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Are Sunken Warships Biodiversity Havens for Corals?

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Abstract: Coral reefs are threatened by climate change, overfishing, and pollution. Artificial reefs may provide havens for corals, both to escape warming surface waters and to assist in the geographic migration of corals to more habitable natural reef conditions of the future. The largest artificial reefs have been generated by nearly 2000 shipwrecks around the world, but the coral diversity on these wrecks is virtually unknown. Ship size and hull material, location relative to natural reef, time since sinking, ocean currents, and water depth may affect coral diversity. As a test of the biodiversity capacity of very large sunken structures relative to surrounding natural reef, we carried out technical diver-based surveys to quantify genus-level coral diversity on 29 warships sunk in Bikini Atoll and Chuuk Lagoon. We also assessed whether ship length, as an index of substrate availability, and water depth, as an indicator of light and temperature, can serve as predictors of coral diversity. We surveyed a total of 9105 scleractinian corals. The total number of genera identified at Bikini was 34, and at Chuuk it was 51, representing 67% and 72% of genera found on natural reefs at Bikini and Chuuk, respectively. Ship length, but not water depth, was positively correlated with relative abundance and richness at the genus level. Our results suggest that very large wrecks can serve as havens for reef-building corals with a broad genetic diversity, expressed at the genus level, commensurate with corals found on neighboring natural reefs. The role of large artificial reefs could include protecting coral biodiversity from warming surface waters.

Keywords: artificial reef; Bikini Atoll; Chuuk Atoll; coral diversity; coral reef; shipwrecks

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Citation: Asner, G.P.; Giardina, S.F.; Balzotti, C.; Drury, C.; Hopson, S.; Martin, R.E. Are Sunken Warships Biodiversity Havens for Corals? *Diversity* **2022**, *14*, 139. https://doi.org/10.3390/d14020139

Academic Editors: Michael Wink, Atsuko Fukunaga and John Burns

Received: 7 January 2022
Accepted: 14 February 2022
Published: 16 February 2022

1. Introduction

Corals are imperiled by global warming and acidifying ocean conditions as well by local to regional forces of reef degradation, including land-based pollution and overfishing [1–3]. Where corals will persist in a future ocean remains unclear, but there is already emerging evidence of coral losses in some regions and shifts in the range of coral species to areas more conducive to their survival [4–6]. The persistence of corals will likely depend on their ability to move to consistently cooler waters, but other constraints, such as available reef substrate, ocean currents, coral adaptation (i.e., microbiome shuffling, epigenetics, etc.), and water turbidity will set major limits to the migratory potential of corals.

Artificial reefs offer one smaller-scale avenue for harboring marine life in the face of regional to global ocean stressors [7]. It has long been known that artificial reefs can provide habitat for a plethora of marine taxa including fishes, corals, and other organisms. Since 1942, at least 1907 wrecks of various sorts have been purposely generated for artificial reefs ranging from tropical to temperate waters [8]. Moreover, the National Defense Research Institute identified over 350 current U.S. Navy and Maritime Administration ships that would require government-funded disposal in the next twenty years. The report concluded that converting the vessels into artificial reefs would be the lowest-cost approach [9].

While a network of artificial reefs cannot replace the incalculable biodiversity or ecosystem service value of natural reefs, they may provide a range of opportunities for improving the outlook for corals as surface waters warm. It is also conceivable that artificial reefs could provide steppingstones, like seamounts [10], to aid in the migration of marine species to cooler water conditions. Although highly controversial, the potential for assisted migration via artificial reefs remains unexplored.

Several studies have assessed the potential role of artificial reefs for coral conservation. A comparative analysis off the coast of Dubai found that large artificial reefs carried higher coral cover but lower coral diversity relative to neighboring natural reefs [11]. Perkol-Finkel and Benayahu [12] suggested that artificial reefs may provide substrate for coral communities, but that the structural complexity of artificial substrates is a critical determinant of diversity levels. Despite these and similar studies, much of the scientific uncertainty outlined by Bohnsack and Sutherland [13] in 1985 regarding artificial reefs remains today: We do not know enough about their role in coral conservation, particularly in a changing ocean climate.

To further consider artificial reefs as potential networks for saving and migrating corals in a changing ocean, we need more information on the habitat suitability of human-made substrates such as shipwrecks and other abandoned platforms. Material surfaces for use as artificial reefs are limited primarily to steel and concrete as others quickly break down in ocean environments. Even steel eventually degrades; thus, the highest efficacy platforms for such undertakings would be limited to the largest available vessels. How large is sufficient? This, too, is poorly known.

A basic tenet of ecology states that the taxonomic richness of an ecosystem, particularly for sessile taxa such as corals and plants, scales with the area of the ecosystem. The species-area curve defines the rate of accumulation of taxa with increasing ecosystem size [14], and key area–diversity–distance patterns generated the classic theory of island biogeography [15]. Together, these principles provide a well-established foundation upon which to test the efficacy of artificial reefs for biodiversity conservation. Specifically, does the size of an artificial reef affect coral diversity?

