Evaluation of a Fishery Resource Response to a Net-Use Restriction in Saipan Lagoon, Commonwealth of the Northern Mariana Islands[1]

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Abstract: A wide variety of fishing methods is used to harvest coral-reef fishes worldwide, with increasing concerns regarding long-term sustainability. As such, there is a need to determine the degree to which specific fishing methods influence coral-reef fish resources. In 2004 the Commonwealth of the Northern Mariana Islands instituted restrictions on use of gill, drag, and surround nets, limiting use to special exemption for annual fiestas. Historical creel survey data and data from net-use exemptions were reviewed and underwater visual census surveys conducted in southern Saipan Lagoon to assess changes in abundance and biomass from 2004 to 2011. Generalized linear modeling results showed numerical increases in four reef fish families, including Labridae, Scaridae, Mullidae, and the primary target of exempted net-fishing events, Lethrinidae. In addition, mean increases in total reef fish biomass were observed from 2004 to 2011. Positive changes in abundance and biomass of certain coral-reef fish families suggest that decreased fishing mortality via gear restrictions on use of nets can be a useful tool toward the goal of reef fish sustainability in coral-reef ecosystems.

Keywords: Fishing nets, gear restrictions, coral-reef fish, Saipan Lagoon, Micronesia

Expanding human coastal populations in tropical and subtropical regions have resulted in an increased focus on the long-term sustainability of nearshore coral-reef fisheries (Dalzell et al. 1996, Jackson et al. 2001, Ault et al. 2009, Cinner et al. 2012). Many of these ecosystems lack appropriate monitoring and are therefore considered data limited (Vasconcellos and Cochrane 2005). Achieving sustainability in coral-reef fisheries is challenging because a variety of harvest methods are used to capture a diverse array of species that exhibit various life history characteristics. As a result, there has been an amplified focus to determine the most appropriate research and management methods to employ to achieve sustainability. These approaches have included ecosystem-based approaches to management (Pikitch et al. 2004, Arkema et al. 2006), which can include the integration of customary management systems with existing management structures such as the implementation of long-term fisheries-dependent and independent monitoring (Pitcher et al. 2009, Link et al. 2010), as well as management measures that spatially and temporally restrict or prohibit resource extraction (Gell and Roberts 2003, Halpern et al. 2010).

Co-management initiatives in the Pacific region have focused on management integration to attain fishery sustainability goals (Wamukota et al. 2012, Ayers and Kittinger 2014, Frey and Berkes 2014), although in

[1] This study was funded by a U.S. Fish and Wildlife Service Dingell-Johnson Sportfish Restoration Act grant to the CNMI Division of Fish and Wildlife. Manuscript accepted 18 October 2017.

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Pacific Science (2018), vol. 72, no. 3:291–306
doi:10.2984/72.3.1 (Includes online supplements)

areas where custom-based systems are no longer functional this approach can be challenging (Adams 1998, Aswani et al. 2012). Although the movement toward community co-management initiatives to empower communities with a sense of ownership remains a long-term government and community goal (Cinner et al. 2012), the need for direct and immediate management has often resulted in the establishment of no-take Marine Protected Areas (MPA). Even though MPA implementation has proved useful in some circumstances (Rassweiler et al. 2012, Edgar et al. 2014), it has become apparent that MPAs are only one part of achieving fisheries sustainability for ecological (Hargreaves-Allen 2011, Mora and Sale 2011) and socioeconomic reasons (McClanahan et al. 2006, Pollnac et al. 2010). As a result, many communities have also implemented gear restrictions and modifications to improve resource sustainability (McClanahan 2010, Hicks and McClanahan 2012).

The Commonwealth of the Northern Mariana Islands (CNMI) has gone through a well-documented cultural transformation over the past several hundred years, which has influenced the fishing habits of indigenous peoples (Amesbury and Hunter-Anderson 2003). During the time when the Mariana Islands were under Japanese Mandate (1914–1944), fishery resources in the southern Mariana Islands were heavily exploited (Smith 1947, Uchida 1983). Technological advancement in fishing gear has led to increased fishing power and fishing pressure in nearshore tropical coral-reef fisheries (Jennings and Polunin 1996, Campbell and Paradede 2006). Since the end of World War II, changes in fishing technology such as the use of monofilament line in gill, drag, and surround net fishing have been documented in the Mariana Islands (Amesbury and Hunter-Anderson 2003). In more recent times, use of flashlights and scuba became a part of spearfishing in the Marianas, but scuba spearfishing was later (2003) banned in the CNMI due to concerns regarding the depletion of certain local fish populations around Saipan (Trianni 1998, Richmond et al. 2008, Lindfield et al. 2014).

In 2003 the CNMI Department of Lands and Natural Resources Division of Fish and Wildlife (DFW) passed a regulation restricting the use of gill, drag, and surround nets, with exceptions for cultural events such as annual fiestas. These exceptions helped mitigate against fishing pressure shifting to other fishing methods and allowed for stakeholder buy-in. This regulation was based upon several trends, including an increase in coral-reef fish imports as identified from the CNMI DFW fish import database; increased presence of abandoned gill, drag, and surround nets; and temporal and spatial differences in reef-fish species size in the commercial coral-reef spear fishery (Graham 1994, Trianni 1998). The goal of the regulation was to reduce indiscriminate fishing in the CNMI, decrease habitat damage from abandoned nets, and reduce the fishing power provided by new technologies to allow for a more equitable distribution of fisheries resources to the people of the CNMI.

In this study, we examined three sets of data to examine changes in select reef food-fish families in Saipan Lagoon. We analyzed underwater visual census (UVC) fishery-independent data from 2004, 2007, and 2011 within the southern Saipan Lagoon (SSL) to determine if shifts in select reef food-fish families had occurred following the current net-use restrictions (NUR) passed in 2003 and implemented in 2004. In addition, we reviewed historic Saipan Lagoon creel survey data and recent landings from exempted net-use fishing to potentially supplement and corroborate observed changes from underwater visual fish survey count data observations. Finally, we discuss the importance of gear restrictions as a broad-reaching management tool in conservation of coral-reef fishes.

