Coral-reef monitoring in the Republic of Palau and Capacity Building for Micronesia Challenge Jurisdictions

Progress Report 2011- 2012

Organization/Contact: Micronesian Conservation Trust, Palau International Coral Reef Center, PI

Summary of the Report:

During the one year period of the grant, Palau International Coral Reef Center (PICRC) completed the design of the database, tested it with monitoring data, and conducted workshop to introduce the database in Pohnpei, Marshall Islands, Chuuk, Yap and Palau. During the regional workshop, the MC database was also discussed and presented to representatives from the five MC jurisdictions. PICRC also conducted MPA and reference site surveys in Pohnpei, Marshall Islands, Chuuk, Yap and Palau.

In Palau, PICRC continued to conduct surveys in the permanent monitoring sites as well as the MPAs in Palau.

1. Please complete the follow table for all sites that you have monitored

Site Name	Coordinates		Number of Visits	Visit Dates
	X	y		
Nikko Bay	7 19.570	134 29.667	Once every 2 yrs.	OCt.2012
Airai	7 19.65	134 33.34	Once every 2 yrs.	OCt.2012
Taoch, RI	7 16.585	134 25.625	Once every 2 yrs.	
Uchelbeluu	7 15.70	134 32.57	Once every 2 yrs.	OCt.2012
Ngaremlengui, Patch Reefs			Once every 2 yrs.	
Patch Reef #1	7 33.27	134 29.32	Once every 2 yrs.	
Patch Reef #2	7 33.71	134 29.53	Once every 2 yrs.	
Patch Reef #3	7 33.73	134 29.67	Once every 2 yrs.	
Tsais Reef	7 18.41	134 13.89	Once every 2 yrs.	
Ngemelis, RI	7 06.87	134 14.37	Once every 2 yrs.	
Ngerchong, RI	7 06.65	134 21.94	Once every 2 yrs.	OCt.2012
Ngerdiluches, Koror	7 25.12	134 20.73	Once every 2 yrs.	
Melekeok	7 31.22	134 38.19	Once every 2 yrs.	OCt.2012
Ngaremlengui, Barrier	7 33.39	134 28.10	Once every 2 yrs.	
Kayangel	8 02.527	134 41.179	Once every 2 yrs.	
Peleliu	7 00.40	134 13.06	Once every 2 yrs.	

Ngerchelong, Patch Reefs			Once every 2 yrs.	
Patch Reef #1	7 49.112	134 34.379	Once every 2 yrs.	
Patch Reef #2	7 49.046	134 34.568	Once every 2 yrs.	
Ngaraard	7 35.21	134 38.95	Once every 2 yrs.	OCt.2012
Ngelukes	7 25.09	134 36.46	Once every 2 yrs.	
Nikko II	7 19.357N	134 29.989 E	Once every 2 yrs.	OCt.2012
Ngetngod	7 21.753	134 37.192	Once every 2 yrs.	Oct.2012
Nikko III	7 19.751	134 29.977	Once every 2 yrs.	Oct.2012
Taoch II	7 16.776	134 24.471	Once every 2 yrs.	
Taoch III	7 16.366	134 22.858	Once every 2 yrs.	
Angaur	6 53.893	134 07.352	Once every 2 yrs.	

(Sites are visited once in every 2years. Last visit was in Oct.2010-Dec.2010, and it is an ongoing activity for this month of Oct 2012)

SiteName:Seagrass	State	Status	Statio	Latitude (x)			Longitude (x)			#of visits	Visit dates
Ngederrak Seagrass	Koror	MPA	1	7	17	838	134	28	460	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ngederrak Seagrass	Koror	MPA	2	7	17	739	134	28	433	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ngederrak Seagrass	Koror	MPA	3	7	17	552	134	28	374	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ucheliungs Seagrass	Koror	Reference	1	7	18	644	134	30	263	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ucheliungs Seagrass	Koror	Reference	2	7	18	699	134	30	369	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ucheliungs Seagrass	Koror	Reference	3	7	18	733	134	30	496	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ngelukes Seagrass	Ngches	MPA	1	7	25	63	134	35	694	4x/year	June, Sept, and December

	ar										2011;March,June, Sept and Dec 2012
Ngelukes Seagrass	Ngchesar	MPA	2	7	25	21	134	35	885	4x/year	June, Sept, and December 2011;March,June, Sept and Dec 2012
Ngelukes Seagrass	Ngchesar	MPA	3	7	25	141	134	35	991	4x/year	June, Sept, and December 2011;March,June, Sept and Dec 2012
UedangelSeagrass	Ngchesar	Reference	1	7	24	398	134	35	705	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
UedangelSeagrass	Ngchesar	Reference	2	7	24	475	134	35	690	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
UedangelSeagrass	Ngchesar	Reference	3	7	24	566	134	35	792	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
Ngermeosar Seagrass	Airai	MPA	1	7	20	850	134	32	512	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
Ngermeosar Seagrass	Airai	MPA	2	7	20	926	134	32	628	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
Ngermeosar Seagrass	Airai	MPA	3	7	20	942	134	32	698	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
Badesmarech Seagrass	Airai	Reference	1	7	21	132	134	31	230	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
Ngermeosar Seagrass	Airai	Reference	2	7	21	229	134	31	205	4x/year	June, Sept, and December 2011;March,June, Sept.Dec 2012
Ngermeosar Seagrass	Airai	Reference	3	7	21	282	134	31	75	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Teluleu seagrass	Peleliu	MPA	1	7	2	988	134	15	950	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Teluleu seagrass	Peleliu	MPA	2	7	2	998	134	16	62	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012

Teluleu seagrass	Peleliu	MPA	3	7	3	5	134	16	210	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ngebtakl seagrass	Peleliu	Reference	1	7	2	955	134	15	707	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ngebtakl seagrass	Peleliu	Reference	2	7	3	130	134	15	613	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012
Ngebtakl seagrass	Peleliu	Reference	3	7	2	947	134	15	596	4x/year	July, Sept, and December 2011;March,June, Sept.Dec 2012

2. Methodology: Please give a clear description of the methods you are using for monitoring, including number of people.

2. Methodology: Please give a clear description of the methods you are using for monitoring, including number of people.

At each site, five 50 m transects were laid on the reef at 3 and 10 m depth. At each depth 5 x 50 m fiberglass-transect lines were haphazardly placed along each depth contour and separated by approximately 2 to 3 m intervals. For each transect, a photographs was taken at every meter, resulting in 50 photographs per transect. To estimate coral cover and richness, the photographs were analyzed using CPCe. Five random points from each quadrat were used to determine coral cover. Data from the 50 quadrats were averaged to provide the mean for each transects and the five transect were averaged to provide the mean for each depth at each site. Richness data were extracted from the transect and averaged for the depth at each site.

Coral recruits ≤ 5 cm were recorded on underwater paper along 0.3 m either side of the first 10 m of each transect. Recruits were measured for maximum diameter and categorized to genus level. If the recruit could not be identified to the genus level, it was identified to the lowest taxa as possible.
At each site, visual censuses of fish were conducted along five permanently marked 50 m transects. A diver swam each 50 x 5-m transect at a constant speed and identified to the lowest possible taxon species visible within 2.5 m to either side of the centerline (250-m^2 transect area). Total length (TL) of all fishes was visually estimated.

Edible macro-invertebrates were also surveyed along the fish transects, using a reduced belt width of 2 m.

For seagrass MPA, five stations with five, 25 m transect at each station. The stations were randomly selected and mark by GPS. At each station, fish size and abundance (edible fish) are counted on a 5 m x 5 m x 25 m belt transect. Invertebrates size and abundance (seacucumbers and giant clams) are counted on a 1 m x 1 m x 25 m belt transect. A 0.25 m^2 quadrat is used to estimate total percentage seagrass cover as well as percent cover for each seagrass species. The quadrat is place at every 5 meter on each transect line.

This report is a summary of the progress of activities aimed at achieving the following project objectives.

1. Determine status of Palau's reefs
2. Assess effectiveness of selected MPAs
3. Capacity building at PICRC and local State Government level
4. Provide information to managers and policy makers to help guide conservation and management efforts
5. Prepare reports and publications

The first objective is being achieved through the implementation of monitoring efforts at 22 permanent monitoring sites. The sites are stratified by depth (3 and 10m) and are geographically distributed from the northern atoll of Kayangel to the southern island of Angaur of the main Palau archipelago. The biennial monitoring program examines a range of biophysical indicators that are designed to track the status of Palau's reef over space and time.

The second objective is focused on the assessment of the effectiveness of MPAs. This is being implemented through the establishment of seagrass monitoring at four seagrass MPA sites and corresponding reference sites. This objective also covers the monitoring of groupers and other commercially valuable fish species at 2 known aggregation sites and 2 reference sites. Field work is currently underway.