Here, we address these questions by quantifying the richness and relative abundance of scleractinian corals on the outer hulls of warships sunk in two large events in the western Pacific. At Bikini Atoll in the Marshall Islands, a total of 13 large warships were sunk on 1 and 25 July 1946 in two nuclear bomb tests. These ships rest on the seafloor of the lagoon at 60 m water depth. At Chuuk Lagoon in the Federated States of Micronesia, a naval battle on 17–18 February 1944 resulted in the sinking of more than 40 combatant and transport ships. These ships lie on the lagoon floor at water depths of 30–66 m. We carried out systematic surveys of coral composition in the lagoons of Bikini and Chuuk to assess the efficacy of large steel vessels in providing a haven for habitat-generating hard corals. An important characteristic of these artificial reefs is they lie at water depths that, thus far, have escaped the typical depth of marine heatwaves, a dominant driver of coral mortality worldwide [16–18]. That is, our surveys focused on potential coral refugia below the zone of the most extreme ocean warming.

2. Materials and Methods

2.1. Field Sites

Bikini Atoll (11°36.5′ N, 165°22.6′ W) is in the far northern portion of the Marshall Islands (Figure 1). The atoll is 694 km^2 in area with a lagoon mostly enclosed by reef and 23 small islands. The Marshallese people of Bikini Atoll were relocated in 1946 to make way for nuclear bomb tests, after which 23 atomic tests were conducted until 1958 [19]. The atoll is extremely remote, with only a few caretakers present on one island. The shipwrecks are located just east of the center of the lagoon with a seafloor depth averaging 60 m. Coral diversity was assessed on reefs of Bikini Atoll in 1946, prior to nuclear testing, which resulted in an estimated 126 scleractinian coral species in 52 genera [20]. In 2002, the second survey of reefs at Bikini Atoll was conducted, which yielded 183 species in 51 genera [21].

Species diversity changes may be due to taxonomic reclassifications or local extinction. At the scale of the entire archipelago of the Marshall Islands, there are about 309 coral species in 63 genera [22,23].

