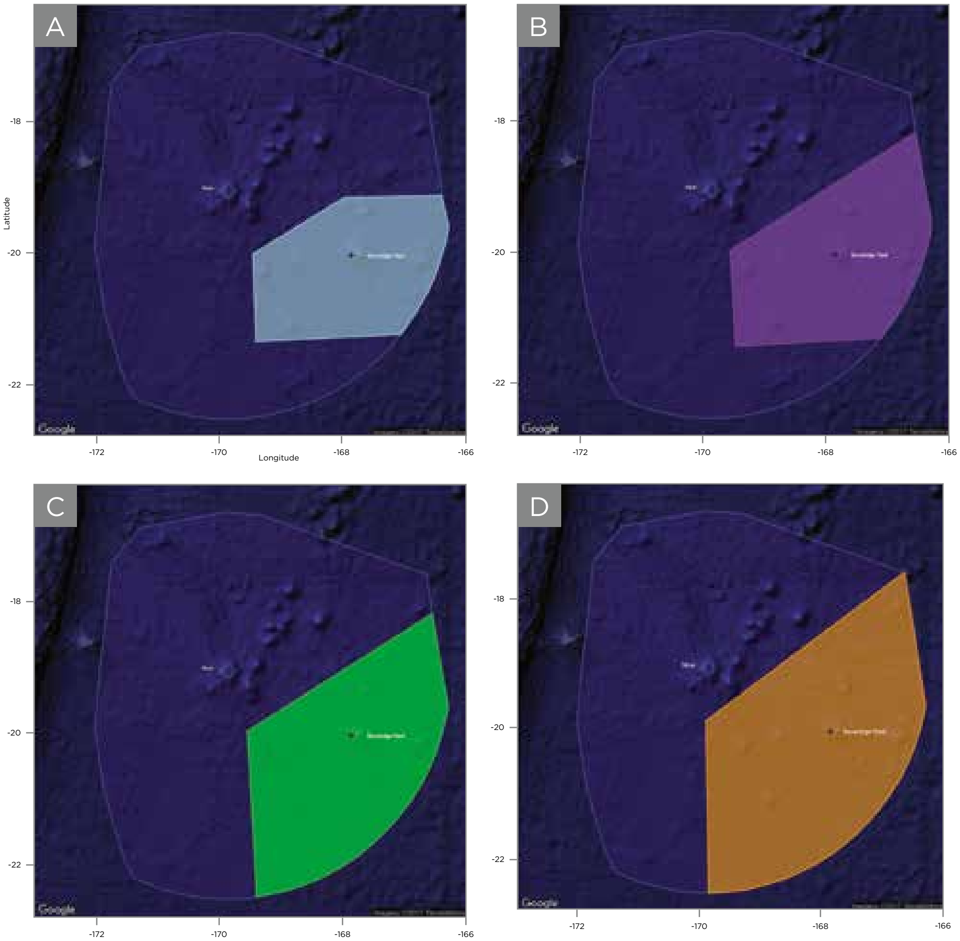
- **Ecotourism:** The proposed marine protected area would position Niue as global leader in marine conservation by protecting 40% of its entire EEZ (> 130,000 km^2). Recent studies suggest that greater levels of protection may bring greater tourism-related economic revenue. In the Caribbean and Pacific Coast of Central America, half of all dives take place in marine protected areas (Green and Donnelly 2003). In the Galápagos, marine-based tourism supports more than one-third of all jobs, bringing nearly US$178 million per year to the local economy. There, the tourism value of a shark over its lifetime is US$5.4 million, while a dead shark brings fishermen less than US$200. In Palau, live sharks in the water bring in $1.9 million to Palau’s economy through dive tourism (Vianna et al. 2012).
- **Shark refuge:** Grey reef shark populations in some areas of the Indo-Pacific have experienced marked declines in recent years due to increased human pressure (Robbins et al. 2006). Large, no-take marine reserves offer important refuge for this threatened species (White et al. 2017).
- **Pelagic fisheries recovery:** Despite the ability of many pelagic species to move great distances, some individuals will spend their entire lives inside the proposed sanctuary, thus increasing the density of marine life inside the reserve, boosting genetic diversity, and increasing local reproductive output, which in turn would benefit adjacent fisheries. Researchers in the western Pacific previously found that half of skipjack tuna spend their entire lives within a radius of 675–750 km and yellowfin tuna were found to have even smaller ranges (Sibert and Hampton 2003). It has been shown that > 91% of the sub-adult yellowfin tuna collected from the nearshore Hawaiian Islands originated from this same nursery. In addition, sub-adults from the offshore location within the Hawaiian Islands appear to originate from the nearshore Hawaiian Islands, highlighting the importance of local production and retention of yellowfin tuna to the standing stock and domestic fisheries of Hawaii (Wells et al. 2012).

Therefore, Niue could achieve benefits from domestic conservation and fishery development policies, although international cooperation could also be necessary. The long reach of global fishing fleets has eliminated nearly all natural refugia, and as a result we urgently need to protect large areas of the ocean to achieve sustainable ecosystems.