In addition, this report also summarizes all the efforts to enhance PICRC capacity to collect, analyze, interpret, and communicate all the monitoring data to various stakeholders and to the scientific community (Objectives 3, 4 and 5).

Below is a more detailed list of activities arranged by Objectives.

Objective I: Determine status of Palau's reefs

Activity
Conduct biennial coral reef monitoring on the 22 permanent coral reef monitoring sites around Palau. Collect biophysical data on fish size and abundance, coral

recruitment, characterization of benthos, water quality, and invertebrate size and abundance to determine changes on the reef over time.

Summary of progress

As of this reporting period, we have completed all 22 monitoring sites. Data on fish size and abundance, coral recruitment, characterization of benthos, water quality, and invertebrate size and abundance were collected. These data are collected along five 50 meter transect tapes on the reef at 10 and 3 meter depths. Characterization of the benthos by photoquadrat have also been analyzed using CPCe. All these data are now being compiled with previous years of monitoring data for further analysis.

In 2009, a rapid ecological assessment was conducted at 80 randomly selected sites throughout the archipelago. In addition to the field surveys, a hydrodynamic model was also used to simulate spawning events at each of the sites and to track dispersal patterns after release. In August 2010 in response to a period of unusually high sea surface temperatures, a rapid bleaching assessment was conducted at 80 randomly selected sites. The sites for both surveys were stratified into three habitats types: bays, patch reefs and outer reefs. Data from these two surveys have been analyzed and reports have been produced.

Results of the REA surveys showed that the outer reefs supported the greatest densities of fishes and invertebrates, and the highest species richness of fish, coral and invertebrates. Particularly striking was the excellent condition of the south-western outer reefs. Further analyses of the outer reefs found significant positive relationships between coral cover and densities of invertebrates and fish densities, yet surprisingly no relationship was found between reef rugosity and fish densities. The results of the simulated spawning events showed that the north-western and south-western reefs retained larvae more so than localities near the channels, which seemed to 'lose' larvae to the outer reefs and beyond. Similarly, there was considerable larval retention within the bays.

The results of the bleaching survey showed that coral bleaching was significantly higher on outer reefs and patch reefs than in bays. In addition, there was a significantly higher bleaching of *Pocillopra* on the outer reefs than in the bays. Faviids also showed a similar trend with significantly less bleaching in the bays than on the patch and outer reefs. In March 2011, we set up 4X4 permanent quadrats on 12 of our 22 permanent monitoring sites and took pictures to look at key processes such as mortality, growth, and recruitment rates.

Objective II: Conduct assessment on effectiveness of MPAs

Activity

1. Conduct monitoring on seagrass MPA and monitor fish size and abundance, invertebrates' size and abundance, and seagrass cover.

2. Conduct regular monitoring at two fish spawning aggregation sites

Summary of progress
In May and June 2011, seagrass monitoring began on 4 MPAs and their 4 reference sites. Data were collected on seagrass cover, fish and invertebrate size and abundance on all 8 sites. Fish data are collected quarterly and seagrass cover and invertebrate data are collected twice a year. Field work and data entry have been on-going. The most recent monitoring fieldwork was on the last week of March 2012.

Monthly monitoring of groupers and other commercially valuable fish species in two MPA aggregations and their reference sites has been on-going. The next scheduled fish monitoring at these aggregation sites is scheduled for April 2012.

Objective III: Capacity building at PICRC and local State Government level

Activity
Build capacity of PICRC staff in data collection, analysis, publication and presentation of results. Also, PICRC will build the monitoring capacity with state conservation officers.

Summary of progress
In August 2011, PICRC Research staff went through coral taxonomy course with Dr. Rob van Woesik. From October 2011 to February 2012, research staff underwent a 16-session GIS training course conducted by the Palau Automated Land and Resource Information System, the local GIS office. A researcher also attended a workshop in February 2012 on data analysis and interpretation hosted by Pacific Marine Resource Institute held in Pohnpei.

The PICRC Research Department has also initiated monthly seminars to create the opportunity for staff to learn from others doing similar work in marine research and conservation. Seminars are given by local partners and visiting scientists. Although the seminars are intended for research staff, they are open to all PICRC staff, locals in the environmental sector and students.

In addition to providing in-house training to PICRC staff, we have continued training Conservation Officers from Ngardmau, Ngchesar, Airai, Ngiwal, Ngarchelong, and Peleliu who continue to assist us in conducting field surveys. These officers have been trained on laying transect tapes; conducting fish, invertebrate, and seagrass surveys as well as conducting benthic surveys with the use of a photo quadrat. They have also been trained in using other field equipment including the use of a GPS, deploying sediment traps and using a Secchi disc. They continue to work with us during monitoring at their sites. We have also trained a community member on fish surveys and he has traveled with us to Chuuk in August to conduct coral reef monitoring.

Objective IV: Provide information to managers and policy makers to help guide conservation and management efforts

Activity
Develop innovative and culturally appropriate methods (mediums) to bring the results of the monitoring work to managers and policy makers

Activity Summary
On April 2011, monitoring results for an MPA in Peleliu was presented to the community including the Governor of Peleliu State. In January 2012, a presentation was given to the National Congress by the Chief Researcher. In March 2012, PICRC met with the leadership of Koror State to brief them on the research and monitoring efforts that are being conducted in the state. Also in March of this year, the Chief Researcher presented to the Council of Chiefs, a group of the traditional leaders representing each of the 16 states of Palau. The presentation, similar to the presentation to the National Congress, focused on the general status of Palau's reefs and some of efforts that PICRC is undertaking to better understand and therefore conserve these reef systems.

In 2011, PICRC initiated a monthly press release on the local television network, OTV. The press releases highlight the research and monitoring efforts that are being implemented and are aimed at increasing local awareness and relevance of PICRC. PICRC also released its 2011 Annual Report titled "Our niche in science and society." The report not only highlights the research projects and PICRC's role in providing sound science to management and conservation, but also acknowledges the valuable support of our partners locally, in the region and the world.

For the past two years PICRC has also been developing a Marine Protected Area Monitoring Protocol. The protocol is intended to provide step-by-step guidance to researchers and managers of marine protected area managers who wish to initiate a monitoring program at a site. It includes monitoring design, indicators, methods and other logistical considerations to starting up a monitoring program. In March 2012, this protocol was adopted by the Palau Protected Areas Network under the Ministry of Natural Resource, Environment and Tourism.

Objective VI: Prepare reports and publications

Activity
Analyze data and prepare publications and reports

Activity Summary
Report for the 2010 bleaching assessment has been produced and circulated to relevant partners.

Preparation for publications will begin once data from the permanent monitoring sites are compiled and analyzed.

The following publication of the monitoring work at the grouper spawning aggregations was published last year:

Golbuu, Y., Freidlander, A.M. 2011. Spatial and temporal characteristics of grouper spawning aggregations in marine protected areas in Palau, western Micronesia. Estuarine, Coastal and Shelf Science 76: 14-20.

van Woesik R, Houk P, Isechal AL, Idechong JW, Victor S, Golbuu Y. 2012. Climate-change refugia in the sheltered bays of Palau: analog of future reefs. Ecology and Evolution. doi: 10.1002/ece3.363

Two talks were presented at the International Coral Reef Symposium in July 2012. One is focused on the effectiveness of small MPAs in Palau and the other presents some of the results of the rapid ecological assessment and compares them to the predictions of hydrodynamic modeling.

Results and Analyses for the FSM and Marshall Islands MPA surveys

Yap

Benthic Assemblages

Mean coral cover at the channel in Nimpal MPA was 27.4%, which is significantly lower than the 44.4 % coral cover at the reference site (Fig.3a). At the exposed side of Nimpal MPA, coral cover was 30.5%, while the reference site had coral cover of 25.2% (Fig. 3b). Coral richness as measured by the different number of coral genera was significantly higher in the reference site than Nimpal, at both the channel and exposed reefs (Fig. 4a and 4b).

