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Atoll Research Bulletin No. 633 ♦ 10 January 2024

Smithsonian
Scholarly Press

Washington, D.C.

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Published by SMITHSONIAN INSTITUTION SCHOLARLY PRESS
P.O. Box 37012, MRC 957
Washington, D.C. 20013-7012
https://scholarlypress.si.edu/

ISSN: 0077-5630 (online)

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BIOLOGICAL SURVEYS OF CARONDELET, A SHALLOW, SUBMERGED SEAMOUNT IN THE PHOENIX ISLANDS, KIRIBATI

SANGEETA MANGUBHAI[1,2*], YASHIKA NAND[1,3], ARANTEITI TEKIAU[4], BRIAN ZGLICZYNSKI[5], and STUART SANDIN[5]

ABSTRACT

Carondelet is a remote seamount in the Phoenix Islands of the Republic of Kiribati. Earlier expeditions to characterize coral reef communities of the Phoenix Islands Protected Area (PIPA) were not able to survey the seamount due to challenging ocean conditions preventing divers from entering the water safely (e.g., large waves and surface currents). In 2015, scientists from the Wildlife Conservation Society, Scripps Institution of Oceanography, and Kiribati Ministry of Fisheries and Marine Resource Development conducted surveys around the shallow habitats (<30 m) of the seamount to characterize coral reef fish and benthic communities. Biodiversity was generally low, with 12 coral genera (six families), 120 bony fish species (25 families), and two shark species (*Triaenodon obesus, Carcharhinus amblyrhynchos*) recorded. The most dominant coral genera were *Montipora* and *Acropora* at 5–8 m and *Porites* and *Pavona* at 20 m. Coral cover ranged from 12.8% (± 5.9 s.d.) at 20 m to 35.3% (± 6.2 s.d.) at 12 m. A patch of black reef was observed around an abandoned anchor line, and the team observed unfouled fishing line around the seamount suggesting that fishing activities had occurred around the time of the survey, despite it being located within PIPA. To our knowledge, this is the only published information on the biodiversity of this remote seamount, and makes an important contribution to document the marine resources found within PIPA and the coral reef communities they support.

Keywords: biodiversity, black reefs, climate change, coral reefs, corals, fish, sharks

INTRODUCTION

The Phoenix Islands (2.5° to 5°S latitude, 174.8°W to 170.1°E longitude) are a remote string of eight atolls and two shallow submerged reefs (28 km^2 land area) that form the central archipelago in the Republic of Kiribati (Figure 1). The Phoenix Islands Protected Area (PIPA) was gazetted in 2006 and extended in 2008 to become (at the time) the largest marine protected area in the world with a surface area of 408,250 km^2 (Rotjan et al., 2014). The protected area was declared as a UNESCO World Heritage Area in 2010 and became fully closed to all commercial and extractive activities except for a 22.2 km sustainable use zone surrounding Kanton Atoll in 2015. The Kiribati government reopened the protected area in January 2023 for economic reasons, after a study found it had negligible impact on the conservation of skipjack and bigeye tuna (Hampton et al., 2023).

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Without nearby human settlements (except for Kanton Atoll with a population of under 50 people), the Phoenix Islands have been considered by some scientists as an area importance for monitoring change in sea levels and evaluating the effects of climate change (Obura and Mangubhai, 2011; Mangubhai et al., 2014; Rotjan et al., 2014). The near-pristine conditions of the reefs as they were documented in 1972–1973 (Jokiel and Maragos, 1978; Maragos and Jokiel, 1978), and again in 2000 and 2002 (Obura, 2011; Obura et al., 2011; Allen and Bailey, 2011), serve as a benchmark for understanding and potentially restoring other degraded atoll ecosystems. However, in 2002–2003 sea surface temperatures in the Central Pacific reached 21 Degree Heating Weeks and resulted in widescale coral bleaching throughout the Phoenix Islands, with subsequent surveys recording a 60% decline in coral cover throughout the group (Obura and Mangubhai, 2011). Mortality varied among sites and islands in accordance with the presence of a lagoon, island size and windward versus leeward exposure. Leeward reefs experienced a consistent decline in coral cover of 71 ± 7.1% (mean ± SE) while windward reefs experienced a lower but more variable average decline of 55 ± 22.6% (mean ± SE) (Obura and Mangubhai, 2011). Additional bleaching events were documented in 2009–2010 and 2015–2016 (Brainard et al., 2018; Fox et al., 2021). Elevated sea surface temperatures have already had a devastating impact on Kiribati's coral reefs and are likely to continue to increase in frequency and intensity (Obura et al., 2016).