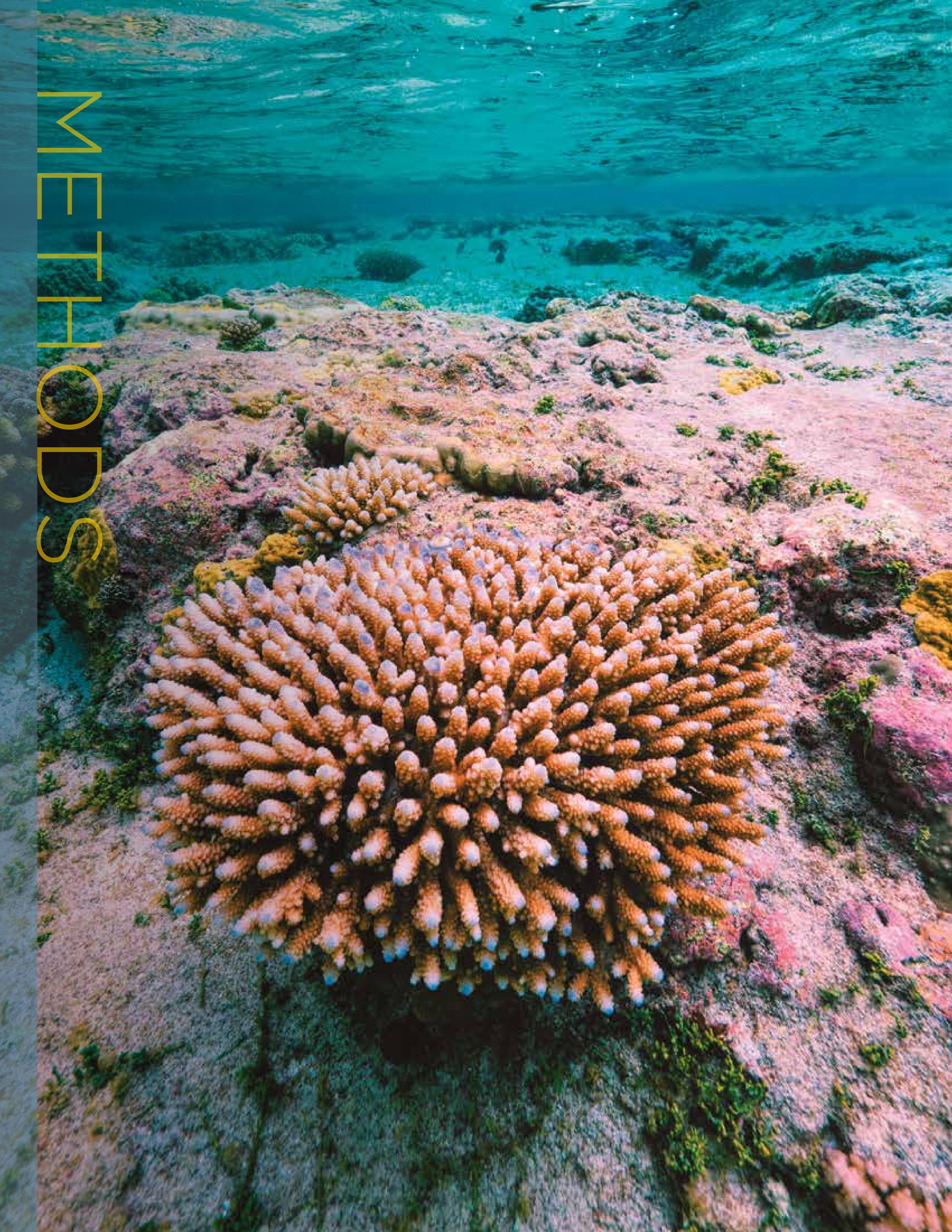
Figure 39 presents potential approaches to expand current protection around Beveridge Reef and its surrounding pelagic zone in a no-take marine protected area. It is important to note that only the 40% EEZ no-take designation (Figure 39D) would qualify as a large-scale MPA according to IUCN and Big Oceans standards. This would well exceed Niue's Aichi Target of protecting 10% of coastal and marine areas and place it second only to Palau in total percent of EEZ protected. We recommend conducting a cost-benefit analysis to determine the optimal reserve size to achieve Niue's long-term goals. This would include a detailed analysis of the historical commercial value of the proposed area, as well as alternatives such as ecotourism. The creation of a large protected area (> 100,000 km^2) around Beveridge Reef would certainly put Niue in an elite group and elevate its status as a global leader in marine conservation.

FIGURE 39.

Potential approach to the Beveridge Reef no-take marine protected area. A. 20% of Niue's EEZ equaling 63,600 km^2, B. 25% of Niue's EEZ equaling 79,250 km^2, C. 30% of Niue's EEZ equaling 95,100 km^2, D. 40% of Niue's EEZ equaling 132,000 km^2.



METHODS



METHODS

Benthos – Characterization of the benthos was conducted along 50 m-long transects running parallel to the shoreline at each sampling depth strata. For algae, corals, and other sessile invertebrates we used a line-point intercept methodology along each transect, recording the species or taxa found every 20 cm on the measuring tape for a total of 250 points per transect. Transects were conducted at 10 and 20 m per site. At Beveridge Reef, we conducted five stations along the backreef area in the lagoon at ~ 1 m water depth to characterize a hard-bottom habitat not found around Niue. At Niue, we conducted transects at 5 m inside and adjacent to the marine protected area, in addition to the 10 and 20 m strata. For mobile invertebrates (primarily echinoderms), we counted individuals in 15, 50 x 50 cm quadrats randomly placed along each of the 50 m transects. Echinoderm test diameter (cm) was estimated for every individual, and total length (cm) was estimated for individual sea cucumbers and longest arm for sea stars.

Benthic functional groups were compared between Niue and Beveridge Reef using SIMPER (similarity percentage analysis) in the PRIMER software package (Clarke et al. 2014) with wind exposures by island as a factor and coral species composition at each site as the dependent variable. The species matrix examined the contribution of each species to average resemblances between sample groups using Bray-Curtis similarities. Principal coordinates analysis using a Bray-Curtis similarity matrix was used to examine the percent cover of benthic functional groups, and coral species that had the most influence in separating reefs at Niue and Beveridge Reef in ordination space. Percent cover of benthic functional groups was arcsine square root transformed prior to statistical analyses. Permutational multivariate analysis of variance (PERMANOVA) was used to examine differences in benthic functional groups between islands, depths (10 and 20 m strata only), and wind exposures (i.e., windward vs. leeward). Data were arcsin square root-transformed and based on a Bray-Curtis dissimilarity matrix for the PERMANOVA.

Fishes – At each depth stratum within a site, divers counted and estimated lengths for all fishes encountered within fixed-length (25 m) belt transects whose widths differed depending on the direction of swim. All fish ≥ 20 cm total length (TL) were tallied within a 4m-wide strip surveyed on an initial "swim-out" as the transect line was laid (transect area = 100 m^2). All fishes < 20 cm TL were tallied within a 2m-wide strip surveyed on the return swim back along the laid transect line (transect area = 50 m^2).

Fish assemblage characteristics (e.g., species richness, numerical abundance, and biomass) were compared among locations using two-way ANOVA with island and exposure as factors. Unplanned comparisons between pairs of locations were examined using the Tukey-Kramer HSD. Numerical abundance and biomass were ln(x+1) transformed prior to statistical analysis.

A similar analysis was conducted between islands and depth strata and within islands among depth strata. Species composition was compared between Niue and Beveridge Reef using SIMPER. Fish biomass was compared between the Alofi MPA and leeward areas of Niue using a two-way ANOVA of depth strata and management (MPA vs. open to fishing). Comparisons within depth strata were conducted using least-squares means. Principal coordinates analysis using a Bray-Curtis similarity matrix was used to compare fish assemblage structure based on species biomass between Niue and Beveridge Reef and among depth strata.

BRUVS – To survey the presence and relative abundance of sharks and other predators of the nearshore environment, we deployed Baited Remote Underwater Video Systems (BRUVS) on the bottom. BRUVS consist of a high-definition camera inside a housing that is mounted on a weighted aluminum frame. A bait bag with 1 kg of crushed fish was placed 1 m from the camera to attract sharks and rays to swim into view. A total of 50 BRUVS were deployed around Niue Island and another 50 around Beveridge Reef. Units were placed a minimum of 500 m apart at a depth of approximately 20 m for 60 minutes per deployment. The relative abundance of each species was calculated as the maximum number of individuals per frame (MaxN) per hour. Of the 100 deployments, 99 were used in this analysis. One drop was omitted because of bias (the bait arm fell out and was out of view).