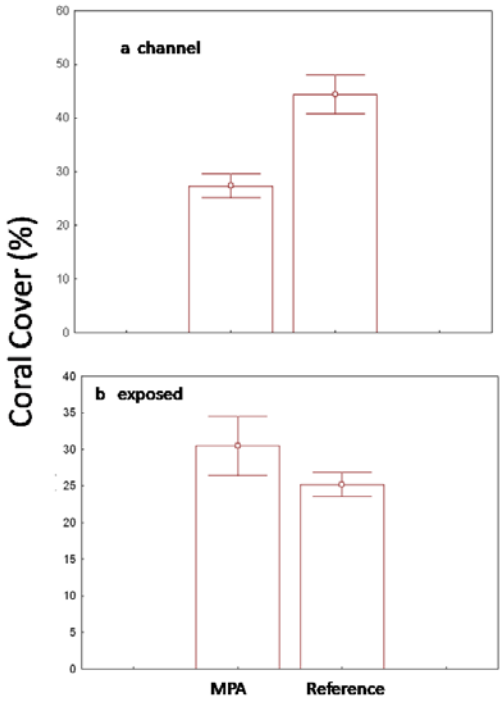


Fig. 3. Coral cover in the MPA and reference site at the a) channel and b) the outer reef.

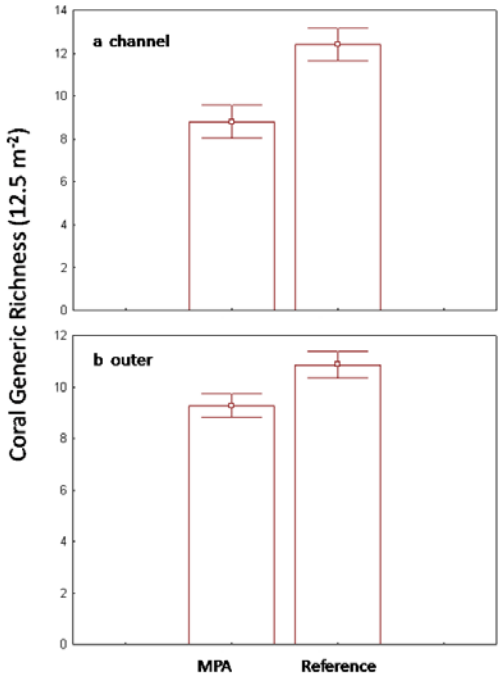


Fig. 4. Coral generic richness at Nimpal and reference site in the a) channel and the b) outer reefs.

The density of coral recruits in Nimpal at the channel was 7.1 recruits $3m^{-2}$, slightly higher than the reference site, which had a density of 4.6. Recruit density at the outer reefs of both Nimpal (24.9) and reference (30.0) were not significantly different, but the outer reefs had much higher recruitment than the channel (Fig. 5).

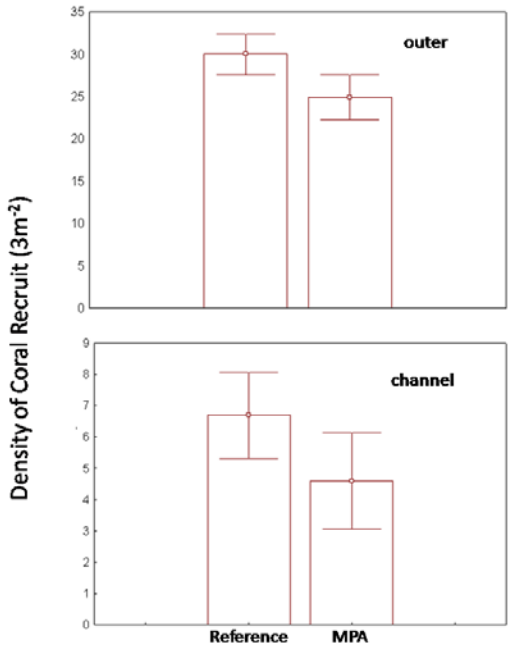


Fig. 51. Density of coral recruits in Nimpal and the reference site at the a) outer reef and b) channel.

Recruit richness followed the same pattern as the recruit density, showing higher richness in the outer reef compared with the channel (Fig. 6). At both the outer reef and the channel, there were no significant different in recruit richness between Nimpal and the reference site (Fig. 6).

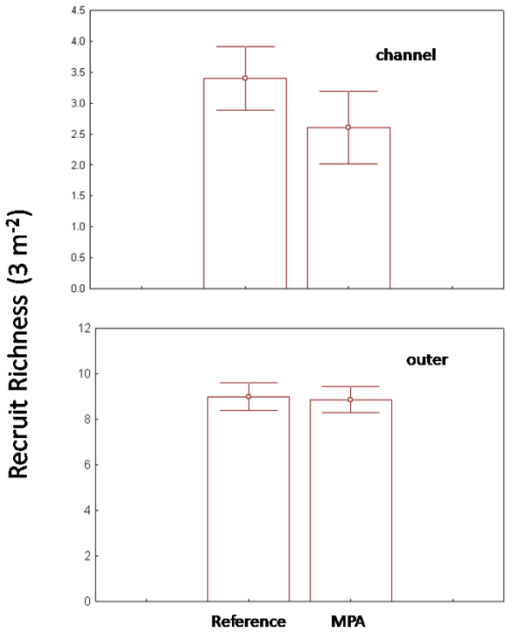


Fig. 62. Recruit richness in Nimpal and reference site in the a)channel and b) outer reef.

The densities of invertebrates at the channel and inner reefs were not significantly different in the MPA compared with the reference site (Figs. 7a, 7b). But at the outer reefs, there were significantly higher number of invertebrates at the reference site compared with the MPA, with densities of 4.2 invertebrates per stations in the reference site while the MPA only had densities of less than one (Fig. 7c).

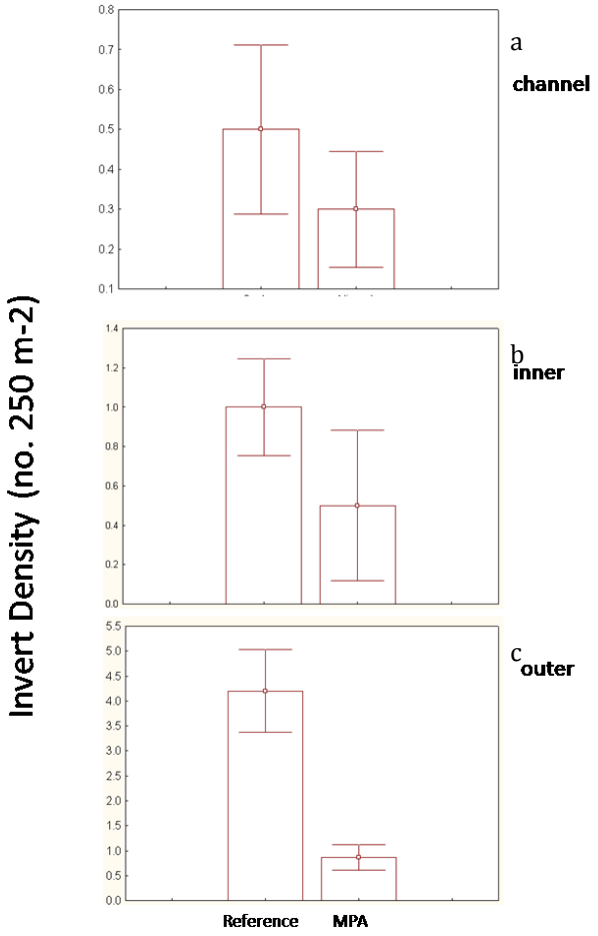


Fig. 7. Macroinvertebrate density in Nimpal and reference site at the a) channel, b) inner, and c) outer reefs.

Fish Assemblages

Fish density at the channels was twice as much in Nimpal MPA compared to its reference site, with densities of 20.2 and 9.3 per 250 m^{-2}, respectively (Fig. 8a). The inner reefs also had higher fish densities in the MPA (23.1) compared with the reference site (16.0) (Fig. 8b). Fish densities at the outer reef was not significantly different in the MPA compared with the reference site (Fig. 8c). Fish densities in the outer reefs were higher than both the channel and the inner reefs (Fig. 8).

Fish species richness was not significantly different between Nimpal MPA and the reference site in the channel (Fig. 9a). At the inner reefs, richness was higher in the MPA, while at the outer reef, the richness in the reference site was higher than the MPA (Fig. 9b and 9c).

Fish biomass was significantly higher in Nimpal MPA compared with the reference site at all habitats. There were also significant differences in biomass among the habitats. (Fig. 10). At the channel, fish biomass in the MPA was almost four times higher than the reference site, with biomass at 9.9 and 2.6 kg 250 m^{-2}, respectively (Fig. 10a). The difference between MPA and reference site was even higher at the inner reefs, with the MPA having over seven time higher biomass than the reference site (Fig. 10b). At the outer reefs, biomass in the MPA was 2 time higher than the reference site.