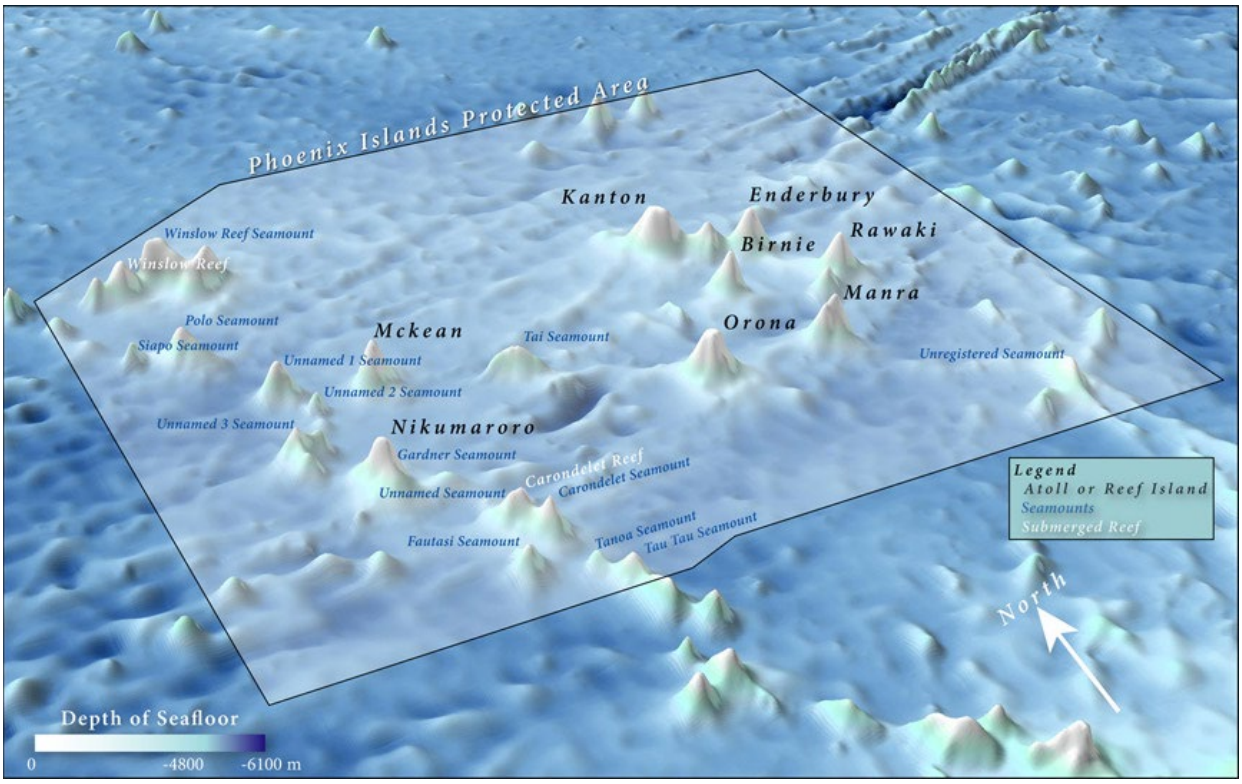

Figure 1. Bathymetry map showing the atolls, seamounts and submerged reefs in the Phoenix Islands. Coral reef surveys were conducted at Carondelet seamount (2) and Kanton (10), Enderbury (6), Birnie (3), Rawaki (7), Manra (3), Orono (8), Nikumaroro (10), and McKean (5) atolls in 2015. Number of sites surveyed in 2015 are provided in parentheses. Source: New England Aquarium

Expeditions to PIPA in 2002, 2005, 2009, 2012, and 2015 have focused on characterizing coral reef communities, long-term monitoring at sites around the atolls, as well as specific studies on paleoclimatology (i.e., coral coring), water chemistry, food webs, and population genetics. Until recently,

there have been few opportunities to survey and document the biological communities of these seamounts within SCUBA depths (<30 m). Here, we present the findings of an opportunistic biological survey of Carondelet Seamount during the 2015 expedition to the Phoenix Islands that make an important contribution to documenting seamounts in the Pacific and the coral reef communities they support. Carondelet Reef was reportedly named by Captain Wilder Farley Stetson on August 31, 1898, after his ship *Carondelet* during a voyage from Puget Sound to Australia.