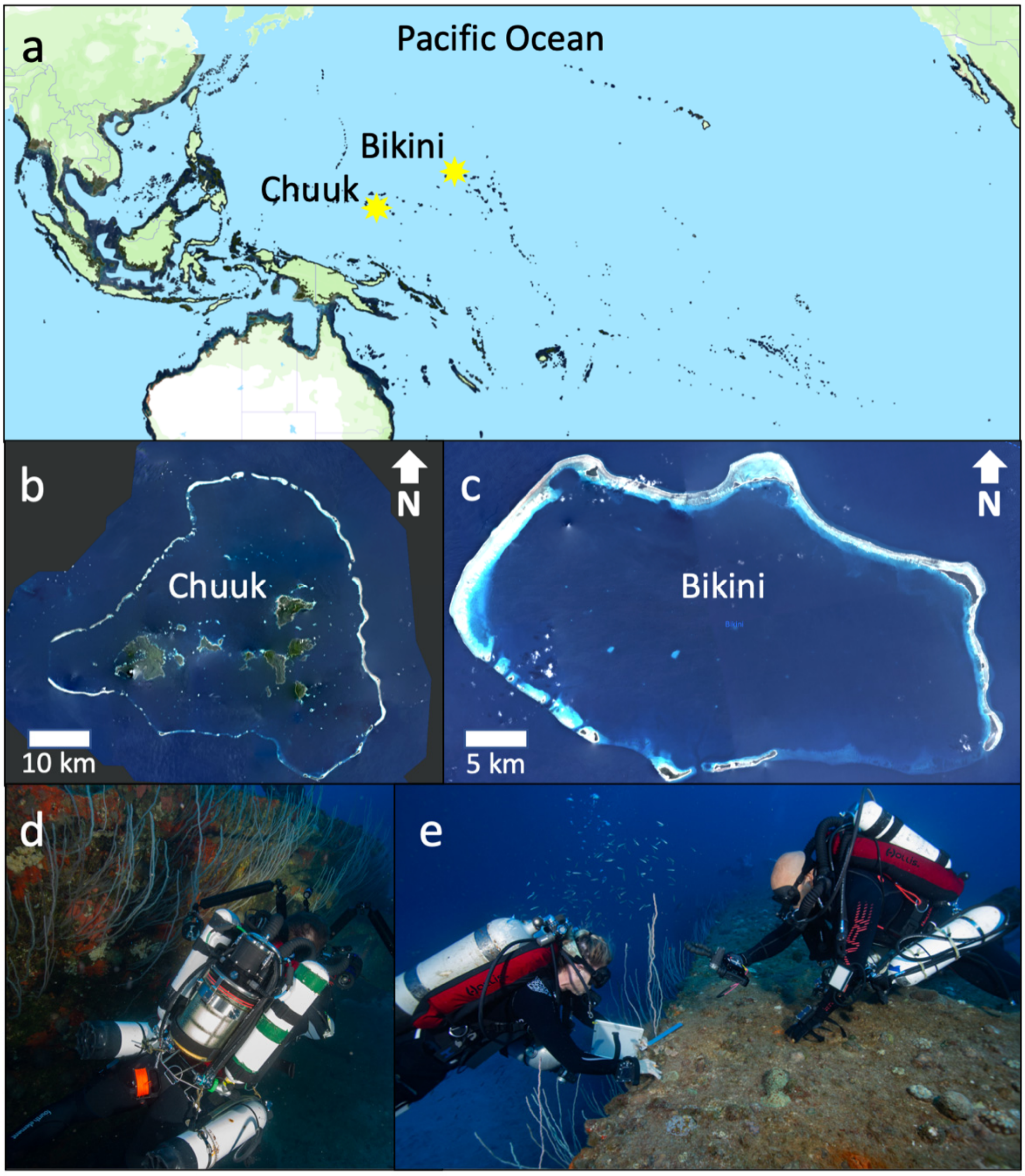

Figure 1. (**a**) Location of Chuuk and Bikini Atolls in the western Pacific. Background image indicates coral reefs in dark colors from the Allen Coral Atlas (http://allencoralatlas.org, accessed on 15 December 2021). (**b**,**c**) Planet Dove satellite images of Chuuk and Bikini Atolls. (**d**) Example hull video transect collected using high-resolution camera, lights, and closed-circuit rebreather. (**e**) Technical divers collecting detailed measurements and photographs for a shipboard coral genus database.

Chuuk Atoll (7°23.5′ N, 151°46.0′ E) lies within the Federated States of Micronesia in the western Pacific Ocean. Chuuk is 2130 km^2 in area and has about 36,000 residents. Compared to Bikini Atoll, Chuuk has undergone far more human activity since 1500 AD, including intensive occupation by European, Japanese, and American personnel. Scleractinian corals of Chuuk Atoll share much of their biogeographic range with the rest of Micronesia. Reefs of Chuuk harbor about 395 coral species in 71 genera [22,23].

2.2. Biodiversity Surveys

In November 2018 at Bikini Atoll, we studied eight ships ranging in length from 95 to 268 m at survey depths of 44 to 52 m, defined by each upward or sideward facing hull (Table 1 and Supplementary Materials). In February 2019 at Chuuk Atoll, we surveyed 21 ships ranging in length from 40 to 161 m with survey depths of 29–56 m. We limited our surveys to upward and sideward facing hulls as a general control over available light levels affecting coral growth. We focused on scleractinian corals because they are long-lived, reef-building organisms.

Table 1. Shipwrecks surveyed for coral diversity in Bikini and Chuuk Atolls.

Ship Name	Length (m)	Survey Depth (m)
Bikini Atoll		
Anderson	106	49
Apogon	95	48
Arkansas	171	44
Carlisle	130	48
Lamson	104	52
Nagato	221	42
Pilotfish	95	52
Saratoga	268	50
Chuuk Atoll		
Aikoku	161	56
Amagisan	137	45
Fujikawa	133	29
Fujisan	156	56
Fumitsuki	101	29
Futagami	40	29
Gosei	82	29
Heian	155	29
Hoki	137	45
Kensho	116	29
Kikukawa	108	29
Kiyosumi	137	29
Momokawa	107	45
Nagano	105	66
Rio de Janeiro	137	29
San Francisco	117	56
Sankisan	113	29
Seiko	120	56
Shinkoku	152	29
Unkai	93	29
Yamagiri	134	29

Coral surveys were conducted by two dive teams and did not require touching of corals or ship hulls. One team focused on building a taxonomic database of scleractinian corals. The second team focused on video transects used for coral richness and relative abundance analysis. The team consisted of up to six technical divers using extended range and closed-circuit rebreather equipment operated with decompression procedures. Dives were repeated until the entire upward and sideward facing hull, decks, and superstructures were surveyed. Dives were limited to 30–45 min bottom times due to pressure exposure and decompression procedures.

The taxonomy team systematically worked their way along each hull, carefully photographing and cataloging each morphotaxonomic species encountered. Data were collected using Nikon™ TG5 cameras with Nauticam™ housings and Light and Motion™ constant lights. The transect team utilized high-resolution videography to systematically survey each hull from stern to bow. Transect footage was captured with a nadir pointing underwater Nauticam™ housing, Nikon™ D850 camera, and two 25,000 lumen Keldan™ constant lights.

2.3. Image Analysis

Coral database development was carried out using global and regional taxonomic references [23]. As there is much synonymy and uncertainty in coral identification at the species level, we generated the database with taxon information at the genus level for subsequent analyses. To support coral identification in the videographic transects, region-specific coral genera identification guides were created for Bikini and Chuuk. These guides were produced using a separate set of high-quality images taken by divers on each ship.

Each videographic transect was broken into still images at a rate of two video frames per second. Standardized boxes were placed on each image to delineate areas for coral identification. First, images taken at an angle or from a distance far from a substrate were discarded. These typically were those taken at the beginning and end of the video transect when the camera was moving towards or away from the ship. We also avoided double counting of coral colonies in overlapping sequential images. Remaining images were imported into an open-source DDG software tool for counting objects (DotDotGoose v.1.2.0, American Museum of Natural History). Coral abundance tabulations were made using the point labeling feature in the DDG software. Dots labeled with the identified genera were placed on their respective coral colonies. Colonies outside of the box on the image were excluded from labeling. Once all images for a ship were analyzed, coral counts were tabulated by ship. If a genus was observed in the coral database but not in the transect data, it was given an abundance count of one for that ship.