Mid-water BRUVS – Mid-water BRUVS were deployed ~ 5 km from shore as a longline with five rigs spaced 200 m apart for a minimum filming time of two hours. Mid-water BRUVS are designed to quantify pelagic fish assemblages and their stereo systems enable fish body length measurements to be taken based on three-dimensional trigonometry (Klimley and Brown 1983). Mid-water BRUVS consisted of a cross bar with two GoPro cameras fixed 0.8 m apart on an inward convergent angle of 8°. In longline formation, three units were deployed concurrently and separated by 200 m. Rigs were baited with ca. 800 g of crushed fish. Each rig consisted of a vertical PVC pipe with a float and flag above the water line and was attached to two horizontal pipes, perpendicular to each other, with the bait container and the stereo video camera system. We deployed mid-water BRUVS at 10 sites each around Niue and Beveridge Reef with a total of 100 individual camera drops or samples, with four rigs deployed at each location in longline formation. Each set of rigs was treated as a single independent sample and species richness and total abundance was averaged across the four deployments for each set.

Deep-sea dropcams – National Geographic's Remote Imaging Team has developed deep ocean dropcams, which are high definition cameras encased in a borosilicate glass sphere that are rated to a depth of 10,000 m. Dropcams have an onboard VHF transmitter that allows for recovery using locating antennae with backup location achieved via communication with the ARGOS satellite system. Dropcameras were deployed on seamounts and other unique geological features on an opportunistic basis; we relied on local expertise and bathymetric charts for optimal deployment locations.

The substrata for each dropcamera deployment were classified into standard geological categories following (Tissot et al. 2007): mud (M), sand (S), pebble (P), cobble (C), boulder (B), continuous flat rock (F), diagonal rock ridge (R), and vertical rock-pinnacle top (T). Two letters were used to represent the dominant benthic composition. The first letter represents at least 50% cover by that category, and the second, at least 30% cover. Combined, the two-letter code represents the dominant (at least) 80% cover of substrata type at a site. Fish species swimming through the camera system were recorded along with relative frequency of occurrence during a three- to four-hour deployment. The substrate and taxonomic composition of each deployment was assessed by depth range to characterize the biodiversity of deepwater biota.

Microplastic sampling – Water samples were collected at 20 sites around Niue and Beveridge Reef. Samples were collected from a one-liter stainless steel bottle that was rinsed three times prior to collection. At each site, we recorded the date, time, time of high tide, and GPS (global positioning system) coordinates. Samples were sent to Adventurers and Scientists for Conservation in Maine for processing. Once received, the water was vacuum pumped over a gridded 0.45-micron filter and dried for a minimum of 24 hours. Using a microscope at 40x magnification, pieces of microplastic (< 5 mm) on the filter were systematically counted along the grid lines. Each plastic piece was categorized based on shape (round, filament/microfiber, other) and color (blue, red, green, black, transparent/white, other). The volume of water was recorded and the final count for the sample was divided by the quantity of water to obtain a density estimate for each.

Micropaleo sampling – We collected 20 samples from the top 1 cm of sediment at both reef systems to determine the community of benthic microfossils present in different environments in these remote locations. Two samples from Beveridge Reef were selected to represent the lagoon and forereef habitats. Approximately 100 ml of sand was collected, preserved in 90% ethanol and stained using rose bengal. A 10 ml aliquot of sample was wet sieved with > 125 um (63–125 um fraction was archived) for microfossil characterization with a focus on foraminifera.

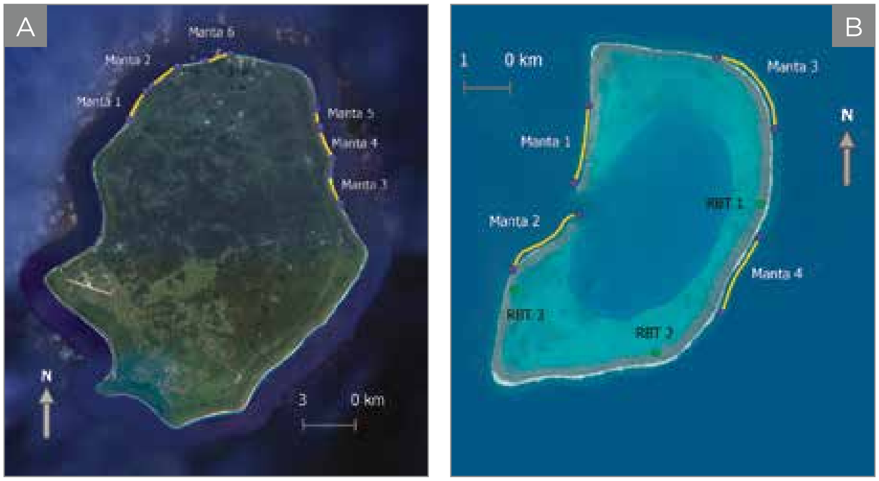
Genetic sampling – To address the potential of connectivity between Beveridge Reef and Niue Island, genetic samples of several species including invertebrates and fish were collected during the expedition. Sampled muscle, mantle, and gonad tissue were preserved in absolute ethanol and sent to a geneticist in New Zealand. Pending collection of comparable genetic tissue from Niue by the Department of Agriculture, Forestry and Fisheries, these tissues will be examined to assess connectivity between Beveridge Reef and Niue.

Manta tow – Surveyors were towed behind a boat at low speed (3–4 km hr^{-1}) on a manta board. Six manta stations were surveyed at Niue and four stations were surveyed at Beveridge Reef (Figure 40). Each station consisted of six 300 x 2 m replicate transects in which large macro-invertebrates were counted. This broad scale methodology allows surveyors to cover a relatively large area quickly, and is particularly effective for rapid assessments of large, non-cryptic benthic invertebrates (e.g., giant clams, sea cucumbers, crown of thorns starfish).

Reef benthos transects – Reef benthos transects were used to provide information on density and size of invertebrate species at fine spatial scales. Three RBT stations were surveyed at different locations on the backreef of Beveridge Reef lagoon (Figure 40). Each station consisted of six parallel 40 x 1 m replicate transects. Stations were surveyed by two snorkelers swimming in parallel. All invertebrate species encountered were enumerated and measured. Due to the lack of comparable habitat no RBT stations were surveyed at Niue.

FIGURE 40.

Locations of Manta and RBT survey stations in A. Niue (© Google Earth) and B. Beveridge Reef (© Earth Science and Remote Sensing Unit, NASA Johnson Space Center).



REFERENCES

Aswani S, Hamilton RJ. 2004. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science in the Rovianna Lagoon, Solomon Islands. Environ Conserv 31:69-83

Bell AV, Currie TE, Irwin G, Bradbury C. 2015. Driving Factors in the Colonization of Oceania: Developing Island-Level Statistical Models to Test Competing Hypotheses. American Antiquity. 80(2):397-407.

Berkes F, Colding J, Folke C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecol Apps 10:1251-1262

Best, E. 1922. Some aspects of Maori myth and religion (No. 1). Dominion museum.

Bradley, D., Papastamatiou, YP and J.E. Caselle. In press. No persistent behavioural effects of scuba diving on reef sharks. Marine Ecology Progress Series.

Bruno, JF, and Selig, ER. 2007. Regional decline of coral rover in the Indo-Pacific: Timing, extent, and subregional comparisons. PLoS ONE 2: e711. doi:710. 1371/journal.pone.0000711.

Burke, L, Reytar, K, Spalding, M and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington, D.C.