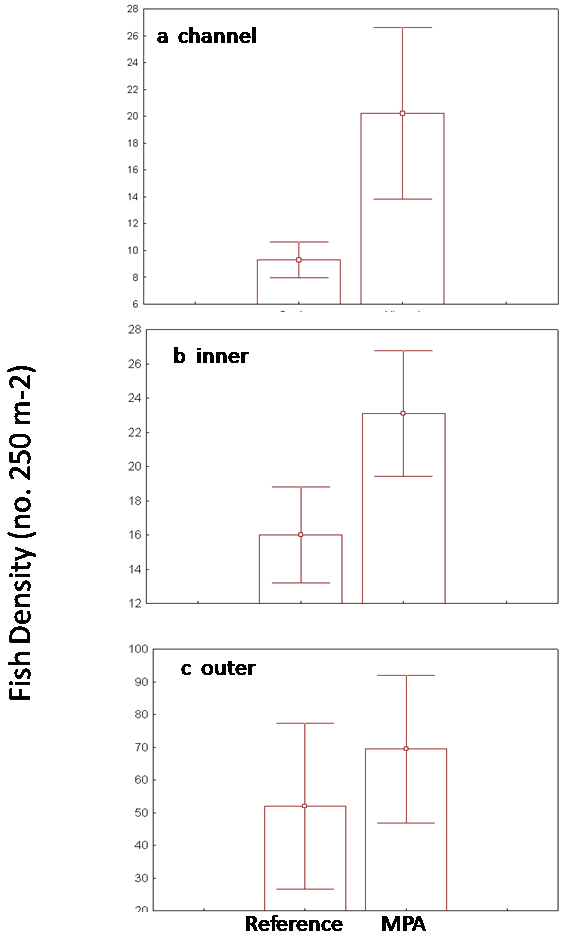


Fig. 8. Fish density at Nimpal MPA and its reference site at the a) channel, b) inner and c) outer reefs.

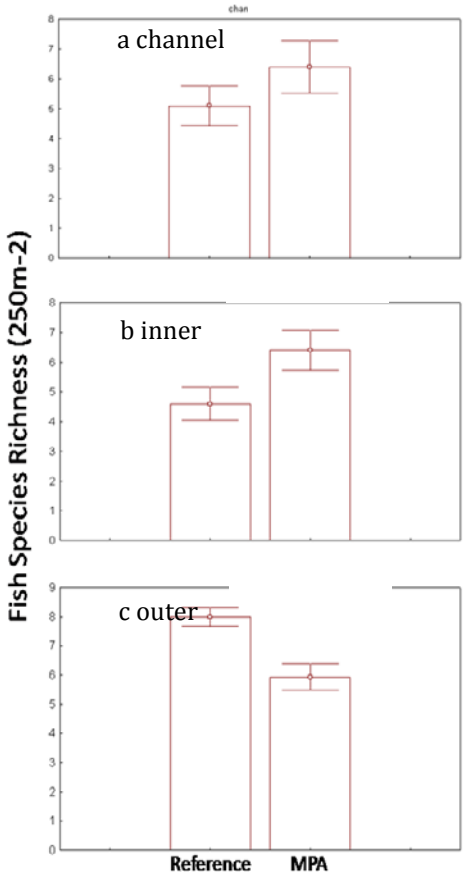


Fig. 3. Fish generic richness in Nimpal MPA and reference site at the a) channel, b) inner and c) outer reefs.

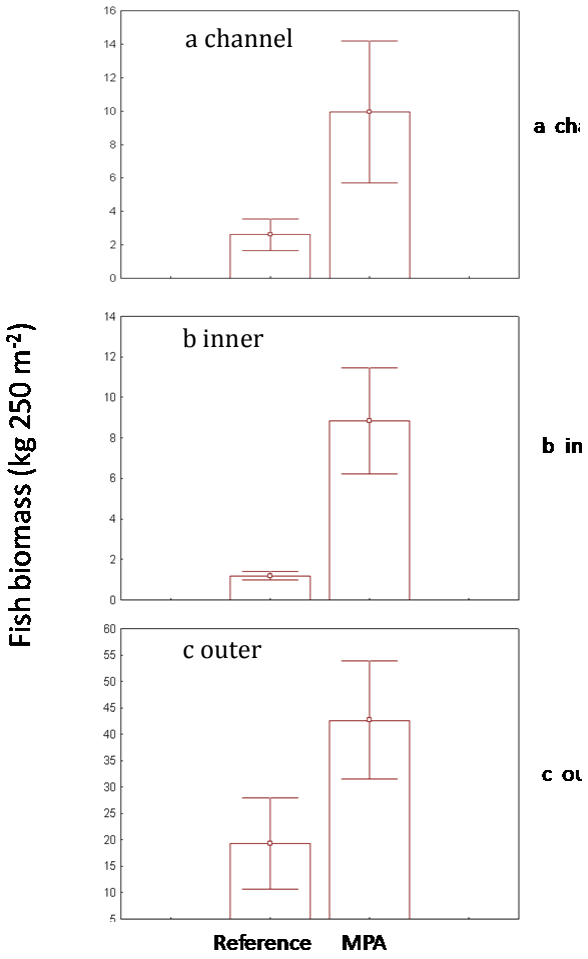


Fig. 4. Fish biomass in Nimpal MPA and reference site at the a) channel, b) inner and c) outer reefs.

Pohnpei

Benthic Assemblages

Mean coral cover at Sapwitik MPA was 32% compared with the reference site, which had a coral cover of 27% (Fig.5a). At Mwahnd MPA, coral cover was 31% inside the MPA and 24% outside of the MPA in the reference site (Fig.5b). Coral cover at the lagoon side at Kehpara MPA was 28%, which was significantly lower than the reference site that had a coral cover of 42%. (Fig.5c). On the exposed side of Kehpara, coral cover in the MPA was 24% while the reference was 13%.

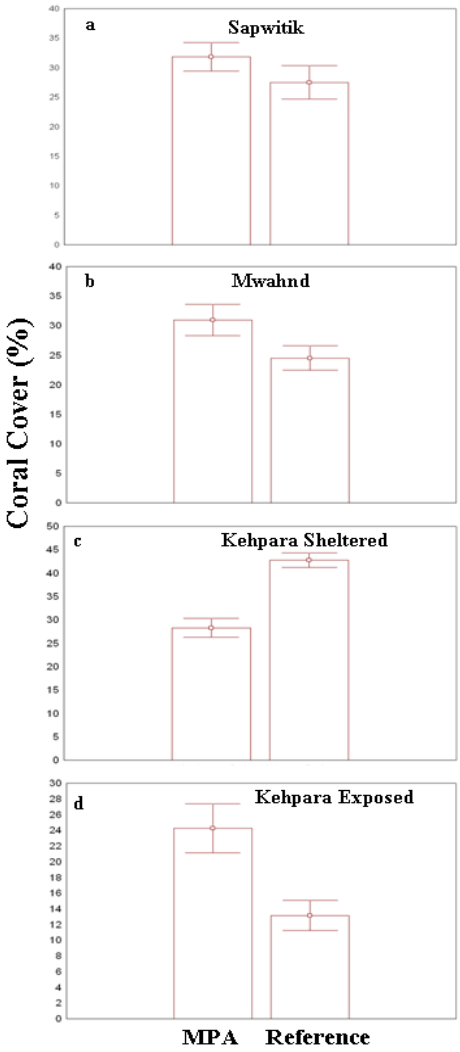


Fig. 5. Coral cover at reference and MPA site at (a) Sapwitik, (b) Mwahnd,(c) Kehpara Sheltered and (d) Kehpara Exposed. Error bars indicate standard errors.

Coral Richness at Sapwitik MPA and its reference sites was 6.7 and 7.1 genera per stations, respectively (Fig.6a). At Mwahnd, there was no significant difference in coral richness between the MPA (7.9) and reference site (9.2) (Fig. 6b). The richness at Kehpara MPA in the lagoon side was similar inside and outside the MPA (Fig. 6c). At the exposed side of Kehpara, richness was higher in the reference site (6.4 genera per station) compared with the MPA, which had a mean richness of 4.6 (Fig. 6d)

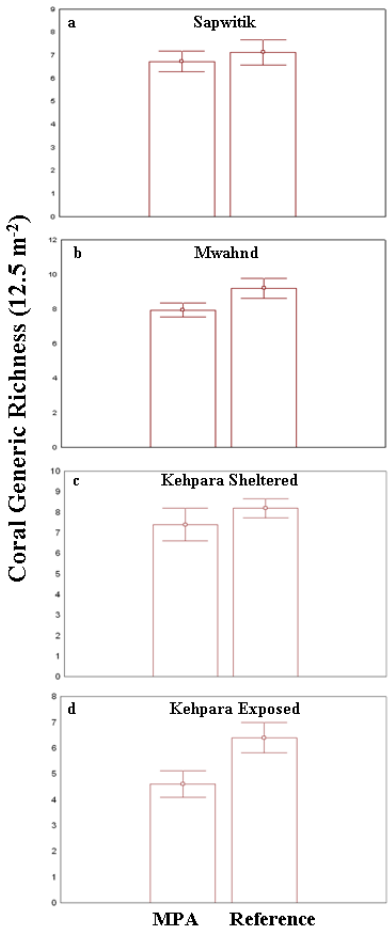


Fig. 6. Coral generic richness in MPA and reference site at (a) Sapwitik, (b) Mwahnd, (c) Kehpara Sheltered and (d) Kehpara Exposed. Error bars indicate standard errors.