2.4. Data Analysis

Absolute richness and abundance were calculated as the number of coral genera and individual colonies, respectively, per ship per site. Relative richness and abundance were calculated as the proportion of all genera found on each ship per site. We also calculated rank abundances of corals to detect hyperabundant genera and to estimate total genus-level richness per site. To further assess differences in coral diversity by shipwreck, we used non-metric multidimensional scaling (NMDS). NMDS is based on a distance matrix computed by placing the diversity data in a two-dimensional coordinate system such that the ranked differences are preserved. NMDS intentionally does not take absolute distances into account.

3. Results

3.1. Coral Diversity

We surveyed a total of 1774 corals on eight ships at Bikini Atoll and 7331 corals on 21 ships in Chuuk Atoll. The total number of genera identified was 34 and 51 at Bikini and Chuuk, respectively. At the individual ship level, coral richness ranged from 22–29 genera per ship at Bikini and 7–29 genera per ship at Chuuk (Table 2).

Both absolute and relative genus richness were more variable among shipwrecks at Chuuk compared to Bikini (Table 2). Whereas relative genus richness varied by a maximum of 23% among the eight ships at Bikini, it varied by 75% at Chuuk.

Total coral colony abundance ranged from 92–377 corals on ships in Bikini and 25–1343 corals on ships in Chuuk. These totals only represent our transects along the upward and sideward facing hulls, decks, and superstructures of the ships, which varied greatly in complexity (rugosity), therefore relative abundance is the more appropriate comparative measure between vessels. We calculated relative abundance per ship as the proportion of all corals found on all ships in each atoll. This resulted in relative abundance estimates of 6.5–21.3 in Bikini and 0.3–18.3 in Chuuk (Table 2). That is, vessels at Chuuk were nearly five times more variable in the distribution of coral genera than were vessels at Bikini Atoll ($p < 0.01$; Mann–Whitney test).

Table 2. Coral genus-level richness and abundance by ship.

Ship Name	Richness	Rel. Richness (%)	Total Abundance	Rel. Abundance (%)
Bikini Atoll				
Anderson	22	64.7	275	15.5
Apogon	27	79.4	116	6.5
Arkansas	28	82.4	377	21.3
Carlisle	25	73.5	92	5.2
Lamson	27	79.4	93	5.2
Nagato	26	76.5	338	19.1
Pilotfish	22	64.7	147	8.3
Saratoga	29	85.3	336	18.9
Chuuk Atoll				
Aikoku	28	54.9	221	3.0
Amagisan	23	45.1	316	4.3
Fujikawa	19	37.3	193	2.6
Fujisan	23	45.1	302	4.1
Fumitsuki	14	27.5	111	1.5
Futagami	9	17.6	117	1.6
Gosei	16	31.4	150	2.0
Heian	19	37.3	1343	18.3
Hoki	15	29.4	174	2.4
Kensho	17	33.3	195	2.7
Kikukawa	7	13.7	25	0.3
Kiyosumi	19	37.3	657	9.0
Momokawa	16	31.4	438	6.0
Nagano	17	33.3	193	2.6
Rio de Janeiro	22	43.1	664	9.1
San Francisco	8	15.7	63	0.9
Sankisan	29	56.9	1109	15.1
Seiko	17	33.3	228	3.1
Shinkoku	21	41.2	356	4.9
Unkai	19	37.3	207	2.8
Yamagiri	17	33.3	273	3.7

Of the 34 identified genera on ships in the lagoon at Bikini Atoll, the five most abundant were *Favia* (n = 442 colonies), *Montastrea* (354), *Favites* (161), *Porites* (137), and *Leptastrea* (126) (Appendix A). These top five genera accounted for 64.5% of all coral colonies on the eight vessels. The rarest five genera included *Cyphastrea* (n = 1 colony), *Heliofungia* (1), *Polyphyllia* (1), *Stylocoeniella* (2), and *Merulina* (2), cumulatively representing just 0.4% of all colonies. At Chuuk, the five most abundant genera were *Porites* (n = 3081 colonies), *Favites* (506), *Favia* (376), *Duncanopsammia* (329), and *Lobophyllia* (319). The least abundant genera were *Stylaster* (1), *Leptoria* (1), *Euphyllia* (1), *Cycloseris* (1), and *Pectinia* (2). It is important to note differences in the distribution of genera among ships: Porites was the most common on all 21 vessels in Chuuk; however, *Duncanopsammia* was hyperabundant on only one vessel, the Sankisan (Appendix B).

Rank abundance analysis resulted in a log scale indicating hyperdominance by very few coral genera (Figure 2). In Bikini Atoll, a log-linear profile indicated roughly stable-equilibrium in the relative abundance of genera among all vessels combined, with *Favia* and *Montastrea* representing 45% of all coral colonies surveyed. However, ranking in Chuuk indicated extreme hyperdominance of one genus—*Porites* (42%)—among all vessels combined, with the remainder of the distribution in relative equilibrium.