MATERIALS AND METHODS

Study Site

The Saipan Lagoon extends along the western side of the island of Saipan, bordered by a nearly continuous barrier reef (Figure 1). Depths in Saipan Lagoon range from <1 m in

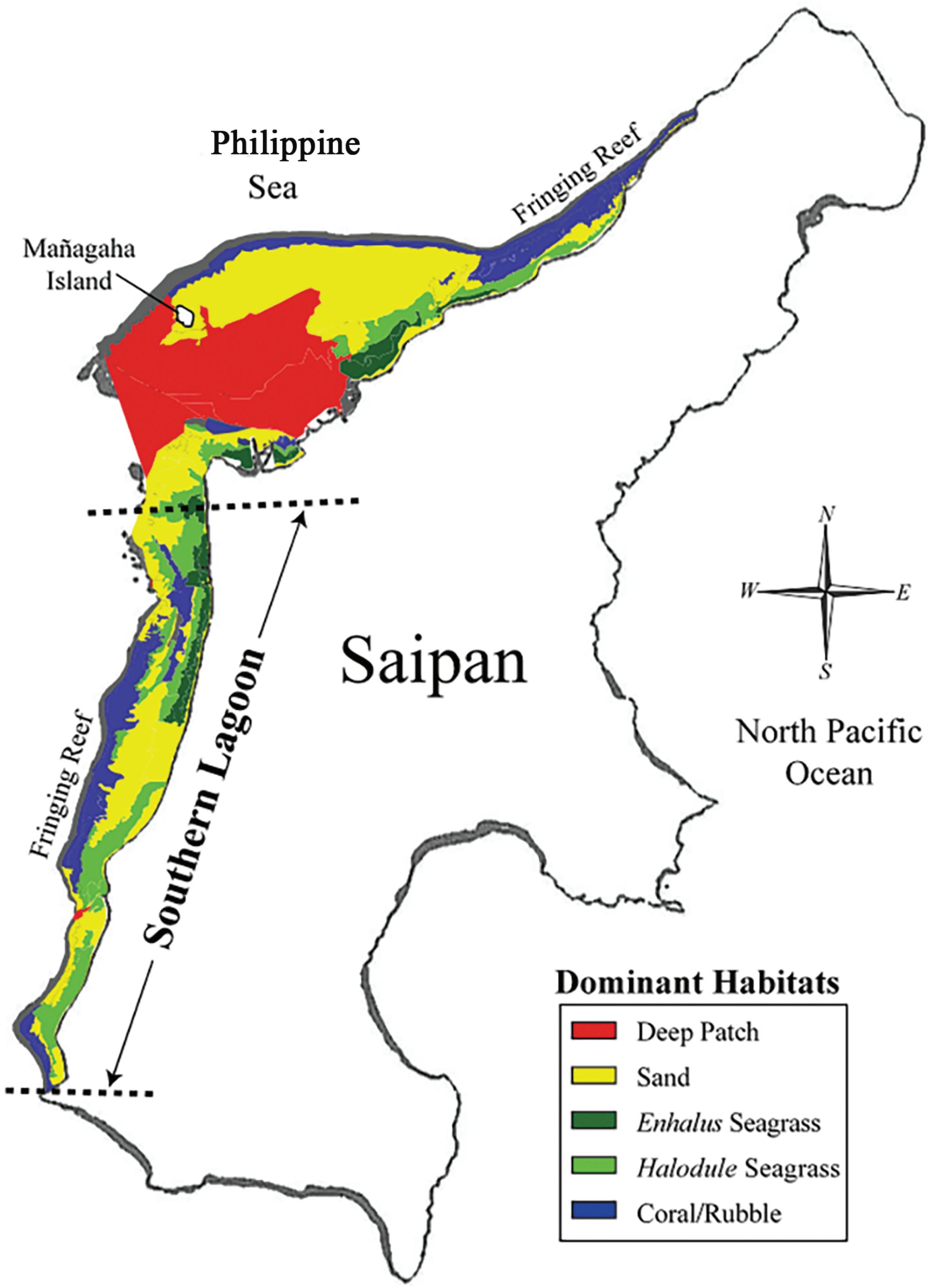

Figure 1. Map of Saipan showing dominant benthic habitats and southern Saipan Lagoon study site.

nearshore areas to about 15 m in the main shipping channel. Saipan Lagoon serves as the primary area for a variety of nonextractive recreational purposes as well as the primary grounds for noncommercial and commercial fishing for the island of Saipan.

Fishery-Independent Data

After implementation of the NUR in January 2004, a UVC fisheries-independent survey was conducted in the SSL to collect abundance data for coral-reef fish. The information from this survey provided the reference point for future comparative surveys to assess the influence of the NUR. The survey was repeated in 2007 and 2011 to determine if any changes in abundance and biomass had occurred for observed coral-reef fish. In addition, inspection of changes in key reef-fish families (KRFF), including Scaridae, Labridae, Mullidae, Lethrinidae, Acanthuridae, and Balistidae, was undertaken. These six families were determined to reflect not only important food-fish families but also a wide range of ecosystem services.