Recruit density at Sapwitik was slightly higher than its reference site, but it was not significantly different (Fig. 7a). At Mwahnd, recruit density was 30.9 recruits per stations inside the MPA compared with the reference site, which had a significantly lower recruit density of 12.7 recruits per station (Fig. 7b). At Kehpara, recruit density at the sheltered side of the MPA did not differ significantly with its reference

site. The exposed part of Kehpara had similar results, with the MPAs and the reference sites having similar densities of coral recruits at 35.9 and 30.9 recruits per stations, respectively (Fig. 7c and 7d).

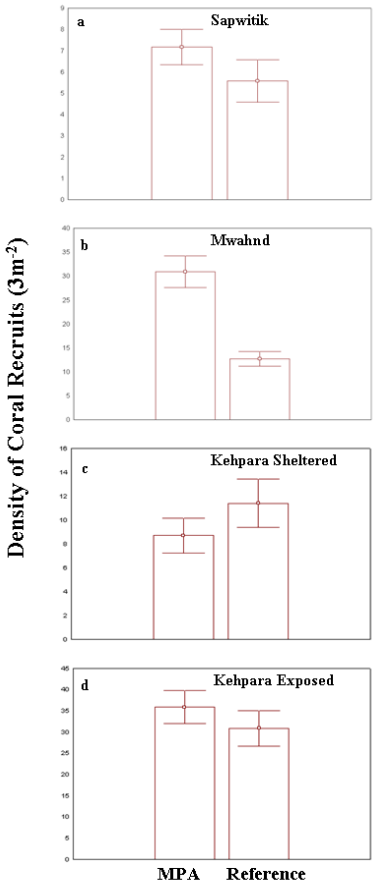


Fig. 7. Density of coral recruits in MPA and reference site at (a) Sapwitik, (b) Mwahnd, (c) Kehpara Sheltered, and (d) Kehpara Exposed. Error bars indicate standard errors.

Invertebrate densities were low at all the MPAs and their reference sites (Fig. 8). Only the exposed side of Kehpara had invertebrates' densities higher than one, while the rest of the sites had average densities lower than one (Fig. 8).

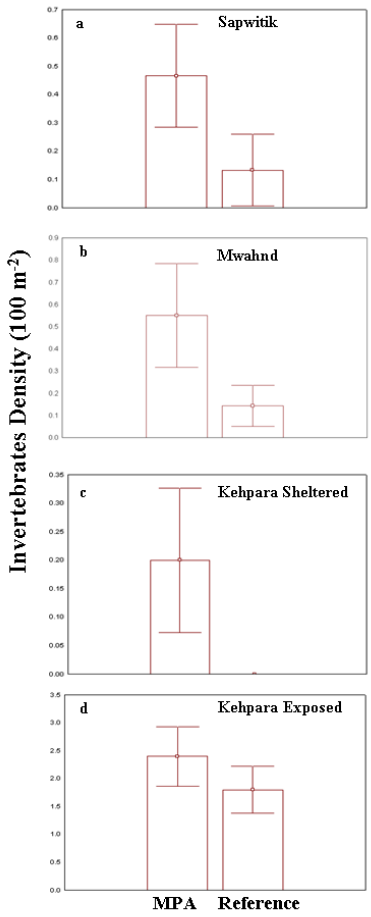


Fig. 8. Density of Invertebrates in MPA and reference site at (a) Sapwitik, (b) Mwahnd, (c) Kehpara Sheltered and (d) Kehpara Exposed. Error bars indicate standard errors.

Fish Assemblages

Fish density at Sapwitik MPA was higher but not significantly different from its reference site (Fig. 9a). In contrast, biomass of fish in Sapwitik MPA was three times more than the biomass in the reference site (Fig. 10a). In terms of fish species richness, there was no significant difference between the MPA and reference site at Sapwitik.

Mwahnd MPA and its reference site had similar fish densities at 9.1 and 9.7 fish per stations, respectively (Fig. 9a). While fish densities were similar, biomass was very different with a much higher biomass of fish found in Mwand MPA than in the control site (Fig. 10a). Fish generic richness was not significantly different between Mwand MPA and it reference site (Fig. 11a).

At Kehpara, fish densities in the MPA and reference site were not significantly different, both for the lagoon site and the outer reef site Fig. 11a). But fish densities was eight times higher in the outer reef side than the lagoon side, regardless of whether the site was protected or not. Biomass of fish in Kehpera MPAs and reference sites followed the same pattern as those of fish densities-there are no significant differences between MPA and reference sites but there is significant difference between exposed and sheltered sites, regardless of MPA status (Fig. 10 c.d). For generic richness, there was also no significant difference between MPA and reference site, but again, richness was higher on the outer reefs than in the lagoon reefs (Fig. 12 c.d).

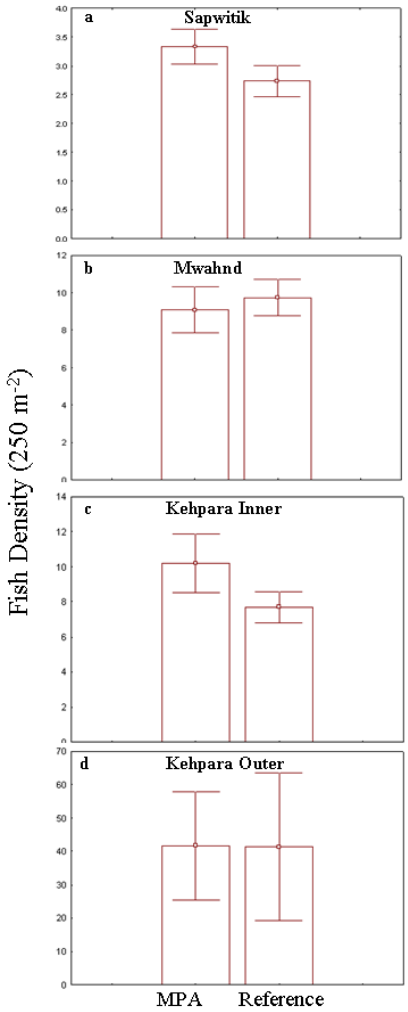


Fig. 9. Fish density in MPA and reference site at (a) Sapwitik, (b) Mwahnd, (c) Kehpara Inner and (d) Kehpara Outer. Error bars indicate standard errors.

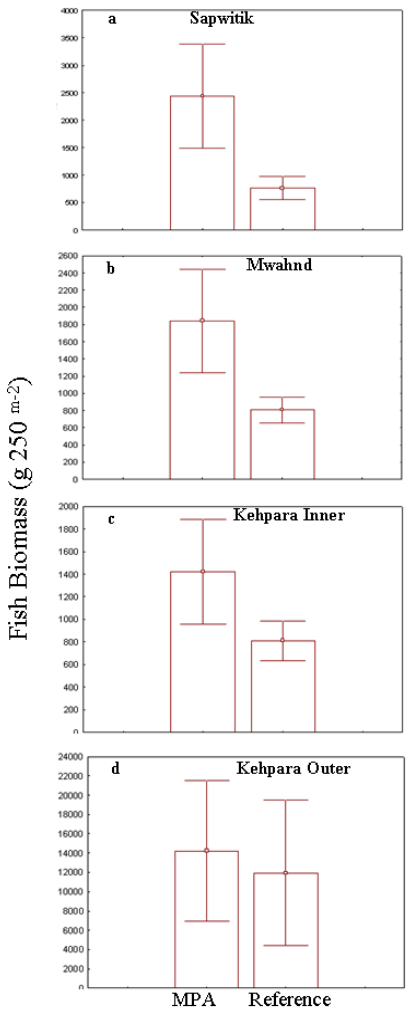


Fig. 10. Fish biomass in MPA and reference site at (a) Sapwitik, (b) Mwahnd, (c) Kehpara Inner and (d) Kehpara Outer. Error bars indicate standard errors.