MATERIALS AND METHODS

Exploratory biological surveys were conducted at Carondelet Seamount (-5°33′59.99″ S, -173°50′59.99″ W), 100 km southeast of Nikumaroro Atoll in the Phoenix Islands on September 24, 2015 (Figure 1). Previous expeditions to this submerged seamount failed to conduct *in situ* surveys due to large breaking waves on the top, thus preventing safe diving access. The seamount is part of Carondelet Reef which is approximately 1.5 km in length.

A cumulative list of scleractinian coral genera and reef fish species were compiled for Carondelet Seamount during two dives conducted on opposite sides of the seamount. Digital still photographs were taken at 5, 8, and 20 m using a fixed camera-to-substrate distance of 0.5–0.75 m with natural light and the white balance set to enhance reds and help distinguish benthic groups such as coralline algae. Of the 30–40 images taken at each depth, 20 were randomly selected and analyzed for benthic composition using Coralnet (http://coralnet.ucsd.net). Each individual image was annotated using a point count method with 25 randomly selected points, with 100 points constituting a transect; five transects were done at each depth. Using the built-in labels in Coralnet, the benthic category (e.g., hard coral, soft coral, macroalgae, turf algae, microbial algae, reef matrix, rubble, sand, dead coral, other invertebrates) under each random point on the photograph was identified, with corals identified to genus and life form (e.g., branching, encrusting, foliose, submassive, massive).

To evaluate the diversity and relative abundance of coral reef fishes, the dive team completed roving diver surveys. This was accomplished by two divers experienced with coral fish species identification swimming along the reefs from 5–25 m searching within the water column and substrate for diurnally active coral reef fishes. The dive team identified fishes to species level and ranked them into relative abundance categories – Abundant, Common, Occasional, and Rare.

RESULTS AND DISCUSSION

Coral Community

The Carondelet Seamount is shallow, with the top sitting 5–7.2 m below the ocean surface (Figure 2). The coral community (between 5−20 m) at Carondelet Seamount supported few taxa relative to other atolls and islands in the Phoenix Islands (Obura et al., 2011). Twelve coral genera (across six families) were recorded on the seamount in 2015 (Table 1). The most abundant coral genera on the seamount were *Montipora* and *Acropora* representing 26.6% and 25.5% of all genera recorded (in units of relative abundance), respectively (Table 2). These two genera dominated the reef at 5 and 8 m depth, but were low in abundance at 20 m. *Porites* and *Pavona* dominated at 20 m. The highest diversity of coral genera (9 in total) was recorded at 8 m.