For the purposes of this study habitat types composing SSL were pared down into four habitat clusters based on substrate dominance: *Halodule* sea grass, *Enhalus* sea grass, Sand, and Coral/Rubble (Figure 1). Sampling locations were randomly selected using a GIS-based sampling design proportionally allocated to habitat cluster size. At each sampling site two UVC techniques were used to estimate abundance of coral-reef fish. Belt transects (BLT) were conducted using a 25 m nylon line weighted on both ends deployed into the direction of the current. A single observer swam the length of the line identifying, counting, and recording food fish within 2.5 m of the transect line for a 10- to 15-min period. Stationary Point Counts (SPC) with a radius of 10 m and observations lasting 8 min were sampled from a location at least 15 m off the end of the BLT. The SPC recorded fish from 20 cm in 5 cm size bins, focusing on larger individuals. The BLT target primarily sedentary species, and the SPC target larger roving species. Observers were trained in the methodologies before data collection, with most observers being consistent between years. Observer training included estimation of distance for the UVC methods and estimation of fish sizes using wood cutouts of various sizes and shapes that matched those of Saipan Lagoon reef fish.

Fishery-Dependent Data

Exempted net-use fishing events in 2007 ($n = 3$) and 2011 ($n = 5$) in the SSL were conducted using the surround-net fishing method, where the net was deployed in a semicircular fashion with fish driven toward the net by fishermen. Once fish were corralled, harvest took place using snorkel-spear. CNMI DFW staff monitored these net-use exemptions (NUE) fishing events and collected total reef fish landings by weight and number, providing information on which families and species were targeted by this method.

Inshore creel survey (ICS) data collected in Saipan Lagoon by the CNMI DFW for the period 1984 to 1993 were reviewed regarding historical net-use activity and compared to ICS landings from 2005 to 2011. Survey participation counts documented the number of times various fishing methods were employed, and fishermen interviews documented the number and weight of sampled catches. These data were used to obtain an estimate of the historical use of gill, surround, and dragnet fishing in Saipan Lagoon. No ICS data were available between 1994 and the resumption of the survey in 2005, which followed the implementation of the NUR. The historical ICS did not contain sufficient resolution to conduct more-detailed analysis.

Data Analysis

There are often many zero observations in ecological count data, resulting in collected data being incompatible with parametric evaluation based on a normal distribution (Ridout et al. 1998). Data transformation is often not possible due to the high number of zero observations, requiring that the data be modeled on a distribution that can accommodate zero inflation (Zuur et al. 2009), such as the Poisson distribution:

$$\Pr\{Y = y\} = \frac{e^{-u}u^{y}}{y!} \quad y \geq 0,$$

which assumes that the variance and mean are equivalent, or $E(Y) = u$ and $\mathrm{var}(Y) = u$ or negative binomial:

$$\Pr\{Y = y\} = \frac{\Gamma(y+k)}{\Gamma(k)\times\Gamma(y+1)} \times \left(\frac{k}{u+k}\right)^{k} \times \left(1 - \frac{k}{u+k}\right)^{y}$$

where $\mathrm{var}(Y) = u + u^2/k$, and if k is large the variance is equitable to the mean and the Poisson distribution is appropriate.

In addition, zero-inflated (ZI) and hurdle models use a two-step modeling approach in analyzing overdispersed data (Zuur et al. 2009). In the first step both models utilize logistic regression to analyze zeros versus nonzeros in the data, but in the second step the models diverge. Although both models utilize either a Poisson or negative binomial regression model, ZI models include zeros in this analysis step (the distribution is not zero-truncated), whereas the Hurdle models use only zero-truncated counts (Zeileis et al. 2008). A special feature of these two-part models is that both model parts are not constrained to be the same. The influence of year and habitat on abundance was evaluated through fitting of data to models based on the Poisson and negative binomial distributions, including ZI and hurdle models. For the two-step models, the ZI and zero-hurdle parts modeled counts dependent upon Year using a binomial logit-link, with the count parts modeled the same as the negative binomial model. The significance of model fits to the data was evaluated with the chi-square test statistic, and competing models were compared using the Akaike Information Criteria (AIC) (Akaike 1976). The R package 'pscl' was used for hurdle model and associated analyses.

A test of the null hypothesis of equidispersion (Cameron and Trivedi 1990) from the R package 'AER' found overdispersion in the total BLT reef-fish count data fit to a Poisson distribution ($z = 4.45$, $P = 0.000$). Rootograms (Kleiber and Zeileis 2016) of fitted Poisson and negative binomial models also revealed significant over- and underprediction of count bins by the Poisson model (Supplemental Figure S1). As a result, three models were fit to the total BLT count data. The first was a negative binomial modeling the total count of reef fish on Year, Habitat, and the interaction of Year × Habitat. The second model was a hurdle model with the binomial logit-link evaluating presence-absence of zero counts using the factor Year and a truncated negative binomial log-link for the count data. The third model was a ZI binomial logit-link model evaluating presence-absence of zeros in the first part and in the second part a nontruncated negative binomial log-link.

Authors' Note: Supplemental materials available online at BioOne (http://www.bioone.org/toc/pasc/current) and Project MUSE (http://muse.jhu.edu/journal/166).

The BLT and SPC biomass data were not amendable to the generalized linear models used to address the zero inflation in the count data, given the continuous nature of observations. To test for differences in BLT and SPC biomass a randomization test was used to compare the mean difference between compared years. The difference in means between the original samples was compared to differences in means generated from 5,000 randomized samples from pooled data between years. The number of randomized means that exceeded the original mean was counted and divided by the total number of randomizations to obtain an estimate of significance. Biomass was estimated using length-weight regressions obtained from NANSIS (2014). Analyses were conducted using the software program R (R Development Core Team 2014).

Data collected from NUE events were summarized for years corresponding to the fisheries-independent surveys to compare the percentage of the total landed from those events for KRFF to the percentages observed during the respective survey years.