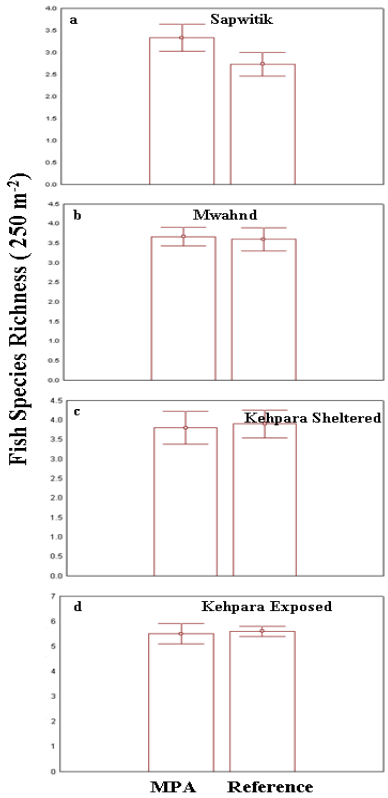


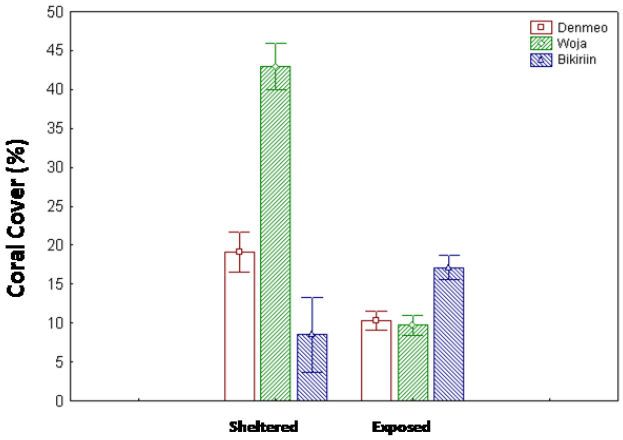
Fig. 12. Richness of fish species in MPA and reference site at (a) Sapwitik, (b) Mwahnd and (c) Kehpara. Error bars indicate standard errors.

Marshall Islands

RESULTS

Benthic Assemblages

Among all the MPAs, there was a significant difference in mean coral cover in the exposed versus sheltered stations. The sheltered stations within all of 3 MPAs, Woja had the highest coral cover of 42.9%, followed by Denmeo with 19.1% and Bikirin with 8.5%. For exposed stations, Bikirin had the highest mean coral cover at 17.1% followed by Denmeo (10.2%) and Woja (9.7%).



Mean coral cover at the sheltered reefs of Bikirin MPA was 8.5% compared with the sheltered reference site, which had a coral cover of 8.9% (Fig.5a). On the exposed reefs, coral cover was 17.1% inside the MPA and 18.8% in the reference site. Coral coverage was not significantly different in the MPA and the reference site in both sheltered and exposed reefs. At Denmeo, the sheltered reefs had a mean coral cover of 19.1% inside the MPA and 21.6% at the reference site (Fig.5b). In the exposed reefs, the reference site had significantly higher coral cover (22.4%) than the MPA (10.3%). Exposed reefs in Woja had a coral cover of 9.7% in the MPA and 13.4% in the reference site (Fig.5c). Sheltered reefs had significantly higher coral cover at 42.9% in the MPA and 39.1% in the reference site.

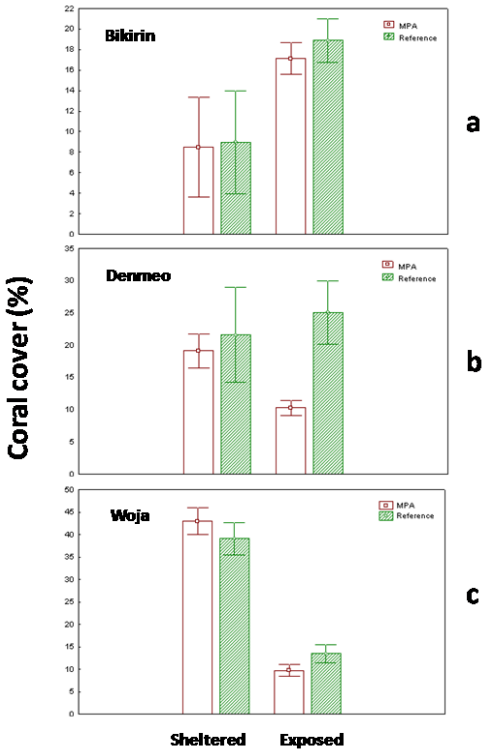


Figure 5 Coral cover in percent in (a) Bikirin, (b) Denmeo, and (c) Woja compared to their corresponding reference sites. Error bars indicate standard error.

Coral richness, measured as the number of coral genera, was not significantly different in the sheltered reefs in Bikirin (1.8) and its reference site (2.0) (Fig.6a). This was also the case for the outer reefs in the MPA (9.6) and reference (8.8). However, coral richness was significantly higher in the outer, exposed reefs than the sheltered reefs both in the MPA and reference site. In the sheltered reefs in Denmeo, coral richness was significantly higher in the MPA (3.9) than the reference (2.4). On the outer reefs in Denmeo, coral richness was 7.3 in the MPA and 5.3 in the reference. In Woja, coral richness for the MPA was 9.7 for the exposed reefs and 42.9 for the sheltered reefs. Coral richness for the corresponding reference site was 13.4 for the outer reef and 39.0 for the inner reef.

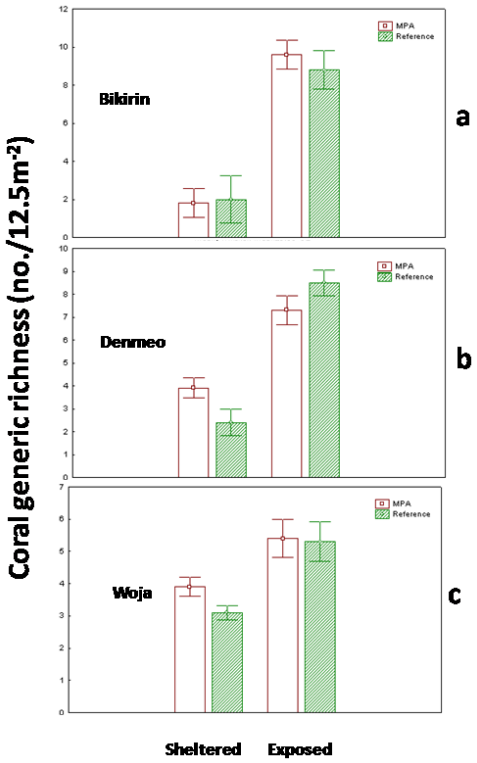


Figure 6 Coral generic richness in (a) Bikirin, (b) Denmeo, and (c)Woja compared to their corresponding reference sites. Error bars indicate standard error.

Recruit density, or the number of juvenile corals in a given area, for Bikirin MPA was 0.8 in the sheltered reefs and 20.6 in the outer reefs. Its reference site also had significantly higher recruit density in the outer reefs (21.2) than the inner reefs (21.2). This comparably lower recruitment density in the inner reefs was also observed in the other two MPAs. Recruit density in the outer reefs of Denmeo was 17.1 and 14.5 for the similar reference site. The inner reefs had recruit densities of 4.6 in the MPA and 2.4 for the reference. Woja had recruit densities of 7.1(MPA) and 4.5 (reference) in the inner reefs and 21.6(MPA) and 37.1(reference) for the outer reefs.

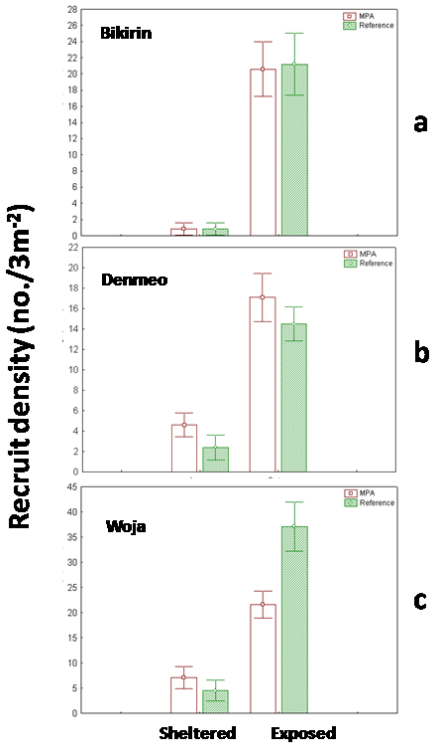


Figure 7 Recruit density in (a) Bikirin, (b) Denmeo, and (c) Woja. Error bars indicate standard error.