Cinner JE, Marnane MJ, McClanahan TR, Almany GR. 2005. Periodic closures as adaptive coral reef management in the Indo-Pacific. Ecology and Society 11(1): 31. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art31/

Clark G. 2010. The sea in the land: maritime connections in the chiefly landscape of Tonga. The Global Origins and Development of Seafaring. McDonald Institute for Archaeological Research, Cambridge. 2010:229-37.

Clarke, KR, Gorley, RN, Somerfield, PJ, Warwick, RM. 2014. Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, UK.

Clarke SC, McAllister MK, Milner-Gulland EJ, Kirkwood GP, Michielsens CG, Agnew DJ, Pikitch EK, Nakano H, Shivji MS. 2006. Global estimates of shark catches using trade records from commercial markets. Ecology letters. 9(10):1115-26.

Dalzell, P, Lindsay, SR, Patiale, H, & South Pacific Commission. 1993. Fisheries resources survey of the island of Niue.

Dulvy NK, Fowler SL, Musick JA, Cavanagh RD, Kyne PM, Harrison LR, Carlson JK, Davidson LN, Fordham SV, Francis MP, Pollock CM. 2014. Extinction risk and conservation of the world's sharks and rays. Elife. 3:e00590.

Espinoza, M, Cappo, M, Heupel, MR, Tobin, AJ, and Simpfendorfer, CA. 2014. Quantifying shark distribution patterns and species-habitat associations: implications of marine park zoning. PloS one, 9(9), p.e106885.

Fergusson IK, Graham KJ, Compagno LJ. 2008. Distribution, abundance and biology of the smalltooth sandtiger shark Odontaspis ferox (Risso, 1810)(Lamniformes: Odontaspididae). Environmental Biology of Fishes. 81(2):207-228.

Ferretti F, Worm B, Britten GL, Heithaus MR, Lotze HK. 2010. Patterns and ecosystem consequences of shark declines in the ocean. Ecology letters. 13(8):1055-71.

Fisk, DA. 2007. Niue sustainable coastal fisheries pilot project: literature review and pilot baseline survey. IWP-Pacific technical report, (38).

Flanders Marine Institute. 2016. Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 9. Available online at http://www.marineregions.org/. http://dx.doi.org/10.14284/242.

Friedlander AM. 2015. A perspective on the management of coral reef fisheries. Pages 208–214 In: The ecology of fishes on coral reefs (C Mora, ed.). Cambridge University Press.

Friedlander AM, JM Shackeroff, JN Kittinger. 2013. Customary Marine Resource Knowledge and Use in Contemporary Hawai‘i. Pac Sci 67:441-460.

Gaines SD, White C, Carr MH, Palumbi SR. 2010. Designing marine reserve networks for both conservation and fisheries management. Proceedings of the National Academy of Sciences. 107(43):18286-93.

Johannes RE. 1978. Traditional marine conservation methods in Oceania and their demise. Annual Rev Ecol Syst 9:349-364.

Johannes RE. 1982. Traditional conservation methods and protected marine areas in Oceania. Ambio 11:258–261.

Jupiter, S., Mangubhai, S. and Kingsford, RT. 2014a. Conservation of biodiversity in the Pacific Islands of Oceania: challenges and opportunities. Pacific Conservation Biology, *20*(2), pp.206–220.

Jupiter, SD, Cohen, PJ, Weeks, R, Tawake, A and Govan, H. 2014b. Locally-managed marine areas: multiple objectives and diverse strategies. Pacific Conservation Biology, *20*(2), pp.165–179.

Klimley, AP, and Brown, ST. 1983. Stereophotography for the field biologist: measurement of lengths and three-dimensional positions of free-swimming sharks. Marine Biology 74:175–185.

Labrosse, P, Yeeting, B, & Pasisi, B. 1999. Survey of the Namoui Fisheries Reserve in Niue. Fisheries Newsletter – South Pacific Commission, 29-36.

Lam VWY, Cheung WWL, Reygondeau G, Sumaila UR. 2016. Projected change in global fisheries revenues under climate change. Scientific Reports. 6:32607. doi:10.1038/srep32607.

Myers, R, Baum, J, Shepherd, T, Powers, S, & Peterson, C. 2007. Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science, 315* (5820), 1846-1850 DOI: 10.1126/science.1138657.

Pakoa K, Friedman K, Moore B, Tardy E, Bertram I. 2014. Assessing Tropical Marine Invertebrates: a Manual for Pacific Island Resource Managers. Secretariat of the Pacific Community. ISBN: 978-982-00-0712-3.

Pikitch EK, Santora EA, Babcock A, Bakun A, Bonfil R, Conover DO, Dayton P, Doukakis P, Fluharty D, Heneman B, Houde ED, Link J, Livingston PA, Mangel M, McAllister MK, Pope J, Sainsbury KJ. 2004. Ecosystem-based fishery management. Science 305:346-347.

Polovina JJ, Howell EA, Abecassis M. 2008. Ocean’s least productive waters are expanding. Geophysical Research Letters. 35(3).

Poepoe K, Bartram B, Friedlander A. 2007. The use of traditional Hawaiian knowledge in the contemporary management of marine resources. In: Haggan N, Neis B, Baird I (eds) Fishers' knowledge in fisheries science and management. UNESCO, Paris, p 117–141.

Randall JE, Williams JT, Smith DG, Kulbicki M, Tham GM, Labrosse PI, Kronen ME, Clua ER, Mann BS. 2003. Checklist of the Shore and Epipegagic Fishes of Tonga. Atoll. Res. Bull. 502. Smithsonian Inst.

Robbins WD, Hisano M, Connolly SR, Choat JH. 2006. Ongoing collapse of coral-reef shark populations. Current Biology. 16(23):2314-2319.

Rosenberg AA, McLeod KL. 2005. Implementing ecosystem-based approaches to management for the conservation of ecosystem services: Politics and socio-economics of ecosystem-based management of marine resources. Mar Ecol Prog Ser 300:271-274.

Ruddle K. 1988. Social principles underlying traditional inshore fishery management systems in the Pacific Basin. Mar Resour Econ 5:351-363.

Schorr GS, Baird RW, Hanson M, Webster DL, McSweeney DJ, Andrews RD. 2009. Movements of Satellite-Tagged Blainville's Beaked Whales Off the Island of Hawaii. Cascadia Research Collective, Olympia, WA.

Sibert J, Hampton J. 2003. Mobility of tropical tunas and the implications for fisheries management. Mar. Pol. 27: 87-95.

Sladek Nowles, J. and A. M. Friedlander. 2005. Marine reserve design and function for fisheries management. Pages 280–301 in: Marine conservation biology: the science of maintaining the sea's biodiversity (E. A. Norse and L. B. Crowder, eds.). Island Press.

Stoddart DR, Scoffin TP. 1983. Phosphate rock on coral reef islands. In: Chemical sediments and geomorphology (Goudie AS and Pye K, eds.). pp. 369–400.

Terry JP, Nunn PD. 2003. Interpreting features of carbonate geomorphology on Niue Island, a raised coral atoll. Z. Geomorph. NF. 131:43-57.