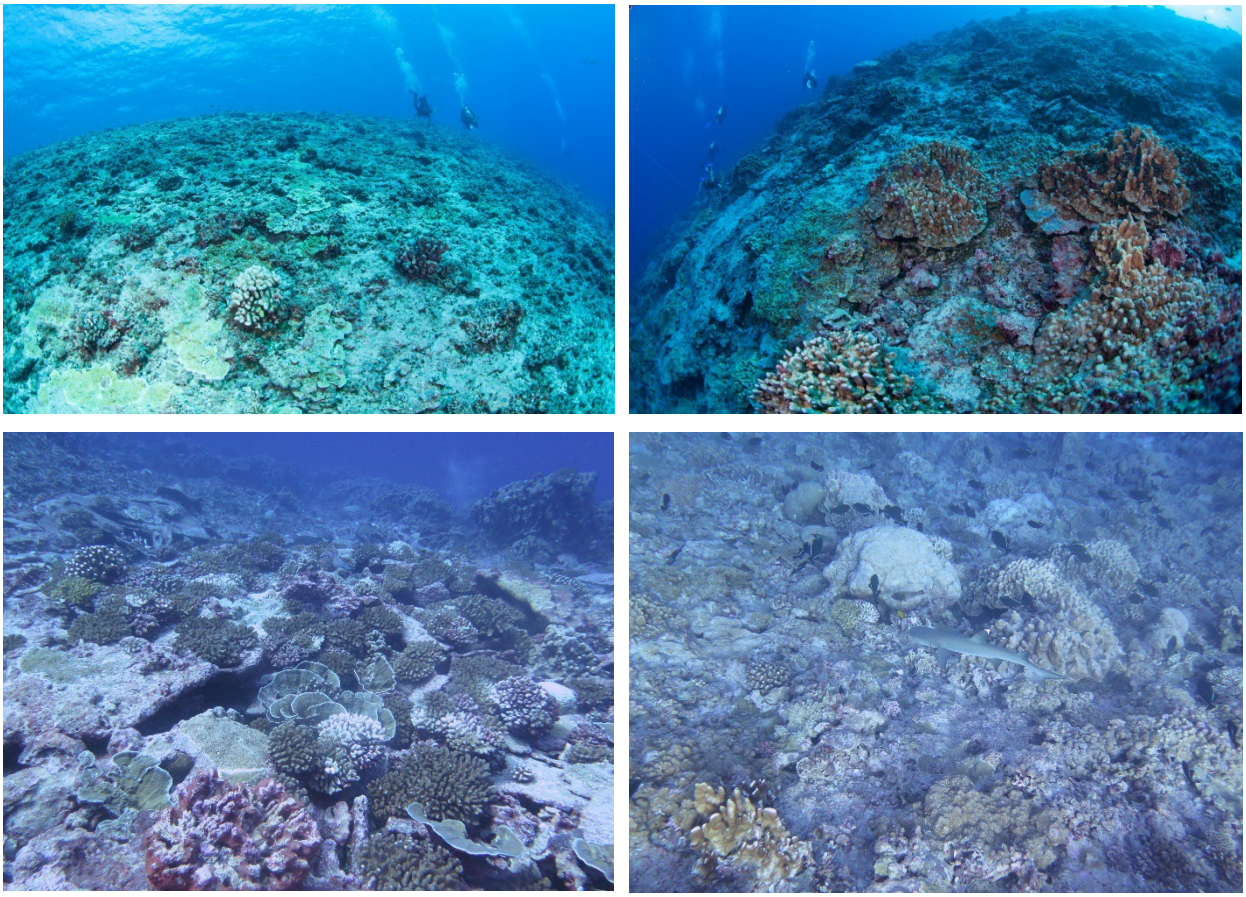

Figure 2. Coral community on Carondelet Seamount. Bottom photographs were taken at 8 m (left) and 12 m (right) depths. © Craig Cook

Table 1. Coral genera and species (where known) that were recorded on Carondelet Seamount in 2015.

Family	**Genus**
Acroporidae	*Acropora valida*
	Acropora spp.
Agariciidae	*Pavona duerdeni*
	P. varians
Faviidae	*Cyphastrea* sp.
	Echinopora gemmacea
	E. lamellosa
	Favia stellegera
	Favia spp.
	Favites spp.
	Montastrea sp.
	Platygyra sinensis
	P. daedalea
Merulinidae	*Hydnophora microconos*
Pocilloporidae	*Pocillopora verrucosa*
	P. eudouxi
Poritidae	*Porites* spp.
	Turbinaria sp.

Table 2. The abundance of coral genera recorded in photographic quadrats at 5, 8, and 20 m depths at Carondelet seamount in 2015.

Genera	5 m	8 m	20 m	Total	%
Montipora	48	44	6	98	26.6
Acropora	48	40	6	94	25.5
Porites	34	5	26	65	17.6
Montastrea	29	10		39	10.6
Favia	4	17		21	5.7
Cyphastrea		14	5	19	5.1
Pavona		1	15	16	4.3
Goniastrea		7		7	1.9
Echinopora			5	5	1.4
Pocillopora	1	3	1	5	1.4
Total genera	**6**	**9**	**7**	**369**	

The dominant benthic cover at 5 m was hard coral (32.8 ± 10.2%; mean ± standard deviation), followed by microbial cyanobacterial mats (30.4 ± 13.1%), and reef matrix (16.6 ± 8.7%) (Table 3, Figure 3). The top of the seamount was dominated by encrusting non-Acroporid corals (17.8 ± 11.1%) and juvenile *Acropora* spp. (mostly <15 cm maximum diameter). This contrasts with the reef at 20 m which was dominated by turf algae (30.0 ± 15.4%), coralline algae (16.8 ± 3.9%), and macroalgae (15.8 ± 4.4%), with hard coral cover at 12.8% (± 5.9). The reef at 8 m was dominated by hard coral (35.3 ± 6.2) especially encrusting non-Acroporid corals (16.5 ± 3.8) and turf algae (33.4 ± 11.8%).