Recruit richness for Bikirin in the inner reefs was 0.2 in the MPA and 0.6 in the reference. On the outer reefs recruit richness was 7.8 in the MPA and 8.0 in the reference. In Denmeo, recruit generic richness was higher in the outer reefs in both the MPA (17.1) and reference (14.5). Richness was significantly lower in the inner reefs—MPA (4.6) and reference site (2.4). The outer reefs of Woja and its reference site also had significantly higher richness than the inner reefs. The outer reefs in the MPA had a recruit richness of 21.6 and the outer reefs of the reference site had a recruit richness of 37.1. The inner reefs had lower recruit richness of 7.1 in the MPA and 4.5 in the reference site.

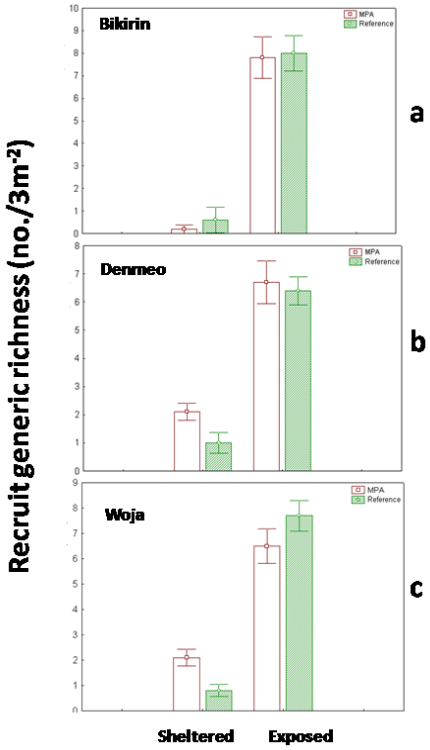


Figure 8 Recruit generic richness in (a) Bikirin, (b) Denmeo, and (c) Woja. Error bars indicate standard error.

Macro-invertabrates

The densities of invertebrates in all the sites surveyed were very low and the data collected were not analyzed.

Fish Assemblages

Fish density in the sheltered reefs of Bikirin was 7.2 compared to 12.8 in the reference site (Fig.9a). Fish biomass was also greater in the reference site. However, these differences in density and biomass were not significant (Fig.10a). Differences in fish density and biomass in the outer reefs in the MPA and reference site were also not significant. Denmeo and Woja compared to their reference sits

also showed no significant difference in fish density and biomass in the sheltered and exposed reefs (Fig.9b,c and Fig10b,c).

Fish density at Fonemu was twice as much in the MPA compared to its reference site (Fig. 10a). The difference with biomass was even greater with the MPA having 7 times more biomass inside it than in the reference site that was open to fishing (Fig. 11a). Fish species richness was also significantly higher in the MPA at Fonemu than the reference site Fig. 12a). In Fananang, there were no significant differences in both fish density and biomass in the MPA compared to its reference site (Fig. 10b and 11b). Only species richness showed significant difference with more species in the Fananang MPA than the reference site (Fig. 12c). Fish density, biomass and richness were not significantly different at Onunum MPA compared with its reference sites (Fig. 10c, 11c, and 12c). Onunum MPA and it reference sites also had the lowest density and biomass of fish compared with the other two MPAs surveyed.

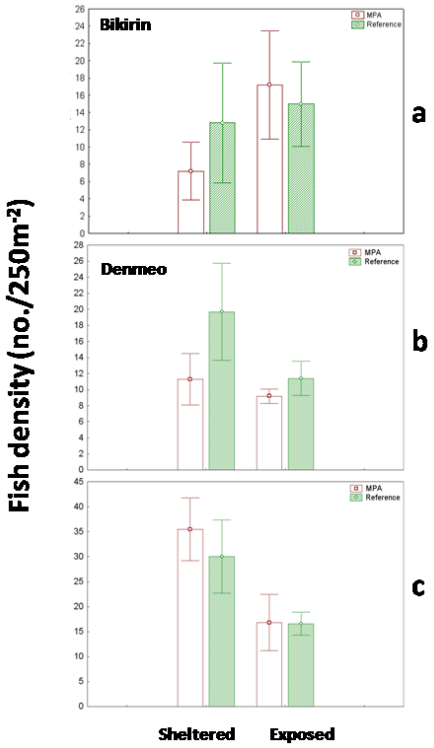


Figure 9 Fish density in (a) Bikirin, (b) Denmeo, and (c) Woja. Error bars indicate standard error.

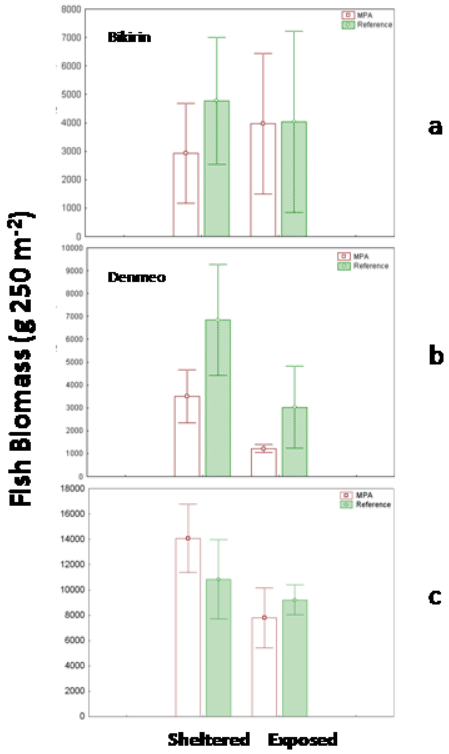


Figure 10 Fish biomass in grams in (a) Bikirin, (b) Denmeo, and (c) Woja. Error bars indicate standard error.

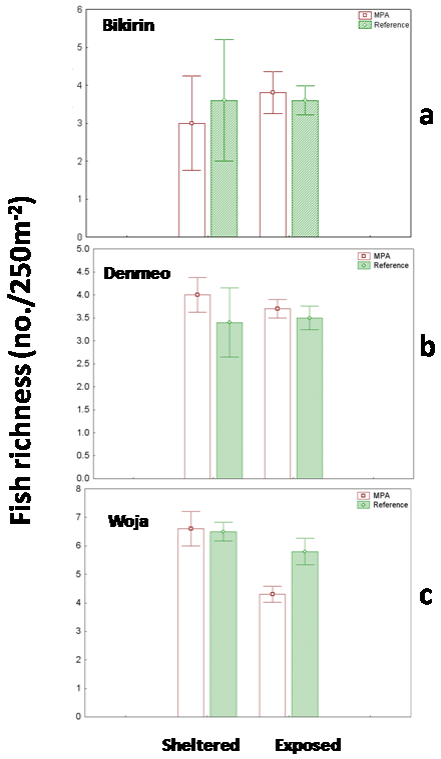


Figure 11 Fish richness in (a) Bikirin, (b) Denmeo, and (c) Woja. Error bars indicate standard error.

Chuuk

Benthic Assemblages

Mean coral cover at Fonemu MPA was 30.4% compare with the reference site, which had a coral cover of 11.1% (Fig.5a). At Fananang MPA, coral cover was 25.6% inside the MPA and 12.0% outside of the MPA in the reference site (Fig.5b). Coral cover at Onunun and its reference site were not significantly different with coral cover at 7.7% and 6.3%, respectively (Fig.5c).

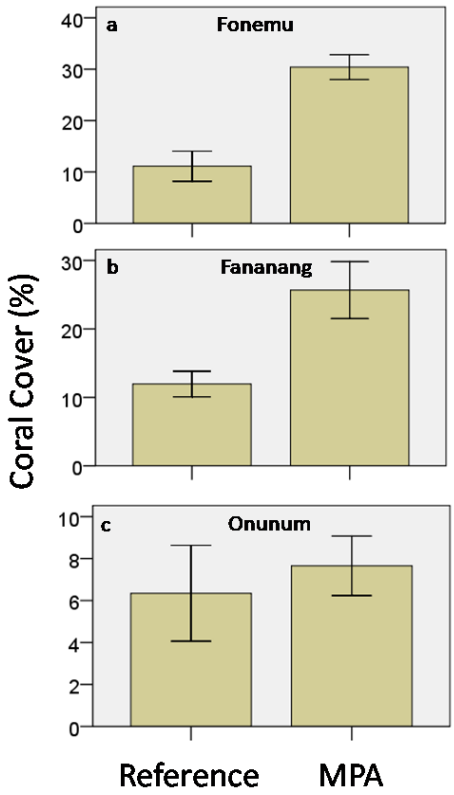


Fig. 5. Coral cover at reference and MPA site at (a) Fonemu, (b) Fananang, and (c) Onunum. Error bars indicate standard errors.