TABLE 1

Akaike Information Criteria Rankings for Generalized Linear Models Fit to Belt Transect Count Data from Saipan Lagoon

Model	df	AIC
Negative binomial Count ~ Year × Habitat	13	2853.492
Zero-inflated negative binomial Count ~ Year × Habitat | Year	16	2835.156
Hurdle negative binomial Count ~ Year × Habitat | Year	16	2834.659

RESULTS

Fishery-Independent Data

Evaluations of fitted models to BLT abundance survey data using AIC model selection are provided in Table 1. A hurdle model using a negative binomial regression for counts was found to provide the best fit to abundance data from the BLT survey using the AIC (Supplemental Table S1). Interpretation of the hurdle model for BLT abundance showed in the logistic part of the model the exponentiated baseline (year 2004) that the odds of a positive count versus a zero count were 4.04: it was over four times more likely to see a fish on a BLT survey during 2004 than not. The 2004 baseline odds of seeing a fish on a BLT were increased by a significant factor of 12.6 times during the 2011 survey, and by a nonsignificant factor of 1.8 times during the 2007 survey.

Given the presence of fish on a BLT in 2004, the average count of reef fish on a BLT was about 44 (exponentiated intercept coefficient), with neither subsequent survey year having a significant impact on that average. The interaction of year and habitat showed that the change in the odds ratio was increased by 4.9 times in *Enhalus* habitat during 2007 and by 4.2 times in *Enhalus* habitat during 2011. No significant changes were observed in any other interaction of year and habitat.

Similar models were also fit separately to numbers of the family Labridae and Scaridae. For Labridae, the logistic zero hurdle model for the year 2004 baseline odds of a positive count versus a zero count was 1.2 (Supplemental Table S2), with the odds of observing Labridae on a BLT significantly increased by a factor of 2.6 during the 2007 fisheries-independent survey and 6.06 during the 2011 survey. In the count portion of the Labridae model, given a positive response the baseline average count was approximately 12. The only significant result in the count model was a decrease in the *Enhalus* habitat against the Coral habitat baseline. Results from the Scaridae logistic zero hurdle model for the 2004 baseline odds of a positive versus a zero count was 0.61, and the exponentiated coefficients of the main effects odds ratios of observing a scarid on a BLT were significantly increased by a factor of 2.59 during the 2007 fisheries-independent survey and 2.52 during the 2011 survey (Supplemental Table S3). In the Scaridae count model the 2004 baseline average was 24, which was significantly decreased by 0.22 in the *Enhalus* habitat. The baseline average count odds ratio was significantly increased by 7.7 times in *Enhalus* habitat during 2007.

Binomial models were fit to the SPC count data with the factor Year because observations were not sufficient to accommodate an interaction term. The SPC count data were not adequate to fit a Poisson, negative binomial, or two-step model. Binomial models were fit to the total observed reef fish and the families Lethrinidae, Scaridae, Mullidae, and Labridae. Model results for all reef fish showed the odds of observing fish in an SPC in the 2004 baseline case to be 0.22, increased significantly to 3.34 times in 2007 and 7.04 times in 2011 (Table 2). For the Lethrinidae the odds in the 2004 baseline case were 0.17, increased significantly to 2.64 times in 2007 and 4.58 times in 2011. Similar results were obtained for the Labridae, where baseline odds of 0.01 were increased significantly to 26.74 times in 2007 and 35.48 times in 2011. The 2004 Scaridae baseline odds of 0.02 were significantly increased to 6.9 times in 2011, and for Mullidae 2004 baseline odds of 0.01 were significantly increased to 23.71 times in 2011.

Sample sizes for the BLT biomass randomization tests were 111 (2004), 116 (2007), and 105 (2011). Randomization tests for BLT biomass resulted in significant differ-

TABLE 2

Results from Binomial Models Fits to the Total Number and Select Families of Coral-Reef Fish Observed during Stationary Point Counts in Saipan Lagoon during 2004, 2007, and 2011

Category	Term	Estimate	SE	*Z* Value	Pr (>|z|)
Total number	Intercept	−1.500	0.213	−7.047	0.000
	2007	1.207	0.283	4.262	0.000
	2011	1.952	0.255	7.669	0.000
Lethrinidae	Intercept	−1.745	0.231	−7.553	0.000
	2007	0.974	0.305	3.196	0.001
	2011	1.522	0.269	5.667	0.000
Scaridae	Intercept	−3.878	0.583	−6.649	0.000
	2007	−0.174	0.921	−0.189	0.850
	2011	1.932	0.619	3.124	0.002
Mullidae	Intercept	−4.990	1.003	−4.974	0.000
	2007	0.939	1.231	0.763	0.446
	2011	3.166	1.022	3.097	0.002
Labridae	Intercept	−4.990	1.003	−4.974	0.000
	2007	3.286	1.035	3.171	0.002
	2011	3.569	1.018	3.506	0.000

ences between the years, with values for 2011 greater than those for 2004 (randomized P value = .05) and 2007 (randomized P value = .01). For the SPC biomass randomization test, sample sizes were 148 (2004), 117 (2007), and 210 (2011). Results showed that values for 2007 were greater than those for 2004 (randomized P value = .06), and those for 2011 were greater than those for 2004 (randomized P value = .02).