Tissot, BN, Hixon, MA, & Stein, DL. 2007. Habitat-based submersible assessment of macro-invertebrate and groundfish assemblages at Heceta Bank, Oregon, from 1988 to 1990. Journal of Experimental Marine Biology and Ecology, 352(1), 50-64.

Veitayaki J. 1997. Traditional marine resource management practices used in the Pacific Islands: an agenda for change. Ocean Coast Manage 37:123-136.

Wells RD, Rooker JR, Itano DG. Nursery origin of yellowfin tuna in the Hawaiian Islands. Marine Ecology Progress Series. 2012 Aug 8;461:187-96.Sibert J, Hampton J. 2003. Mobility of tropical tunas and the implications for fisheries management. Mar. Pol. 27: 87-95.

Worm B, Davis B, Kettemer L, Ward-Paige CA, Chapman D, Heithaus MR, Kessel ST, Gruber SH. 2013. Global catches, exploitation rates, and rebuilding options for sharks. Marine Policy. 40:194-204.

Zachos, JC., Pagani, M, Sloan, L, Thomas, E, and Billups, K. 2001. Trends, rhythms, and aberrations in global Climate, 65 Ma to Present. Science. 292 (5517): 686–693.

Zylich K, Harper S, Winkler N, Zeller D. 2012. Reconstruction of marine gheries catches for Niue (1950-2010). pp. 77–86. In: Harper, S., Zylich, K., Boonzaier, L., Le Manach, F., Pauly, D., and Zeller D. (eds.) Fisheries catch reconstructions: Islands, Part III. Fisheries Centre Research Reports 20(5). Fisheries Centre, University of British Columbia.

APPENDICES

Appendix I.

Expedition Team.

Name	Role	Institution
Paul Rose	Expedition Leader	NGS & the Royal Geographical Society
Alan Friedlander	Chief scientist – fishes	NGS & University of Hawaii
Jessica Cramp	Fishes, sharks, BRUVS	Sharks Pacific, James Cook University, Oceans 5
Jenn Caselle	Fishes, BRUVS	University of California, Santa Barbara
Eric Brown	Benthos	US National Park Service, Molokai, Hawaii
Kike Ballesteros	Benthos	Centre d'Estudis Avançats de Blanes-CSIC, Spain
Pelayo Salinas de León	BRUVs, Sharks	NGS & Charles Darwin Foundation, Galápagos
Chris Thompson	Pelagic cameras	Centre for Marine Futures, University Western Australia
Dave McAloney	DSO, logistics	NGS
Manu San Félix	Underwater video	NGS
Jose Arribas	Underwater video assistant	NGS
Jon Betz	Producer	NGS
Steve Spence	Assistant Producer	NGS
Alan Turchik	Drop Cameras	NGS Remote Imaging
Brendon Pasisi	Niue rep., field collaborator	Dept Agriculture, Forestry and Fisheries, Niue
Pauline Bosserelle	Marine ecology	SPC
Nadia Helagi	Fisheries/general marine ecology	DAFF Niue/Secretariat of the Pacific Community
Taaniella Faakianga Launoa Gataua	Fisheries/general marine ecology	DAFF Niue
Alana Fiafia Richmond'Rex	Fisheries/general marine ecology	DAFF Niue

Appendix II.

List of scleractinian (hard) corals at Niue and Beveridge Reef.

Family	Species	Niue	Beveridge Reef
Acroporidae	*Acropora anthocercis*	X	
	Acropora austera	X	X
	Acropora bushyensis		X
	Acropora cf. secale		X
	Acropora cytherea	X	X
	Acropora digitifera	X	
	Acropora divaricata	X	X
	Acropora florida	X	
	Acropora gemmifera	X	X
	Acropora globiceps	X	X
	Acropora horrida	X	
	Acropora hyacinthus	X	X
	Acropora latistella	X	
	Acropora listeri	X	
	Acropora lutkeni	X	
	Acropora microclados	X	
	Acropora monticulosa	X	X
	Acropora nasuta	X	X
	Acropora polystoma	X	
	Acropora retusa	X	
	Acropora samoensis	X	X
	Acropora secale	X	X
	Acropora selago	X	
	Acropora sp. *juvenile*	X	X
	Acropora subulata	X	
	Acropora tenuis	X	X
	Acropora tutuilensis	X	

APPENDIX II. CONTINUED.

Family	Species	Niue	Beveridge Reef
Acroporidae	*Acropora valida*	X	X
	Acropora verweyi	X	X
	Astreopora myriophthalma	X	X
	Astreopora ocellata		X
	Astreopora randalli	X	X
	Isopora palifera	X	
	Montipora caliculata	X	X
	Montipora corbettensis		X
	Montipora foveolata	X	X
	Montipora grisea	X	X
	Montipora nodosa	X	X
	Montipora peltiformis	X	X
	Montipora tuberculosa		X
	Montipora venosa	X	X
	Montipora verrucosa	X	X
Agariciidae	*Leptoseris mycetoroides*	X	
	Leptoseris scabra	X	
	Pachyseris speciosa	X	
	Pavona clavus	X	
	Pavona duerdeni		X
	Pavona frondifera	X	
	Pavona maldivensis	X	
	Pavona varians	X	
	Pavona varians		X
Dendrophylliidae	*Turbinaria mesenterina*		X
	Turbinaria peltata		X
	Turbinaria reniformis	X	
	Turbinaria stellulata	X	X
Faviidae	*Cyphastrea chalcidicum*	X	X
	Cyphastrea microphthalma		X
	Cyphastrea serailia	X	X
	Favia matthaii	X	X
	Favia speciosa	X	

Family	Species	Niue	Beveridge Reef
Faviidae	*Favia stelligera*	X	X
	Favites abdita	X	
	Favites chinensis	X	
	Favites flexuosa	X	
	Favites halicora	X	
	Favites pentagona	X	X
	Favites russelli		X
	Goniastrea aspera	X	X
	Goniastrea edwardsi	X	X
	Goniastrea favulus	X	X
	Goniastrea pectinata	X	
	Goniastrea retiformis	X	
	Leptastrea pruinosa	X	X
	Leptastrea purpurea	X	X
	Leptoria phyrgia	X	
	Montastrea curta	X	X
	Oulophyllia crispa	X	X
	Platygyra daedalea	X	X
Fungiidae	*Cycloseris vaughani*	X	
	Cycloseris vaughani		X
	Fungia concinna	X	
	Fungia granulosa		X
	Fungia paumotensis		X
	Fungia scutaria	X	X
	Herpolitha limax	X	
	Sandolitha dentata	X	X
Merulinidae	*Hydnophora exesa*		X
	Hydnophora exesa	X	
	Hydnophora microconos	X	X
	Merulina ampliata		X
Mussidae	*Acanthastrea echinata*	X	X
	Acanthastrea hillae	X	
	Lobophyllia corymbosa	X	

APPENDIX II. CONTINUED.