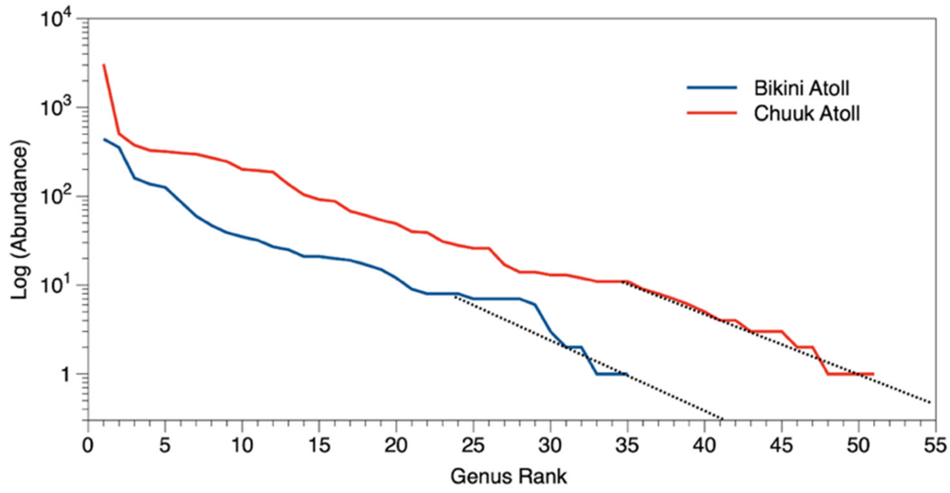

Figure 2. A rank-abundance diagram showing the estimated genus diversity of shipwrecks in Bikini (blue line) and Chuuk (red line) lagoons. Dashed lines are linear extrapolations for use in estimating true genus-level richness on each group of vessels.

Extrapolating from these rank abundance curves suggests that there could be additional genera unaccounted for in our surveys. We found 34 genera in Bikini, whereas an extrapolated dashed line suggests upwards of 42–43 genera present (Figure 2). In Chuuk Lagoon, we found 51 genera, but an extrapolation line suggests 57 or more genera present overall.

NMDS analysis indicated that the diversity of corals on ships in Bikini Atoll were different from those of Chuuk Lagoon (Figure 3). Variation among ships in Chuuk was much greater than those within Bikini Atoll. The analysis also revealed that some ships in Chuuk were compositionally distinct from others, particularly the ships named San Francisco, Kikukawa, Nagano, and Yamagiri.

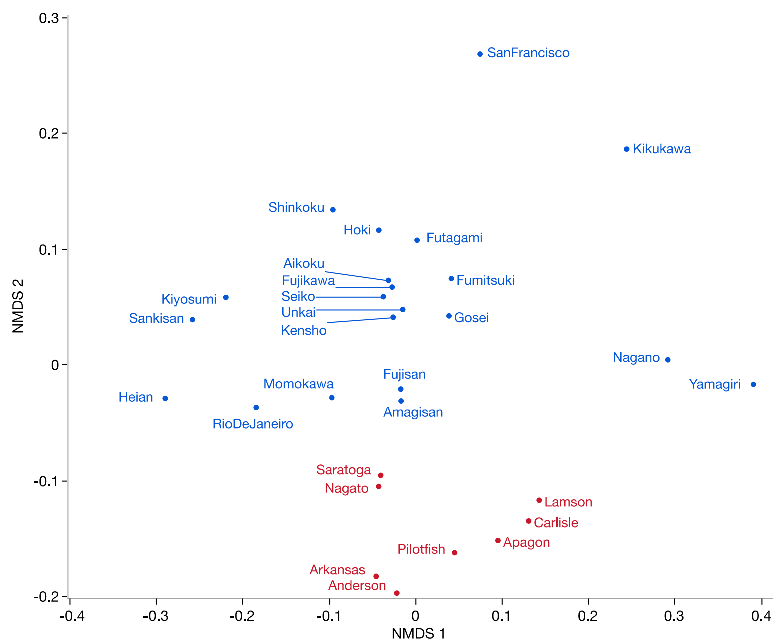

Figure 3. Non-metric multi-dimensional scaling (NMDS) plot of coral genus-level diversity among shipwrecks in Bikini Atoll (red dots) and Chuuk Lagoon (blue dots).

3.2. Ship-Coral Relationships

At Bikini Atoll, coral richness showed no relationship with the length of the vessels (Figure 4a), but relative abundance was significantly correlated with ship length (R = 0.74, $p < 0.05$; Figure 4b). The opposite was true at Chuuk, with richness and ship length related (R = 0.56, $p < 0.05$), while relative abundance was insensitive to length. There was no relationship between survey depth and either richness or relative abundance (Figure 4c,d).