Coral richness as measured by the number of coral genus, was significantly higher in Fonemu and Fananang MPAs compared with their reference sites (Figs.6a and 6b). At Onunum, there was no significant difference in coral richness between the MPA and reference site (Fig. 6c). The density of coral recruits was higher at Fonemu compared with its reference site (Fig. 7a). In Fananang and Onunum, there was no significant difference in recruit density between MPAs and reference sites (Figs. 7b and 7c).

Fig. 7. Coral generic richness in MPA and reference site at (a) Fonemu, (b) Fananang and (c) Onunum. Error bars indicate standard errors.

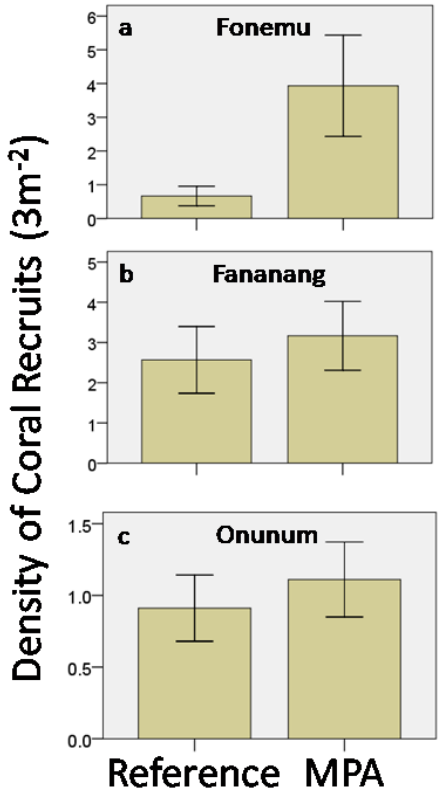


Fig. 8. Density of coral recruits in MPA and reference site at (a) Fonemu, (b) Fananang and (c) Onunum. Error bars indicate standard errors.

The densities of invertebrates in all the sites surveyed were very low with none of the sites having a density higher than one (Figs. 9a, 9b and 9c).

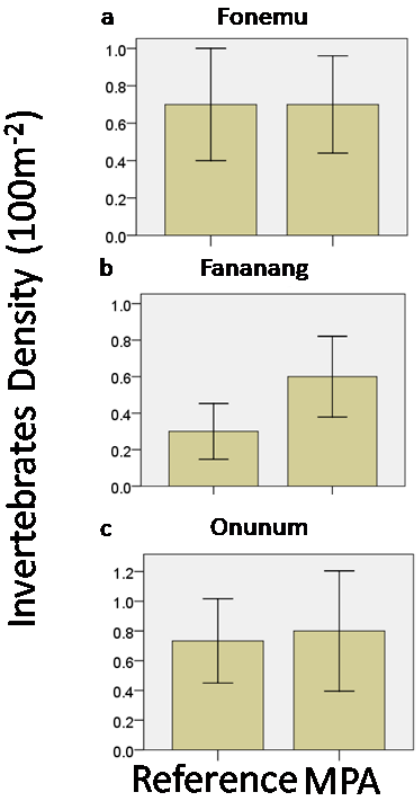


Fig. 9. Density of invertebrates in MPA and reference site at (a) Fonemu, (b) Fananang and (c) Onunum. Error bars indicate standard errors.

Fish Assemblages

Fish density at Fonemu was twice as much in the MPA compared to its reference site (Fig. 10a). The difference with biomass was even greater with the MPA having 7 times more biomass inside it than in the reference site that was open to fishing (Fig. 11a). Fish species richness was also significantly higher in the MPA at Fonemu than the reference site Fig. 12a). In Fananang, there were no significant differences in both fish density and biomass in the MPA compared to its reference site (Fig. 10b and 11b). Only species richness showed significant difference with more species in the Fananang MPA than the reference site (Fig. 12c). Fish density, biomass and richness were not significantly different at Onunum MPA compared with its reference sites (Fig. 10c, 11c, and 12c). Onunum MPA and it reference sites also had the lowest density and biomass of fish compared with the other two MPAs surveyed.

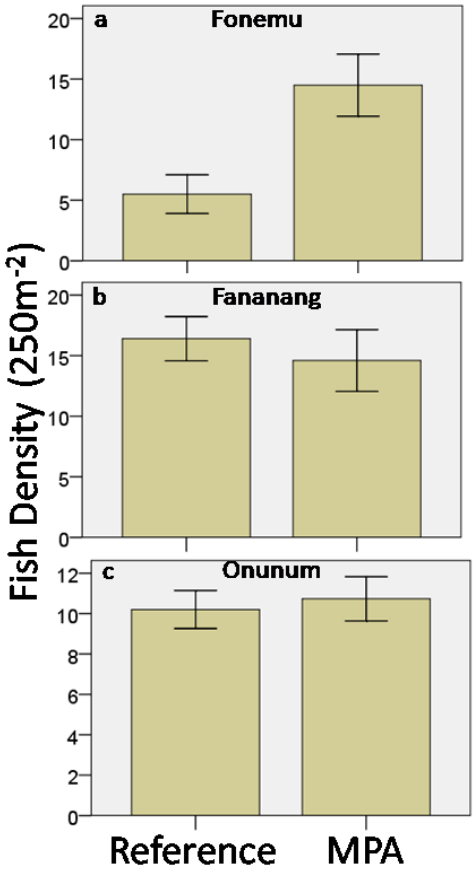


Fig. 10. Fish density in MPA and reference site at (a) Fonemu, (b) Fananang and (c) Onunum. Error bars indicate standard errors.

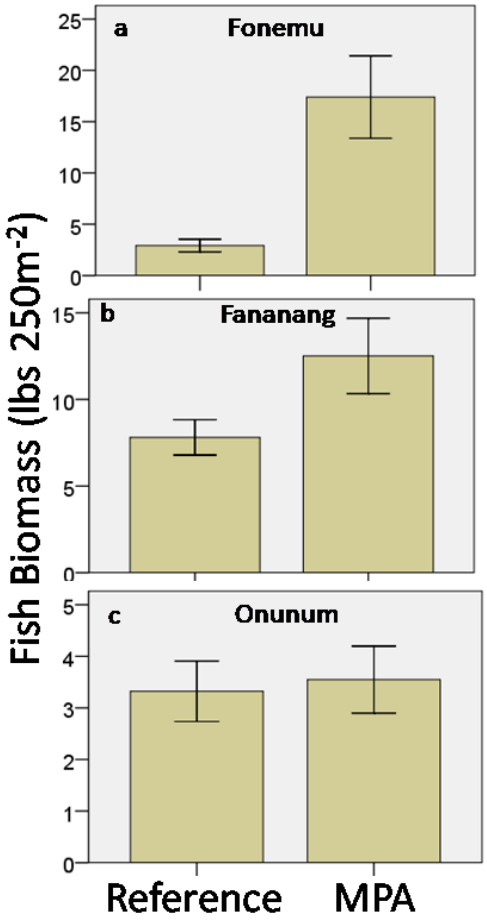


Fig. 11. Fish biomass in MPA and reference site at (a) Fonemu, (b) Fananang and (c) Onunum. Error bars indicate standard errors.

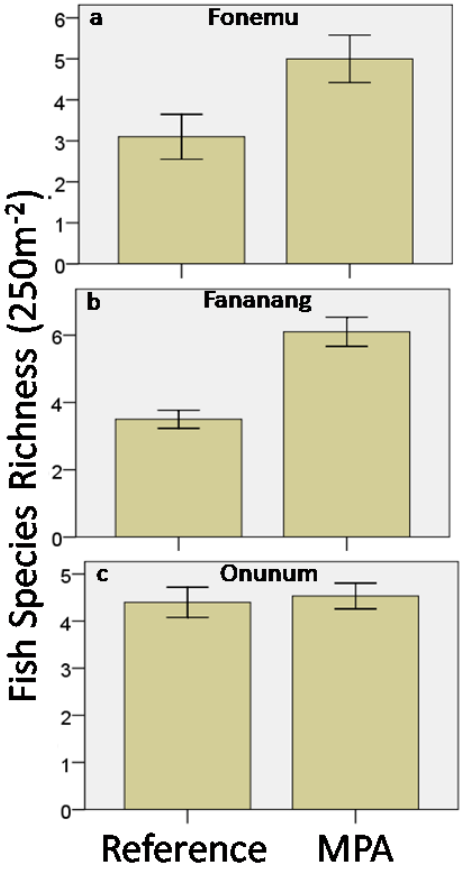


Fig. 12. Richness of fish species in MPA and reference site at (a) Fonemu, (b) Fananang and (c) Onunum. Error bars indicate standard errors.