Family	Species	Niue	Beveridge Reef
Mussidae	*Lobophyllia hemprichii*	X	X
Oculinidae	*Galaxea fascicularis*	X	X
Pectiniidae	*Echinophyllia aspera*	X	
	Echinophyllia echinata	X	
Pocilloporidae	*Pocillopora damicornis*	X	X
	Pocillopora elegans		X
	Pocillopora eydouxi	X	X
	Pocillopora meandrina	X	X
	Pocillopora verrucosa	X	X
	Stylophora pistillata	X	X
	Pocillopora cf capitata	X	
Poritidae	*Goniopora somaliensis*	X	X
	Goniopora stutchburyi	X	X
	Porites australiensis	X	X
	Porites cf. myrmidonensis		X
	Porites lobata	X	X
	Porites lutea	X	X
	Porites monticulosa	X	
	Porites randalli	X	X
	Porites solida	X	X
	Porites sp. 1	X	
	Porites vaughani	X	X
Siderastreidae	*Coscinaraea columna*	X	X
	Coscinaraea exesa	X	
	Psammocora haimeana	X	X
	Psammocora nierstraszi	X	X
	Psammocora profundacella	X	

Appendix III.

List of algae observed at Niue and Beveridge Reef.

Chlorophyta (Green algae)	Niue	Beveridge Reef
Avrainvillea lacerata	X	
Caulerpa macrophysa	X	
Caulerpa nummularia	X	X
Caulerpa serrulata	X	
Caulerpa taxifolia	X	
Caulerpa urvilliana	X	X
Caulerpa webbiana	X	X
Cladophoropsis luxurians	X	X
Dictyosphaeria intermedia	X	
Dictyosphaeria versluysii	X	X
Halimeda cf. distorta		X
Halimeda cf. gracilis		X
Halimeda cf. hederacea	X	
Halimeda lacunalis f. lata	X	
Halimeda micronesica	X	X
Halimeda minima	X	
Halimeda opuntia	X	X
Halimeda pygmaea	X	
Microdictyon sp.	X	X
Neomeris cf. mucosa	X	X
Palmogloea protuberans	X	
Valonia aegagropila	X	X

Cyanophyta (Blue-green algae)	Niue	Beveridge Reef
Hydrocoleum sp.	X	
Phormidium sp.	X	X
Schizothrix sp.	X	X

APPENDIX III. CONTINUED.

Ochrophyta (Brown algae)	Niue	Beveridge Reef
Chnoospora implexa	X	
Dictyota divaricata	X	
Lobophora variegata	X	X
Padina sp.	X	
Turbinaria ornata	X	

Rhodophyta (Red algae)	Niue	Beveridge Reef
Acrosymphyton taylorii	X	
Actinotrichia fragilis	X	
Amphiroa fragilissima	X	
Botryocladia skottsbergii	X	
Dasya sp.	X	X
Erythrymenia sp.		X
Galaxaura filamentosa	X	
Galaxaura marginata	X	
Gelidiella acerosa	X	
Gibsmithia hawaiiensis	X	X
Haematocelis sp.	X	X
Haloplegma duperreyi	X	
Hydrolithon gardineri	X	X
Hydrolithon onkodes	X	X
Hypnea sp.	X	
Jania sp.	X	X
Liagora ceranoides	X	
Liagora sp.	X	X
Lithophyllum flavescens	X	
Martensia elegans	X	
Neogoniolithon frutescens	X	X
Peyssonnelia cf. conchicola	X	
Peyssonnelia cf. harveyana	X	
Peyssonnelia sp. 1	X	
Peyssonnelia sp. 2	X	X
Peyssonnelia sp. 3	X	X
Porolithon craspedium	X	X
Tricleocarpa fragilis	X	
Yamadaella sp.	X	

Appendix IV.

List of all invertebrate species recorded at Niue and Beveridge Reef.

Techniques (manta tow, reef benthos transects [RBT])
Mean Density = number of individuals per hectare with standard deviation.

Taxa		Species	Common Name	Mean Density	Method	Location
Echinoderm	**Urchins**	*Diadema* sp.	Long spined sea urchin	1,013.89 ± 972.52	RBT	Beveridge Reef lagoon
		Echinometra mathaei	Rock-boring urchin	1,555.56 ± 527.78	RBT	Beveridge Reef lagoon
		Echinostrephus aciculatus	Needle spined urchin	97.22 ± 97.22	RBT	Beveridge Reef lagoon
		Echinothrix calamaris	Banded urchin	194.44 ± 174.03	RBT	Beveridge Reef lagoon
		Echinothrix diadema	Blue-black urchin	9,250.00 ± 2,752.21		
		Echinothrix spp.		996.04 ± 345.78 461.97 ± 210.83	Manta Tow Manta Tow	Beveridge Reef Niue
			Pencil sea urchin	190.08 ± 129.08 736.11 ± 427.86	Manta Tow RBT	Beveridge Reef Beveridge Reef lagoon
	Sea cucumber	*Bohadschia argus*	Leopardfish	2.08 ± 2.08	Manta Tow	Beveridge Reef
		Holothuria atra	Lollyfish	0.69 ± 0.69 930.56 ± 222.22 4.72 ± 3.11	Manta Tow RBT Manta Tow	Beveridge Reef Beveridge Reef lagoon Niue
		Holothuria whitmaei	Black teatfish	0.69 ± 0.69 41.67 ± 24.06 3.33 ± 0.85	Manta Tow RBT Manta Tow	Beveridge Reef Beveridge Reef lagoon Niue
		Stichopus horrens	Dragonfish	13.89 ± 13.89	RBT	Beveridge Reef lagoon
		Thelenota ananas	Prickly redfish	2.78 ± 2.78 6.02 ± 3.40	Manta Tow Manta Tow	Beveridge Reef Niue
	Sea star	*Linckia laevigata*	Blue linckia	41.67 ± 41.67	RBT	Beveridge Reef lagoon
Molluscs	**Bivalves**	*Tridacna maxima*	Elongate giant clam	1,375.00 ± 674.86	RBT	Beveridge Reef lagoon
		Tridacna spp.	Giant clam	1,011.97 ± 643.41 58.09 ± 32.57	Manta Tow Manta Tow	Beveridge Reef Niue
		Tridacna sp.	Giant clam	41.67 ± 24.06	RBT	Beveridge Reef lagoon
	Gastropods	*Drupa morum*	Purple drupe	13.89 ± 13.89	RBT	Beveridge Reef lagoon
		Astralium sp.		13.89 ± 13.89	RBT	Beveridge Reef lagoon
		Turbo argyrostomus	Turban snail	180.56 ± 160.17	RBT	Beveridge Reef lagoon
		Reischia armigera	Belligerent rock-shell	41.67 ± 24.06	RBT	Beveridge Reef lagoon

Appendix V.

List of fish species and families observed at Niue and Beveridge Reef.

Main Diet – H = herbivore, Z = planktivore, C = carnivore, P = piscivore.