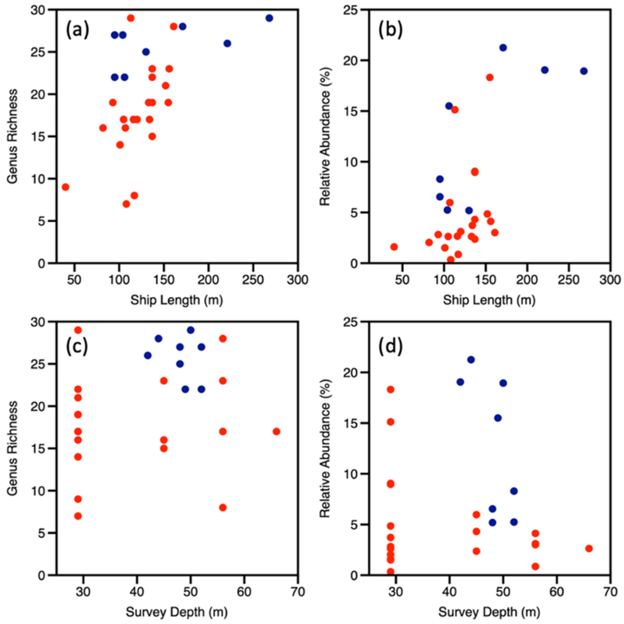

Figure 4. Relationships between the length and depth of sunken vessels and (**a**,**c**) coral genus richness and (**b**,**d**) relative abundance. Red and blue dots indicate ships in Chuuk and Bikini lagoons, respectively.

4. Discussion

Systematic coral surveys of shipwrecks and other artificial reefs are rare, yet they can assist our understanding of the efficacy of human-made habitats on coral survival. This is particularly important in a time when natural coral reefs are declining, particularly in shallow (<15 m) environments, from repeated marine heatwaves. If deeper (30–50 m) artificial reefs harbor corals normally found at the more vulnerable shallow depths, it not only suggests the utility of direct human intervention to generate new coral habitat but also serves as an indicator of possible geographic steppingstones that could be generated to help corals migrate from warmer to cooler environments over time.

We found that the shipwrecks of Bikini and Chuuk contained 34 and 51 coral genera, respectively, on their upward and sideward facing hulls, decks, and super structures. Comparing these findings to the diversity of their surrounding shallow reefs, the ships harbor 67% and 72% of genera at Bikini and Chuuk, respectively. There was no evidence suggesting that water depth controlled either genus richness or relative abundance, despite our surveys taking place below 29 m depth. Many of our surveys were below 40 m depth, which is below the layer most impacted by marine heatwaves [24]. Vertical depth gradients of marine heatwaves remain poorly understood, but studies point to the top 20 m as most impacted [25]. The ultimate depth limit of the coral genera we surveyed is not known, but it must be somewhere in the euphotic zone where there is sufficient light to stimulate photosynthesis in coral–algal symbionts. Waters in the lagoon at Bikini Atoll are extremely clear, which is not true in Chuuk lagoon, where we encountered much higher levels of turbidity (data not shown). Our results suggest that euphotic zone coral genera can persist, in large abundances in some cases, to depths of 50 m. Nonetheless, we also recognize that such depths have limited light availability which then limits overall coral productivity, cover, and reef-building potential.

The two research sites differ in another way beyond water quality: Bikini Atoll is much smaller and more remote, with far fewer visitors and no legal fishing, compared to Chuuk with more land area, thousands of visitors, and high fishing pressure. Such secondary stressors are at an absolute minimum at Bikini, which may provide a baseline against which to test the role of very large artificial reefs under pristine environmental conditions. This is, of course, limited by the fact that the ships sank just 72 years before our surveys, and underwent unknown levels of repeated radioactivity with poorly reported effects on the biotic environment underwater. The fact that, today, the Bikini ships carry two-thirds of the coral genera found on neighboring reefs, combined with the fact that all of the coral genera remain on Bikini's natural reefs long after the bomb tests [21], indicates this site may indeed serve as the benchmark we seek for very large artificial reefs in pristine waters.

In comparison to Bikini, Chuuk Lagoon has more shipwrecks that yield more substrate and habitat for corals to settle and grow. We indeed found that more ships in Chuuk yielded more coral colonies and greater coral diversity compared to Bikini (Figure 2). However, we also discovered much more variation in coral diversity among vessels in Chuuk (Figure 3). While ship depth had no apparent effect on coral diversity, ship length was a significant determinant of either richness or relative abundance, depending upon the site. The very largest ships in the lagoon at Bikini, including the USS Arkansas (battleship), USS Saratoga (aircraft carrier), and IJN Nagato (battleship), carried the greatest number and diversity of corals. Additionally, ship length was correlated with genus-level coral richness at Bikini. This is likely our best indicator that the classic ecological genus-area relationship holds for deep artificial reefs. In Chuuk, the results also show increasing coral richness with ship length, which reached a maximum diversity comparable to the largest ships in Bikini Atoll.

Despite two large and complex expeditions, we ultimately only studied two groups of large shipwrecks. We are thus uncertain as to how the total surface area of the wrecks might relate to the area of natural source reefs that surround the wrecks. The Allen Coral Atlas (http://allencoralatlas.org, accessed on 15 December 2021) provides estimates of 45.8 km^2 and 29.1 km^2 of coral/algal cover at Chuuk and Bikini, respectively. There is also more than three times the reef slope, crest, and flat area in Chuuk than in Bikini. It is tempting to relate the increased coral richness of the shipwrecks in Chuuk to the larger source area of reef compared to Bikini. However, additional surveys of wrecks in other coastal and atoll settings, combined with distance and current data, will be required to better assess how large deep artificial reefs may or may not harbor corals from locally sourced shallow reefs.