Graphical representation of abundance and biomass by habitat types for the KRFF is depicted in Figures 2 and 3. From BLT observations for abundance and biomass, increases in KRFF across habitats were notable for Labridae, with increases in Mullidae appearing prominent from Sand and *Enhalus* sea grass habitats (Figure 2). General changes in BLT observations between years for other families were nuanced, although Lethrinidae biomass increased substantially in both sea grass habitats from 2004. Scaridae BLT abundance was found to be significant from 2004 in the zero hurdle model, which appears to have been driven by increases in the *Enhalus* sea grass habitat (Figure 2). This increase of Scaridae abundance was not reflected in biomass, indicating the presence of greater numbers of juveniles. In SPC abundance and biomass observations the KRFF generally increased from 2004 in all habitat types except *Halodule* sea grass, where only two of the KRFF (Lethrinidae and Labridae) increased from 2004; large Scaridae were observed in this habitat type for the first time in 2011 (Figure 3). The majority of increases in habitat from SPC surveys were in the 2011 survey, showing increase in abundance and biomass in comparison to the 2004 reference survey, whereas BLT surveys were split between 2007 and 2011 being greater than the 2004 baseline. Fish biomass and abundance did not decrease in any habitat from 2004 and subsequent survey years. Mullidae were observed to increase substantially in 2011 from the 2004 baseline in the *Enhalus* and Sand habitats for both abundance and biomass from both BLT and SPC observations, and also for SPC in the Coral habitat (Figure 3). Labridae also substantially increased in all habitats, in particular the *Halodule* BLT, in both the BLT and SPC observations in comparison to the 2004 baseline, as noted in the zero hurdle model.

Fishery-Dependent Data

Gill, surround, and dragnet fishing, which were restricted in 2004, accounted for about 73% of landings by number and 52% by

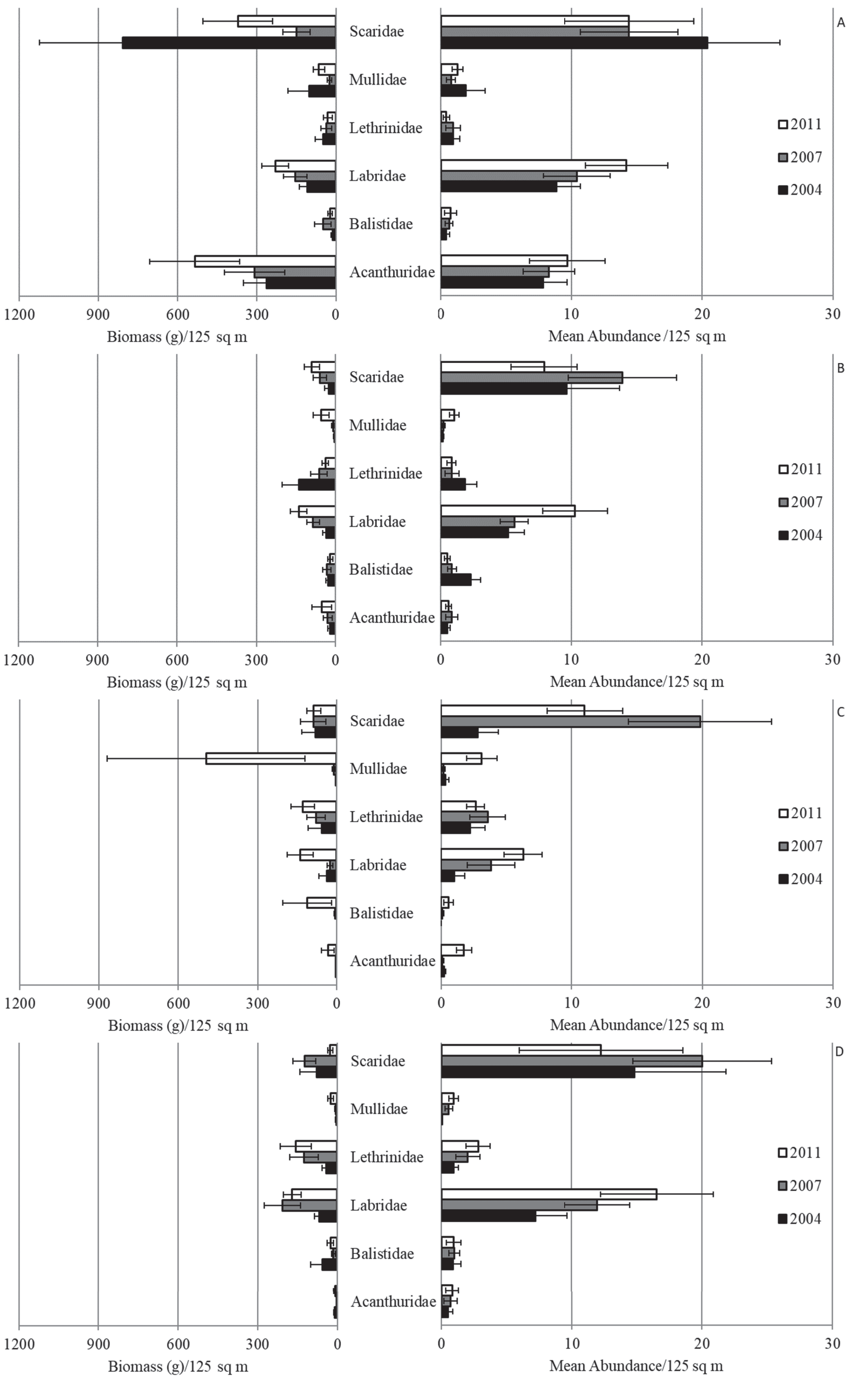

Figure 2. Belt transect mean abundance and biomass for Acanthuridae, Balistidae, Labridae, Lethrinidae, Mullidae, and Scaridae from 2004, 2007, and 2011 for southern Saipan Lagoon habitats: (*A*) Coral/rubble, (*B*) Sand, (*C*) *Enhalus* sea grass, and (*D*) *Halodule* sea grass. Error bars represent standard error.