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Acanthuridae	*Acanthurus achilles*	H	X	X
	Acanthurus albipectoralis	Z	X	X
	Acanthurus blochii	H	X	X
	Acanthurus guttatus	H	X	X
	Acanthurus leucopareius	H	X	X
	Acanthurus lineatus	H		X
	Acanthurus nigricans	H	X	X
	Acanthurus nigrofuscus	H	X	X
	Acanthurus nigroris	H	X	X
	Acanthurus nubilus	Z		X
	Acanthurus olivaceus	H	X	X
	Acanthurus pyroferus	H	X	X
	Acanthurus thompsoni	Z	X	X
	Acanthurus triostegus	H	X	X
	Acanthurus xanthopterus	H		X
	Ctenochaetus binotatus	H		X
	Ctenochaetus cyanocheilus	H	X	X
	Ctenochaetus flavicauda	H	X	X
	Ctenochaetus hawaiiensis	H	X	X
	Ctenochaetus striatus	H	X	X
	Naso brevirostris	H	X	X
	Naso hexacanthus	Z	X	X
	Naso lituratus	H	X	X
	Naso tonganus	H	X	X
	Naso unicornis	H	X	X
	Naso vlamingii	Z	X	X
	Paracanthurus hepatus	Z	X	
	Zebrasoma scopas	H	X	X
	Zebrasoma veliferum	H	X	X

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Apogonidae	*Cheilodipterus macrodon*	P		X
	Ostorhinchus angustatus	C	X	X
	Ostorhinchus nigrofasciatus	Z	X	
Balistidae	*Balistapus undulatus*	C	X	X
	Balistoides conspicillum	C	X	X
	Balistoides viridescens	C		X
	Melichthys niger	Z	X	X
	Melichthys vidua	H	X	X
	Pseudobalistes flavimarginatus	C		X
	Pseudobalistes fuscus	C	X	
	Rhinecanthus aculeatus	C	X	
	Rhinecanthus lunula	C	X	X
	Rhinecanthus rectangulus	C	X	X
	Sufflamen bursa	C	X	X
	Sufflamen chrysopterum	C	X	
	Sufflamen fraenatum	C	X	
	Xanthichthys auromarginatus	Z	X	X
	Xanthichthys caeruleolineatus	Z		X
	Xanthichthys mento	Z	X	
Blenniidae	*Blenniella gibbifrons*	H		X
	Cirripectes alboapicalis	H	X	X
	Cirripectes sp.	H		X
	Cirripectes variolosus	H	X	X
	Ecsenius niue	H		X
	Exallias brevis	H		X
	Plagiotremus rhinorhynchos	P	X	X
	Plagiotremus tapeinosoma	P	X	X
Caesionidae	*Caesio teres*	Z		X
	Pterocaesio tile	Z	X	
Caracanthidae	*Caracanthus maculatus*	C		X
Carangidae	*Carangoides ferdau*	P		X
	Carangoides orthogrammus	P	X	X
	Caranx ignobilis	P	X	
	Caranx lugubris	P	X	X
	Caranx melampygus	P	X	X
	Elagatis bipinnulata	P	X	
	Scomberoides lysan	P	X	X
	Seriola dumerili	P	X	

APPENDIX V. CONTINUED.

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Carangidae	*Seriola lalandi*	P	X	
	Seriola rivoliana	P	X	X
Carcharhinidae	*Carcharhinus amblyrhynchos*	P	X	X
	Triaenodon obesus	C	X	X
Chaetodontidae	*Chaetodon auriga*	C	X	X
	Chaetodon bennetti	C		X
	Chaetodon citrinellus	C	X	X
	Chaetodon ephippium	C	X	X
	Chaetodon flavirostris	C		X
	Chaetodon lineolatus	C		X
	Chaetodon lunula	C	X	X
	Chaetodon lunulatus	C		X
	Chaetodon mertensii	C	X	X
	Chaetodon ornatissimus	C	X	X
	Chaetodon pelewensis	C	X	X
	Chaetodon quadrimaculatus	C	X	X
	Chaetodon reticulatus	C	X	X
	Chaetodon trifascialis	C		X
	Chaetodon ulietensis	C	X	X
	Chaetodon unimaculatus	C	X	X
	Forcipiger flavissimus	C	X	X
	Forcipiger longirostris	C	X	X
	Hemitaurichthys polylepis	Z	X	X
	Hemitaurichthys thompsoni	Z	X	
	Heniochus chrysostomus	C	X	X
	Heniochus monoceros	C	X	X
	Heniochus singularius	C		X
Cirrhitidae	*Cirrhitichthys falco*	C	X	X
	Cirrhitichthys oxycephalus	C		X
	Cirrhitops hubbardi	C	X	X
	Cirrhitus pinnulatus	P	X	X
	Neocirrhites armatus	C	X	X
	Paracirrhites arcatus	C	X	X
	Paracirrhites forsteri	P	X	X
	Paracirrhites hemistictus	P	X	X
Dasyatidae	*Himantura fai*	C		X
Diodontidae	*Diodon holocanthus*	C		X
	Diodon hystrix	C	X	X

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Echeneidae	*Echeneis naucrates*	C		X
Fistularidae	*Fistularia commersonii*	P	X	X
Gobiidae	*Ctenogobiops tangaroai*	C		X
	Gnatholepis anjerensis	C		X
	Nemateleotris magnifica	Z	X	X
	Ptereleotris evides	Z	X	X
	Ptereleotris heteroptera	Z	X	
	Ptereleotris zebra	Z		X
	Valenciennea strigata	C		X
Grammistidae	*Grammistes sexlineatus*	P	X	X
	Pogonoperca punctata	C	X	
Holocentridae	*Myripristis berndti*	C	X	X
	Myripristis kuntee	Z	X	X
	Myripristis vittata	C		X
	Neoniphon opercularis	C	X	X
	Neoniphon sammara	C	X	X
	Sargocentron caudimaculatum	C	X	X
	Sargocentron diadema	C	X	
	Sargocentron microstoma	C		X
	Sargocentron spiniferum	C	X	X
	Sargocentron tiere	C	X	X
Kuhliidae	*Kuhlia mugil*	C	X	X
Kyphosidae	*Kyphosus bigibbus*	H	X	X
	Kyphosus cinerascens	H		X
	Kyphosus vaigiensis	H	X	X
Labridae	*Anampses caeruleopunctatus*	C	X	X
	Anampses femininus	C		X
	Anampses twistii	C	X	X
	Bodianus axillaris	C	X	X
	Bodianus loxozonus	C	X	X
	Bodianus mesothorax	C	X	X
	Cheilinus chlorourus	C	X	X
	Cheilinus trilobatus	C	X	X
	Cheilinus undulatus	C		X
	Cirrhilabrus rubrimarginatus	Z	X	
	Cirrhilabrus scottorum	Z	X	X
	Coris aygula	C	X	X
	Coris dorsomacula	C	X	X

APPENDIX V. CONTINUED.