Coral reefs in Kiribati have experienced a high frequency of bleaching-level heat stress due to the El Niño conditions in combination with ongoing ocean warming (Mangubhai et al., 2019). Given that there were relatively few colonies of *Acropora* and *Pocillopora* spp. and similar coral community composition to the islands and atolls in the Phoenix Islands, Carondelet Seamount may have been affected similarly by the 2002−2003 bleaching event that resulted in widescale loss of the coral community in the island group (Obura and Mangubhai, 2011). Coral bleaching was only observed in a few colonies of *Pocillopora* spp., and was less than what was recorded in the Phoenix Islands atolls during the 2015 expedition (Fox et al., 2021). The isolated nature of the atolls and seamounts in Phoenix Islands suggests that recruitment is largely from local sources, and thus recovery from island-wide disturbances will be slow. Some signs of coral community recovery were observed; similar to that documented on Kanton Atoll (Mangubhai et al., 2019), *Acropora* recruits were observed on the top of the seamount which might facilitate recovery. With accelerating climate change and the recent opening of the protected area to industrial fishing, it is expected that seamounts like Carondelet will continue to change for the worse.

The Phoenix Islands is a naturally iron poor region, and the introduction of iron to this environment from shipwrecks is linked to degraded 'black reefs' – a term used to describe coral reefs dominated by cyanobacterial (microbial) mats and devoid of coral and crustose coralline algae (Kelly et al., 2012; Mangubhai and Obura, 2019; Mangubhai et al., 2019). A black reef patch (0.5–1 m wide) was documented around an abandoned anchor line on Carondelet Seamount, suggesting iron may be leaching onto the reef (Figure 4). There was fresh fishing line on the seamount suggesting that fishing was occurring around the time of the survey.

Table 3. Average percentage benthic cover (± standard deviation in parentheses) at 5, 8, and 20 m on Carondelet seamount in 2015.

Cover categories	5 m	8 m	20 m
Hard corals	32.8 (10.2)	35.3 (6.2)	12.8 (5.9)
Acropora branching	3.5 (0.7)	4.0 (4.2)	1.0 (0)
Acropora digitate	6.6 (2.7)	6.0 (4.6)	0 (0)
Acropora encrusting	1.5 (0.7)	2.7 (1.5)	1.5 (0.7)
Acropora tabulate	1.3 (0.5)	3.0 (2.8)	1.0 (0)
Coral encrusting	17.8 (11.1)	16.5 (3.8)	6.3 (4.7)
Coral foliose	0 (0)	4.0 (0)	1.7 (1.2)
Coral submassive	1.0 (0)	7.0 (5.0)	3.3 (3.3)
Coral massive	13.0 (14.1)	3.0 (0)	5.0 (5.2)
Dead coral	1.0 (0)	2.0 (0)	0 (0)
Coralline algae	7.6 (5.6)	14.2 (7.3)	16.8 (3.9)
Macroalgae	0 (0)	0 (0)	15.8 (4.4)
Turf algae	12.2 (9.4)	33.4 (11.8)	30.0 (15.4)
Microbial mats	30.4 (13.1)	2.8 (1.9)	5.6 (3.7)
Reef matrix	16.6 (8.7)	4.5 (3.4)	13.6 (7.8)
Rubble	0 (0)	14.3 (13.5)	3.2 (2.3)
Sand	0 (0)	10.5 (3.5)	1.8 (1.3)
Other invertebrates	1.0 (0)	1.5 (0.5)	1.0 (0)