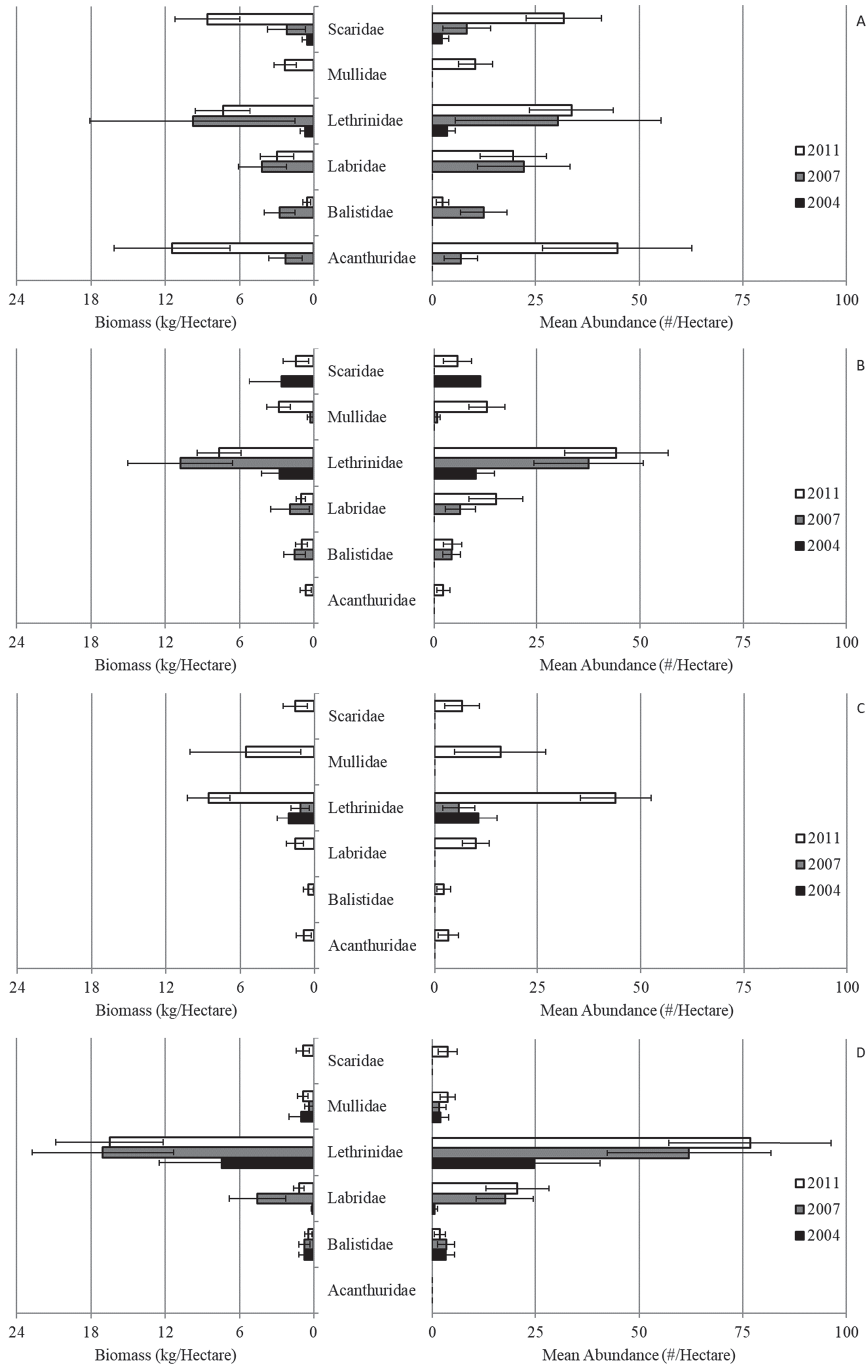

FIGURE 3. Stationary point count mean abundance and biomass for Acanthuridae, Balisitidae, Labridae, Lethrinidae, Mullidae, and Scaridae from 2004, 2007, and 2011 for southern Saipan Lagoon habitats: (*A*) Coral/rubble, (*B*) Sand, (*C*) *Enhalus* sea grass, and (*D*) *Halodule* sea grass. Error bars represent standard error.

TABLE 3

Relative Percentages of Gill, Surround, and Dragnet Fishing from CNMI DFW Inshore Creel Survey (ICS) Records Showing Percentage of Methods Used, Percentage of Landings by Number and Weight from 1984 to 1994, and Percentage Landings by Weight for ICS 2005–2011

		1984–1994		2005–2011
Method	% Use	% Number	% Weight	% Weight
Surround net	3.0	68.5	44.3	
Hook and line	51.0	9.6	5.5	31.0
Cast net	17.8	8.7	4.2	11.4
Snorkel-spear	15.5	6.7	29.9	57.6
Dragnet	0.86	2.6	1.5	
Gill net	7.7	1.7	6.2	
Scuba-spear	0.3	1.4	8.1	
Gleaning	3.4	0.7	0.2	

TABLE 4

Relative Percentages of Southern Saipan Lagoon Coral-Reef Fish from Stationary Point Counts (SPC), Belt Transects (BLT), and Net-Use Exemptions (NUE) (Net-Use Percentages Reflect Landings from 2007 and 2011)

	2004		2007		2011		2007 and 2011
	SPC	BLT	SPC	BLT	SPC	BLT	NUE
Abundance							
Family							
Acanthuridae	0.7%	7.3%	1.0%	8.6%	8.2%	9.9%	1.4%
Balistidae	4.3%	4.9%	6.6%	3.0%	4.8%	2.4%	0.2%
Labridae	0.0%	23.5%	20.4%	30.0%	13.1%	32.8%	2.6%
Lethrinidae	51.4%	7.2%	61.2%	7.7%	40.6%	4.6%	62.9%
Mullidae	2.2%	1.9%	1.0%	2.2%	8.5%	4.4%	9.5%
Scaridae	16.7%	53.6%	2.1%	33.3%	9.5%	37.9%	10.8%
All others	24.6%	1.7%	7.6%	15.2%	14.9%	7.9%	12.6%
Biomass							
Acanthuridae	0.4%	12.9%	1.1%	9.6%	10.3%	15.3%	3.0%
Balistidae	1.5%	9.9%	6.2%	5.5%	5.4%	7.1%	0.1%
Labridae	0.0%	4.1%	9.3%	18.8%	6.2%	18.0%	2.0%
Lethrinidae	25.5%	20.2%	73.8%	16.6%	43.1%	10.4%	46.4%
Mullidae	2.5%	4.6%	1.1%	1.4%	10.9%	10.6%	7.2%
Scaridae	7.4%	43.2%	2.0%	9.7%	12.0%	17.4%	6.7%
All others	62.6%	5.1%	6.6%	38.5%	12.1%	21.1%	34.6%