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Labridae	*Coris gaimard*	C	X	X
	Epibulus insidiator	C		X
	Gomphosus varius	C	X	X
	Halichoeres claudia	C	X	X
	Halichoeres hortulanus	C	X	X
	Halichoeres margaritaceus	C		X
	Halichoeres marginatus	C		X
	Halichoeres melanurus	C	X	X
	Halichoeres melasmapomus	C		X
	Halichoeres trimaculatus	C	X	
	Hemigymnus fasciatus	C	X	X
	Hologymnosus annulatus	P	X	X
	Hologymnosus doliatus	P	X	X
	Iniistius aneitensis	C		X
	Labroides bicolor	C	X	X
	Labroides dimidiatus	C	X	X
	Labroides rubrolabiatus	C	X	X
	Macropharyngodon meleagris	C	X	X
	Novaculichthys taeniourus	C	X	X
	Oxycheilinus unifasciatus	C	X	X
	Pseudocheilinus evanidus	C	X	X
	Pseudocheilinus hexataenia	C	X	X
	Pseudocheilinus octotaenia	C	X	X
	Pseudocheilinus tetrataenia	C	X	X
	Pseudocoris yamashiroi	Z		X
	Pseudodax moluccanus	C		X
	Pseudojuloides atavai	C	X	X
	Pseudojuloides cerasinus	C		X
	Stethojulis bandanensis	C	X	X
	Thalassoma amblycephalum	Z	X	X
	Thalassoma hardwicke	C	X	X
	Thalassoma lutescens	C	X	X
	Thalassoma nigrofasciatum	C	X	
	Thalassoma purpureum	C	X	X
	Thalassoma quinquevittatum	C	X	X
	Thalassoma trilobatum	C	X	
Lethrinidae	*Gnathodentex aureolineatus*	C	X	X
	Monotaxis grandoculis	C	X	X

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Lutjanidae	*Aphareus furca*	P	X	X
	Aprion virescens	P	X	X
	Lutjanus bohar	C	X	X
	Lutjanus kasmira	P	X	X
	Lutjanus monostigma	P		X
	Macolor macularis	C		X
	Macolor niger	C	X	X
Malacanthidae	*Hoplolatilus starcki*	Z		X
	Malacanthus brevirostris	C		X
	Malacanthus latovittatus	C	X	X
	Aluterus scriptus	H	X	X
	Amanses scopas	C		X
	Cantherhines dumerilii	C	X	X
	Cantherhines pardalis	C	X	X
	Oxymonacanthus longirostris	C		X
	Pervagor melanocephalus	H		X
Mugiloididae	*Parapercis clathrata*	C	X	X
	Parapercis hexophtalma	C	X	X
Mullidae	*Mulloidichthys flavolineatus*	C	X	
	Mulloidichthys vanicolensis	C	X	
	Parupeneus barberinus	C	X	
	Parupeneus crassilabris	C	X	X
	Parupeneus cyclostomus	P	X	X
	Parupeneus multifasciatus	C	X	X
	Parupeneus pleurostigma	C	X	
Muraenidae	*Gymnothorax eurostus*	C	X	
	Gymnothorax javanicus	P		X
	Gymnothorax melatremus	C	X	
	Gymnothorax meleagris	P	X	
	Rhinomuraena quaesita	P		X
Myliobatididae	*Aetobatus narinari*	C	X	
Ostraciidae	*Ostracion meleagris*	C	X	X
Pempheridae	*Pempheris oualensis*	Z		X
Pomacanthidae	*Centropyge bispinosa*	H	X	X
	Centropyge fisheri	H		X
	Centropyge flavissima	H	X	X
	Centropyge heraldi	H	X	X
	Centropyge loricula	H	X	X

APPENDIX V. CONTINUED.

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Pomacanthidae	*Pomacanthus imperator*	C	X	X
	Abudefduf sordidus	H		X
	Amphiprion chrysopterus	Z	X	X
	Amphiprion perideraion	Z	X	
	Chromis acares	Z	X	X
	Chromis agilis	Z	X	X
	Chromis bami	Z	X	X
	Chromis iomelas	Z	X	X
	Chromis margaritifer	Z	X	X
	Chromis vanderbilti	Z	X	X
	Chromis xanthura	Z	X	X
	Chrysiptera taupou	Z	X	X
	Dascyllus aruanus	Z		X
	Dascyllus auripinnis	Z	X	X
	Dascyllus reticulatus	Z	X	X
	Dascyllus trimaculatus	Z	X	X
	Lepidozygus tapeinosoma	Z		X
	Plectroglyphidodon dickii	H	X	X
	Plectroglyphidodon imparipennis	C	X	X
	Plectroglyphidodon johnstonianus	C	X	X
	Plectroglyphidodon lacrymatus	H	X	X
	Plectroglyphidodon phoenixensis	H	X	X
	Pomacentrus spilotoceps	H	X	X
	Pomacentrus vaiuli	H	X	X
	Pomachromis fuscidorsalis	Z	X	X
	Stegastes albifasciatus	H		X
	Stegastes fasciolatus	H	X	X
	Stegastes nigricans	H	X	X
Scaridae	*Calotomus carolinus*	H	X	X
	Calotomus spinidens	H		X
	Chlorurus frontalis	H	X	X
	Chlorurus microrhinos	H	X	X
	Chlorurus sordidus	H	X	X
	Scarus altipinnis	H	X	X
	Scarus chameleon	H	X	X
	Scarus festivus	H	X	
	Scarus forsteni	H	X	X

Family	Scientific Name	Main Diet	Beveridge Reef	Niue
Scaridae	*Scarus frenatus*	H	X	X
	Scarus longipinnis	H	X	X
	Scarus niger	H		X
	Scarus oviceps	H		X
	Scarus psittacus	H	X	
	Scarus rubroviolaceus	H	X	X
	Scarus schlegeli	H	X	
Scombridae	*Gymnosarda unicolor*	P	X	X
Scorpaenidae	*Pterois antennata*	C		X
	Scorpaenopsis diabolus	P		X
	Scorpaenopsis papuensis	P		X
Serranidae	*Cephalopholis argus*	P	X	X
	Cephalopholis sonnerati	P		X
	Cephalopholis spiloparaea	P		X
	Cephalopholis urodeta	P	X	X
	Epinephelus fasciatus	C	X	X
	Epinephelus hexagonatus	P	X	X
	Epinephelus macrospilos	C		X
	Epinephelus melanostigma	P		X
	Epinephelus spilotoceps	P		X
	Gracila albomarginata	P		X
	Plectropomus laevis	P	X	X
	Pseudanthias cooperi	Z	X	X
	Pseudanthias olivaceus	Z	X	X
	Pseudanthias pascalus	Z	X	X
	Variola louti	P	X	X
Siganidae	*Siganus argenteus*	H	X	
Sphyraenidae	*Sphyraena barracuda*	P	X	X
	Sphyraena helleri	P	X	
	Sphyraena qenie	P		X
Synodontidae	*Saurida gracilis*	P		X
	Synodus rubromarmoratus	P		X
Tetraodontidae	*Arothron meleagris*	C	X	X
	Canthigaster amboinensis	C	X	X
	Canthigaster janthinoptera	C	X	X
	Canthigaster solandri	C	X	X
	Canthigaster valentini	C	X	X
Zanclidae	*Zanclus cornutus*	C	X	X

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