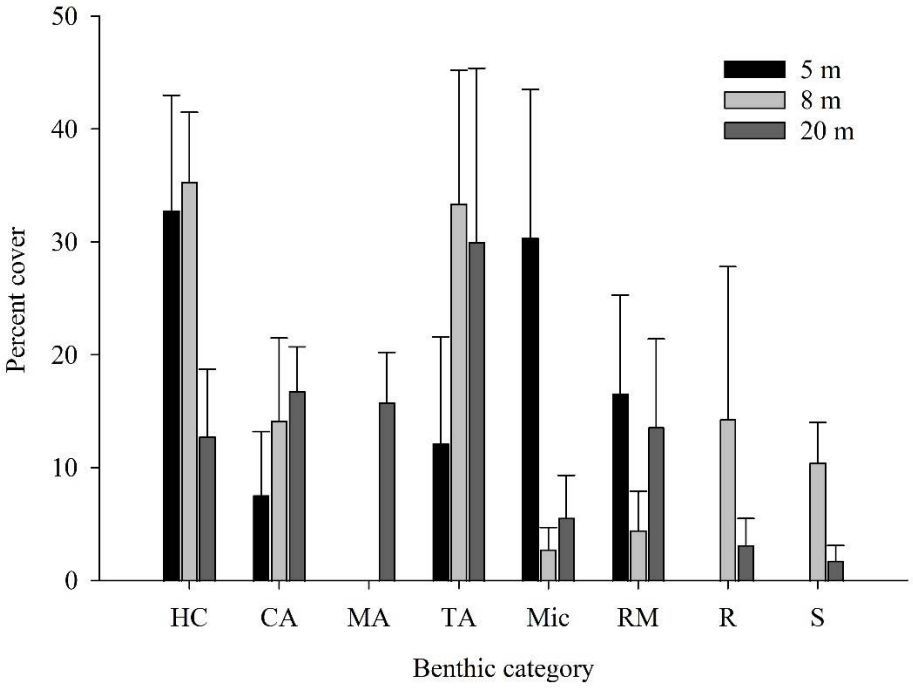

Figure 3. Comparison of main benthic categories recorded at 5, 8, and 20 m. HC=hard corals, CA=coralline algae, MA=macroalgae, TA=turf algae, Mic=microbial mats

Figure 4. Abandoned anchor line leaching iron and causing a small patch of black reef. © Craig Cook

Fish Diversity

A total of 120 species of diurnally active coral reefs fishes (not including cryptic species) were recorded with common community assemblages resembling those of proper atolls visited previously within PIPA (Appendix 1). The most abundant taxonomic groups included the surgeonfishes (Acanthuridae), triggerfishes (Balistidae), wrasses (Labridae), and damselfishes (Pomacentridae). Wrasses and Surgeonfishes were the most well-represented groups in terms of diversity with 24 and 20 species observed respectively. While wrasses were the most diverse group observed, the abundance of individual species varied among the group. The most abundant wrasse was the fivestripe wrasse (*Thalassoma quinquevittatum*), a gregarious species observed swimming along the reef in small groups. The most abundant surgeonfish species observed was the yellowfin surgeonfish (*Acanthurus xanthopterus*), a larger-bodied grazer-detritivore observed in the water column and along the benthos. Damselfishes were also very abundant and included the midget chromis (*Pycnochromis acares*), the bicolor chromis (*P. margaritifer*), and Vanderbilt's chromis (*P. vanderbilti*) all of which are planktivores and are commonly observed in small aggregations 1–2 m off the substratum. For the triggerfishes (Balistidae), the most abundant species was the black durgon (*Melichthys niger*), observed in small groups swimming up in the water column just off the reef slope.

Other notable observations included the whitetip reef shark (*Triaenodon obesus*) and gray reef shark (*Carcharhinus amblyrhynchos*), two of the species of concern from the IUCN Red List that were observed (Appendix 1). There was an expectation that reef sharks would be common due to the remote geography of the seamount and assumption that fishing would be uncommon. The commonness of fishing gear observed on the shallow portions of the seamount suggest that this expectation was not accurate. However, a healthy aggregation of >50 smaller-bodied grey reef sharks (*C. amblyrhynchos*) was documented along outer reef slopes along a more exposed region of the seamount.

CONCLUSION

This opportunistic survey was limited to SCUBA depths (<30 m), and the low diversity on top does not mean the seamount does not support important marine life. Deep sea habitat expeditions to the Phoenix Islands in March and October 2017 (aboard the NOAA ship Okeanos Explorer and Schmidt Ocean Institute R/V Falkor) documented "a multitude of ancient and undisturbed ecosystems, such as forests of bamboo corals, diverse coral gardens, and hexactinalid glass sponges," with corals estimated to be between 300 to 1000 years old (Mangubhai et al., 2019). Fourteen seamounts were located within the boundaries of the PIPA, prior to its opening. It is important that future research expeditions to the Phoenix Islands consider including biodiversity surveys of seamounts. Furthermore, the region would benefit from a joint vision or policy for the conservation and management of seamounts within the territorial waters of Pacific Island countries and territories.