Beyond the ecological limitations of our study, there were significant technical challenges associated with data collection in the field. We used technical diving techniques to achieve the bottom times needed to carry out repeated hull-length surveys on deep wrecks. Extended decompression times over intensive periods of activity presented significant challenges to the dive team. Future studies could augment diver-based surveys with surface-supplied remotely operated vehicles. However, carrying out systematic transects, particularly in areas of high rugosity such as on ship superstructures, will remain difficult and likely more readily obtained by divers. More effort is needed to develop improved survey methods for structurally complex, deep artificial reefs.

While our findings represent just two sunken warship seascapes, each was strategically selected for its centralized location within a lagoon of a large atoll. Each atoll reef completely surrounds the group of wrecks, providing a biological source to the artificial reefs. Furthermore, the wrecks were of similar steel substrates of the WWII era, sunk within two years of one another, thereby providing basic control for comparative analysis among ships and locations. Our results strongly suggest that very large wrecks can serve as havens for scleractinian, reef-building corals with a basic genetic diversity, defined at the genus level, commensurate with corals found on neighboring natural reefs. Further study should include more wrecks in other reef-related configurations, including along coastlines, on sandy bottoms, and other locations farther from natural reefs. Perhaps the future of large artificial reefs will include a role in protecting coral biodiversity in changing ocean temperature.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d14020139/s1, A video highlighting aspects of the underwater surveys is provided online at https://vimeo.com/333153463 (accessed on 15 December 2021).

Author Contributions: Conceptualization, G.P.A.; methodology, all authors; software, S.F.G. and C.B.; formal analysis, G.P.A., S.F.G. and C.B.; data curation, S.F.G. and C.B.; writing—original draft preparation, G.P.A.; writing—review and editing, G.P.A., S.F.G., C.B., C.D., S.H. and R.E.M.; and funding acquisition, G.P.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Leonardo DiCaprio Foundation, grant number GPA-LD-2017.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: All genus counts are available in the attached appendices.

Acknowledgments: We thank colleagues and friends in the Marshall Islands and the Federated States of Micronesia for their assistance in the field. We thank the Leonardo DiCaprio Foundation for financial support that made this study possible.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Listing of coral genera found on eight ships in the lagoon of Bikini Atoll.

	SHIP NAME								
GENUS	**Anderson**	**Apogon**	**Arkansas**	**Carlisle**	**Lamson**	**Nagato**	**Pilotfish**	**Saratoga**	**Total Abundance by Genus**
Acanthastrea	1	1	3	1	1	8	0	2	**17**
Acropora	5	3	1	9	7	3	1	18	**47**
Astreopora	0	1	8	1	2	17	1	30	**60**
Cynaria	0	0	0	0	0	0	0	0	**0**
Cyphastrea	0	0	0	0	1	0	0	0	**1**
Echinophyllia	1	4	3	6	2	1	1	1	**19**
Euphyllia	1	2	1	1	1	0	1	1	**8**
Favia	84	37	132	22	15	53	70	29	**442**
Favites	41	5	36	6	4	24	27	18	**161**
Fungia	0	11	2	1	1	1	3	2	**21**
Galaxea	0	0	0	0	0	0	0	0	**0**
Goniastrea	9	17	19	18	5	9	3	7	**87**
Goniopora	0	1	1	1	1	1	1	1	**7**
Heliofungia	0	1	0	0	0	0	0	0	**1**
Herpolitha	1	1	1	1	1	1	8	1	**15**
Hydnophora	1	1	1	1	1	1	1	2	**9**
Leptastrea	29	5	43	6	2	26	1	14	**126**
Leptoseris	0	1	0	1	1	0	0	0	**3**
Lithophyllon	1	1	1	1	1	1	1	1	**8**
Lobophyllia	3	1	7	1	1	4	0	4	**21**
Merulina	0	0	1	0	0	0	0	1	**2**
Montastrea	63	11	74	3	19	90	11	83	**354**
Montipora	1	1	1	1	1	9	0	6	**20**
Oulophyllia	0	0	1	0	0	3	1	2	**7**
Pavona	0	1	3	2	1	0	0	1	**8**
Plerogyra	1	1	1	2	12	3	1	4	**25**
Pocillopora	1	1	1	1	1	6	1	27	**39**
Polyphyllia	0	0	0	0	0	0	1	0	**1**
Porites	1	1	13	1	4	54	3	60	**137**
Psammocora	1	1	0	1	1	1	1	1	**7**
Scolymia	14	0	12	0	1	2	1	2	**32**
Stylocoeniella	0	0	1	0	0	1	0	0	**2**
Symphyllia	7	2	1	0	1	13	0	3	**27**
Tubastrea	0	1	0	1	0	1	0	4	**7**
Turbinaria	1	0	1	0	0	0	0	4	**6**
UND	8	3	8	3	5	5	8	7	**47**
Total Individuals by Ship	**275**	**116**	**377**	**92**	**93**	**338**	**147**	**336**	**1774**

Appendix B

Table A2. Listing of coral genera found on 21 ships in the lagoon of Chuuk Atoll.