weight in 1984–1993, indicating that the restricted methods had been an important component of the total catch in the area (Table 3). Mullidae (24.5%) and Lethrinidae (18.2%) had the highest percentage occurrence in these landings. Only three methods represent the current nearshore coral-reef fishery, with snorkel-spear and hook and line accounting for over 88% of landings by weight from the 2005–2011 ICS, in contrast to about 35% from the 1984–1993 ICS (Table 3).

Relative percentages of the KRFF landed during net-exemption fishing activity averaged from 2004, 2007, and 2011 were compared with the percentages observed from the BLT and SPC surveys in each of those years (Table 4). Similarity between net-exemption and UVC observations varied. Lethrinidae dominated KRFF compositions from the SPC and NUE, comparing well in all years for both abundance and biomass, but BLT compositions were much lower. For Scaridae, BLT observations were greater than those of NUE for all years for both abundance and biomass, while SPC percent compositions in 2007 were lower than NUE landings. In comparison to NUE landings, Labridae were most dominant in the BLT surveys, though also greater than in NUE in SPC surveys in 2007 and 2011 (Table 4). Acanthuridae BLT abundance and biomass were greater than NUE landings for all years, whereas SPC abundance and biomass were greater in 2011. Balistidae were lower in NUE landings for both biomass and abundance in comparison to SPC and BLT for all years, and the percentage of Mullidae landed from NUE exceeded SPC and BLT abundance in all years and for biomass in 2004 and 2007.

DISCUSSION

Overall changes in coral-reef fish abundance trended positively from the 2004 baseline as results from both BLT and SPC surveys showed a greater probability of observing coral-reef fish in 2011 compared to the 2004 baseline from zero hurdle and binomial models, with SPC additionally observing a greater probability of observing reef fish in 2007. The BLT survey results also indicated that the families Scaridae and Labridae were more prominent in 2007 and 2011, whereas the SPC showed Lethrinidae and Labridae to be more observable in 2007 and 2011 and Scaridae and Mullidae being more conspicuous in 2011. Biomass was also found to have increased overall from 2004 in both BLT and SPC surveys.

The increase in SPC observed abundance and biomass from the 2004 to the 2011 surveys coincided with the CNMI-wide NUR on the use of gill, drag, and surround nets promulgated in December 2003. CNMI DFW ICS data showed that from 1984 to 1994 the use of gill, drag, and surround nets composed about 12% of reef fish methods employed as estimated from observed ICS participation targeting Saipan Lagoon, while making up substantial portions of fishery landings during that period. The positive response in SPC abundance and biomass between 2004 and 2007–2011 indicated the susceptibility of larger individuals to gill and surround net fishing, supported by the continued positive response in BLT and SPC abundance and biomass from 2007 to 2011. The increased abundance of the Lethrinidae from the fisheries-independent SPC data, and the observed NUE landings where lethrinids averaged 46% of the biomass and 62% of the abundance from 2007 and 2011 (Table 4), suggest that NUR have had a beneficial effect on larger individuals of this family in the SSL, although the consistency of Lethrinidae BLT abundance and biomass in the SSL habitats implied that NUR did not have a considerable impact on juveniles and subadults of this family. Trianni (2016) estimated the asymptotic length of the thumbprint emperor, *Lethrinus harak*, to be about 30.1 cm fork length (FL). In that same study the thumbprint emperor was found to compose about 35% of Lethrinidae NUE landings from 2005 to 2011. Using one-half of that asymptotic length, 15 cm FL, as a guide, about 0.5% of the estimated length-frequency data from the 2007 and 2011 NUE harvests, averaging 22.8 cm FL ($n = 1{,}621$), were less than 15 cm FL. Although CNMI NUR remain in place, other methods such as snorkel-spear and rod and reel are still employed by local fishers in Saipan Lagoon. Estimated average lengths of Lethrinidae from 2005–2011 CNMI DFW Saipan Lagoon ICS landed by rod and reel averaged 17.8 cm FL ($n = 1{,}142$) and by snorkel-spear 19.0 cm FL ($n = 132$) with a combined total of 33.6% being less than 15 cm FL. These length-frequency observations indicate that fishermen fishing with nets, in particular surround nets, target larger Lethrinidae, because larger individual fish can be preferentially selected. Tuda et al. (2016) found that gill nets in Kenya captured large *Lethrinus harak*, with 84% of that species being larger than size at female maturity. In Saipan Lagoon, Trianni (2016) noted that 83% of NUE landings of the most abundant Lethrinidae in Saipan Lagoon, *L. harak*, were above the estimated size at maturity for females, 19.8 cm FL, whereas ICS data from 2005 to 2011 showed 63% of sampled thumbprint emperor to be less than the estimated size at female maturity.

The positive increases in Mullidae abundance and biomass in 2011 were particularly evident from the SPC surveys in all habitats in addition to the significant increase in the odds of observation. Although no significance was observed in BLT surveys, an increase was observed in the 2011 *Enhalus* sea grass habitat. Mullidae were found to make up the largest percentage of reef fish from the 1984–1994 CNMI DFW ICS data, and it is reasonable to assume that like the Lethrinidae, Mullidae have benefited from the NUR. Mullidae made up about 9% of the ICS landings from 2005 to 2011 with NUR in place, in comparison to 24.5% from the 1984–1994 ICS, during which time the use of nets was not regulated. Alternatively, in addition to the Carangidae and Siganidae, Mullidae support recruitment fisheries harvested by cast net from shorelines, especially in Saipan Lagoon. Recruitment to these fisheries can be prone to high variability from year to year.