ACKNOWLEDGMENTS

Foremost, we thank the government of the Republic of Kiribati for the permission to conduct this research. We are grateful for the assistance of the staff of the M/Y *Hanse Explorer* for providing logistical support and to Craig Cook for allowing us to use his photographs. Thank you to Randi Rotjan for being instrumental in fundraising and planning the research expedition. This expedition was funded through the generous support of The Robertson Foundation, The Prince Albert of Monaco II Foundation, The New England Aquarium, and The Woods Hole Oceanographic Institution Ocean Life Initiative. We thank our reviewer for their useful comments which improved our manuscript. We dedicate this article to Tuake Teema, who served as the Kiribati Government observer and scientist on expeditions to the Phoenix Islands in 2000, 2002, 2009, and 2012, and sadly passed away in 2022.

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APPENDIX 1: CHECKLIST OF FISHES FROM CARONDELET SEAMOUNT

List of fish species recorded on Carondelet Reef in 2015. Presence categories are Abundant (A), Common (C), Occasional (O), or Rare (R). IUCN Red List status is: Endangered (EN), Vulnerable (VU), Near Threatened (NT), Data Deficient (DD), Least Concern (LC), and Not Evaluated (NE).

Family	Species	Presence	IUCN Red List
Acanthuridae	*Acanthurus achilles*	O	LC
	Acanthurus achilles x nigricans (hybrid)	R	NE
	Acanthurus leucocheilus	R	LC
	Acanthurus nigricans	C	LC
	Acanthurus nigrofuscus	O	LC
	Acanthurus nigroris	C	LC
	Acanthurus olivaceus	O	LC
	Acanthurus thompsoni	C	LC
	Acanthurus xanthopterus	A	LC
	Ctenochaetus cyanocheilus	C	LC
	Ctenochaetus flavicauda	C	LC
	Ctenochaetus hawaiiensis	O	LC
	Ctenochaetus marginatus	C	LC
	Ctenochaetus striatus	C	LC
	Naso brevirostris	O	LC
	Naso hexacanthus	O	LC
	Naso lituratus	O	LC
	Naso vlamingii	O	LC
	Zebrasoma rostratum	R	DD
	Zebrasoma scopas	O	LC
Balistidae	*Balistapus undulates*	O	LC
	Balistoides viridescens	R	LC
	Canthidermis maculata	R	LC
	Melichthys niger	A	LC
	Melichthys vidua	O	LC
	Pseudobalistes flavimarginatus	O	LC
	Rhinecanthus rectangulus	O	LC
	Sufflamen bursa	C	LC
	Xanthichthys auromarginatus	C	LC
Belonidae	*Tylosurus crocodilus*	O	LC
Blenniidae	*Cirripectes stigmaticus*	O	LC
Caracanthidae	*Caracanthus maculatus*	C	LC
Carangidae	*Carangoides orthogrammus*	O	LC
	Caranx ignobilis	O	LC
	Caranx lugubris	O	LC
	Caranx melampygus	O	LC
	Elagatis bipinnulata	O	LC