	SHIP NAME																					
GENUS	**Rio de Janeiro**	**Heian**	**Fumitsuki**	**momokawa**	**Seiko**	**Hoki**	**Kensho**	**Fujikawa Com-bined**	**Sankisan**	**Shinkoku**	**Yamagiri**	**San Francisco Combined**	**Kiyosumi Combined**	**Aikoku**	**Amagisan**	**Gosei**	**Fujisan**	**Unkai**	**Nagano**	**Futagami**	**Kikukawa**	**Total Abundance By Genus**
Acropora	6	1	0	1	0	1	0	1	9	7	1	0	1	0	3	3	1	4	0	1	0	**40**
Astreopora	20	0	0	4	2	0	1	0	1	0	1	0	1	0	0	1	0	0	0	0	0	**31**
Cycloseris	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**1**
Cynarina	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	3	0	0	0	0	**7**
Diploastrea	5	4	1	11	11	11	4	6	15	18	101	0	49	6	37	2	14	2	0	0	1	**298**
Distichopora	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	0	0	0	**5**
Duncanopsammia	0	0	0	0	0	0	0	0	305	0	0	0	0	0	0	0	16	8	0	0	0	**329**
Echinophyllia	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	1	0	0	0	**11**
Echinopora	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	5	0	6	0	0	**14**
Euphyllia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Favia	15	56	11	92	13	3	22	3	28	0	2	4	9	4	32	4	51	14	12	0	1	**376**
Favites	29	131	14	78	9	7	14	15	35	14	12	0	24	15	37	28	24	9	4	5	2	**506**
Fungia	2	1	0	0	0	0	0	5	5	23	0	0	0	1	0	0	0	0	1	1	0	**39**
Galaxea	0	0	0	0	0	0	0	0	18	0	1	0	0	0	1	8	0	0	0	0	0	**28**
Gardineroseris	0	0	0	0	0	0	0	0	9	0	0	0	1	0	1	0	1	1	0	0	0	**13**
Goniastrea	32	33	5	32	17	10	3	11	24	1	1	1	8	7	37	40	15	14	3	8	5	**307**
Goniopora	0	1	12	0	8	6	8	1	19	36	2	27	8	4	7	1	43	4	14	0	0	**201**
Heliofungia	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	**3**
Herpolitha	0	0	0	0	0	2	0	15	4	22	0	0	0	2	0	0	0	0	9	0	0	**54**
Hydnophora	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**
Leptastrea	169	3	1	0	0	0	1	1	0	0	0	0	0	2	10	0	0	0	0	0	0	**187**
Leptoria	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**1**
Leptoseris	0	0	0	0	0	0	0	0	3	0	0	0	1	1	0	0	0	7	1	0	0	**13**
Lithophyllon	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**
Lobophyllia	19	38	13	34	28	9	27	23	32	59	0	0	17	2	2	0	5	9	2	0	0	**319**
Merulina	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	**11**
Montastrea	17	18	4	31	8	1	11	4	8	0	0	2	7	6	27	4	28	9	1	8	1	**195**
Montipora	6	3	0	1	0	0	1	1	37	1	2	0	3	0	1	1	0	0	4	0	0	**61**
Moseleya	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	**6**
Mycedium	0	0	0	0	4	5	0	0	1	0	0	3	0	11	1	0	0	0	1	0	0	**26**
Oulophyllia	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0	0	0	0	0	0	**4**
Oxypora	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	**3**
Pachyseris	0	3	0	0	4	10	2	7	15	5	0	0	0	2	0	0	1	0	0	0	0	**49**
Pavona	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	**2**
Pectinia	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Physogyra	0	0	3	0	8	5	3	0	42	4	1	3	0	8	4	1	15	6	0	1	0	**104**
Platygyra	2	56	0	9	6	0	2	0	5	1	0	0	6	0	0	0	0	0	1	0	0	**88**
Plerogyra	0	1	0	0	0	0	0	0	0	0	8	0	0	4	0	0	1	0	0	0	0	**14**
Pocillopora	57	0	0	0	0	0	0	0	6	2	0	0	3	0	0	0	0	0	0	0	0	**68**
Polyphyllia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Porites	235	961	41	120	90	102	71	77	363	102	0	21	498	94	45	43	43	87	0	82	6	**3081**
Psammocora	10	0	0	0	0	0	0	1	0	0	118	0	0	0	0	0	0	3	114	0	0	**246**
Scolymia	0	0	0	2	0	0	0	0	0	0	0	0	0	4	4	0	2	0	0	0	0	**12**
Seriotopora	2	14	2	19	10	1	19	9	100	20	0	0	4	14	25	7	14	7	5	0	0	**272**
Stylaster	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Stylophora	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	**11**
Symphyllia	10	1	0	0	0	0	0	0	2	0	0	0	3	1	0	0	0	0	0	0	0	**17**
Trachyphyllia	2	3	0	1	1	0	0	1	8	8	6	0	0	2	28	5	16	8	3	0	0	**92**
Tubastrea	0	0	2	0	1	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	**8**
Turbinaria	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	1	1	0	0	1	0	**9**
UND	14	15	1	2	8	1	4	11	6	3	3	0	13	4	9	0	1	10	12	10	9	**136**
Zoopilus	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	**26**
Total Abundance By Ship	**664**	**1343**	**111**	**438**	**228**	**174**	**195**	**193**	**1109**	**356**	**273**	**63**	**657**	**221**	**316**	**150**	**302**	**207**	**193**	**117**	**25**	**7335**

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