The Acanthuridae showed some increases in larger fish by habitat from SPC surveys in 2011 from those in 2004 and 2007, with no clear patterns observed for the Acanthuridae BLT or Balistidae UVC. No significance was demonstrated in model fitting for either family. Although these two families are not large components of net-exemption landings, Acanthuridae have accounted for more than 30% of total landings from the historical scuba-spear fishery (Graham 1994, Trianni 1998) and from the current nighttime commercial snorkel-spear fishery (Pacific Islands Fisheries Science Center, unpubl. data). Observations of Scaridae showed positive changes in BLT and SPC abundance and biomass, and this family was also observed to be an important component of historical scuba-spear and current snorkel-spear fisheries (20–30%). NUR may have less management impacts on these species because they are effectively targeted in other gear fisheries such as snorkel-spear. Other management options may be more beneficial to these groups, such as the CNMI-wide scuba spearfishing ban.

Archaeological evidence along the coast of Saipan Lagoon showed bones from the six KRFF in this study to have been represented, in particular Scaridae, Acanthuridae, and Lethrinidae (Amesbury and Hunter-Anderson 2003). Although it cannot be presumed from the archaeological evidence that those KRFF were specifically targeted by net fishing, observations from the 1984–1994 CNMI DFW ICS indicate the presence of those families in Saipan Lagoon as targets of fishing effort. The 1984–1994 DFW ICS data also showed surround nets to be the fishing method that overwhelmingly landed the greatest percentages of reef fish by number and weight. This is supported by NUE in the years 2007 and 2011, all using a surround net fishing method, with landings in those years being composed of over 87% KRFF by abundance and over 65% by biomass. Surround nets are deployed in midlagoon areas, with these deployments typically occurring near lagoon channels. Gill nets, although not deployed during NUE to date, were deployed near or in lagoon channels to capture fish moving in and out of the lagoon. Drag nets, although not deployed during NUE to date, were typically used nearshore in sea grass habitats where a net was dragged through a sea grass bed, targeting fisheries resources but also disrupting other benthos and associated abiotic habitat. In addition to NUE in reflecting the importance of KRFF as a food resource, the current ICS program that commenced in 2005 (post-NUR) showed that from 2005 to 2011 the KRFF accounted for 47% of landings, even though the current ICS underestimates spear fish landings because sampling during early morning hours is not adequately covered.

KRFF include groups that provide important ecosytem functions. Scaridae and Labridae are composed of scrapers and small excavators, which manage macroalgae growth and allow coral recruitment, and Acanthuridae is composed largely of grazers, detritivores, and browsers, which help control turf algae and macroalgae (Green and Bellwood 2009). Lethrinidae also play an important role in ecosystem and trophic balance by feeding on other fish and invertebrate species, thereby providing important top-down effects on community structure (Boaden and Kingsford 2015). Changes in ecosystem services through top-down effects, although not a focus of this study, would be expected to parallel observed improvements in KRFF populations.

Variation in observer length estimates have been examined for UVC approaches under many circumstances (Harvey et al. 2002, Bernard et al. 2013), and knowledge of the precision and accuracy of BLT and SPC observations would improve future NUR evaluation surveys in Saipan Lagoon. In addition, estimating fish length with greater accuracy can provide a more specific evaluation of temporal changes in fish size, which in turn provides a more detailed understanding of biomass changes, resulting in a more cost-effective survey by allowing broader use of collected data.

One challenge in conducting surveys in fished areas is the tendency of targeted fish to shy away from observers, in particular the Lethrinidae (Jennings and Polunin 1995, Williams et al. 2012), the family that represented the greatest percentage of UVC observations. Despite a tendency to display avoidance behavior, Lethrinidae were found to increase considerably from the 2004 baseline. Larger individuals of other KRFF may also have been difficult to observe due to avoidance behavior before detection (Bozec et al. 2011).

This study assessed the usefulness of implementing a single management measure, net restrictions, with subsequent observed increases in abundance and biomass for reef-fish families typically targeted by net fishing. The NUR promulgated in the CNMI were an uncommon regulatory action in the greater western Pacific region, impacting both commercial and noncommercial uses. Permitting limited NUE to this regulation allowed for the controlling of fishing pressure and providing the ability to monitor catch, while allowing traditional cultural events that engender community support. This approach was different than achieved and attempted net fishing closure regulations in other areas, where the commercial use of nets was specifically targeted for banning along with denigration of those fishermen (Loring 2017). The positive response of certain reef fish will likely add value to the local tourism industry through diving and fishing charters as well (Haider et al. 2006). Studies pertaining to assessing the influence of gear restrictions on fish abundance and biomass, in particular restrictions on nearshore and coastal nets, are uncommon, which is perhaps indicative of the difficulties management agencies have when trying to enact changes in the use of those gears. Because the resilience of coral-reef fish to increasing fishing effort and fishing power will become a mounting concern over time, the importance of documenting and disseminating study results can be considered essential to formulating coherent management approaches to long-term coral-reef fishery resource sustainability.

ACKNOWLEDGMENTS

We thank former and current CNMI Natural Resource Agency staffs who have participated in the Saipan Lagoon surveys.

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Evaluation of a Fishery Resource Response to a Net-Use Restriction in Saipan Lagoon, Commonwealth of the Northern Mariana Islands

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Source: Pacific Science, 72(3):291-306.
Published By: University of Hawai'i Press
https://doi.org/10.2984/72.3.1
URL: http://www.bioone.org/doi/full/10.2984/72.3.1