	Scomberoides lysan	O	LC
Carcharhinidae	*Carcharhinus amblyrhynchos*	O	EN
	Triaenodon obesus	O	VU
Chaetodontidae	*Chaetodon lunula*	O	LC
	Chaetodon ornatissimus	O	LC
	Chaetodon punctatofasciatus	O	LC
	Chaetodon quadrimaculatus	O	LC
	Chaetodon reticulatus	O	DD
	Chaetodon trifascialis	R	NT
	Chaetodon ulietensis	R	LC
	Chaetodon unimaculatus	R	LC
	Forcipiger flavissimus	O	LC
	Forcipiger longorostris	O	LC
	Heniochus chrysostomus	R	LC
Cirrhitidae	*Cirrhitichthys hubbaridi*	O	LC
	Cirrhitichthys oxycephalus	O	LC
	Cirrhitus pinnulatus	O	LC
	Paracirrhites arcatus	C	LC
	Paracirrhites forsteri	O	LC
	Paracirrhites hemistictus	O	LC
	Paracirrhites xanthus	R	LC
Echeneidae	*Echeneis naucrates*	R	LC
Epinephelidae	*Aethaloperca rogaa*	R	LC
	Cephalopholis argus	C	LC
	Cephalopholis miniata	R	LC
	Cephalopholis urodeta	C	LC
	Epinephelus hexagonatus	O	LC
	Epinephelus macrospilos	R	LC
	Gracila albomarginata	C	LC
	Luzonichthys whitleyi	O	LC
	Pseudanthias bartlettorum	C	LC
	Pseudanthias dispar	O	LC
	Pseudanthias olivaceus	O	LC
	Pseudanthias pascalus	O	LC
	Variola louti	O	LC
Holocentridae	*Myripristis amaena*	C	LC
	Myripristis berndti	C	LC
	Myripristis earlii	O	LC
	Myripristis kuntee	O	LC
	Sargocentron tiere	C	LC

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Family	Species	Presence	IUCN Red List
Labridae	*Anampses caeruleopunctatus*	O	LC
	Anampses melanurus	R	LC
	Anampses twistii	O	LC
	Bodianus axillaris	R	LC
	Bodianus diana	R	LC
	Bodianus mesothorax	O	LC
	Cheilinus undulatus	R	EN
	Cirrhilabrus exquisitus	C	DD
	Gomphosus varius	C	LC
	Halichoeres hortulanus	C	LC
	Halichoeres ornatissimus	C	LC
	Hemigymnus fasciatus	O	LC
	Labroides bicolor	O	LC
	Labroides dimidiatus	O	LC
	Labroides rubrolabiatus	O	LC
	Labropsis xanthonota	O	LC
	Macropharyngodon meleagris	C	LC
	Novaculicthys taeniourus	O	LC
	Oxycheilinus unifasciatus	R	LC
	Pseudocheilinus hexataenia	C	LC
	Pseudocheilinus octotaenia	C	LC
	Pseudodax moluccanus	R	LC
	Thalassoma amblycephalum	C	LC
	Thalassoma quinquevittatum	A	LC
Labridae (Scarinae)	*Calotomus carolinus*	O	LC
	Chlorurus microrhinos	R	LC
	Scarus niger	O	LC
	Scarus rubroviolaceus	O	LC
	Scarus tricolor	O	LC
Lethrinidae	*Gnathodentex aureolineatus*	O	LC
	Monotaxis grandoculis	C	LC
Lutjanidae	*Aphareus furca*	O	LC
	Aprion virescens	R	LC
	Lutjanus bohar	C	LC
	Lutjanus gibbus	O	LC
	Lutjanus kasmira	O	LC
	Macolor macularis	O	LC
	Macolor niger	O	LC
Monacanthidae	*Aluterus scriptus*	R	LC
Mullidae	*Mulloidichthys vanicolensis*	R	LC
	Parupeneus multifasciatus	O	LC

Muraenidae	*Gymnothorax meleagris*	R	LC
Ostraciidae	*Ostracion meleagris*	R	NE
Pomacanthidae	*Apolemichthys griffisi*	O	LC
	Centropyge flavissima	R	LC
	Centropyge loricula	O	LC
	Pomacanthus imperator	R	LC
Pomacentridae	*Chromis alpha*	O	LC
	Chromis xanthura	O	LC
	Lepidozygus tapeinosoma	O	LC
	Plectroglyphidodon dickii	C	NT
	Plectroglyphidodon fasciolatus	C	LC
	Plectroglyphidodon johnstonianus	C	LC
	Plectroglyphidodon phoenixensis	C	LC
	Pycnochromis acares	A	LC
	Pycnochromis agilis	O	LC
	Pycnochromis margaritifer	A	LC
	Pycnochromis vanderbilti	A	LC
	Stegastes aureus	C	NE
Scombridae	*Acanthocybium solandri*	R	LC
	Gymnosarda unicolor	R	LC
Sphyraenidae	*Sphyraena barracuda*	O	LC
	Sphyraena helleri	O	NE
	Sphyraena putnamae	O	NE
Tetraodontidae	*Arothron meleagris*	O	LC
Zanclidae	*Zanclus cornutus*	O	LC