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ARTICLE

Spatial, Temporal, and Biological Characteristics of a Nearshore Coral Reef Fishery in the Northern Mariana Islands

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Abstract
Fishery landings of coral reef fish from a nearshore commercial spear fishery from 2011 to 2014 were analyzed and summarized. Results showed that the fishery comprised two effort components—shore- and boat-based fishing—with shore-based fishing dominating fishery effort. These two components yielded differing fishery characteristics, including landings, CPUE, seasonality, fishing locations, and targeted species. Time series of select species' sizes (family Acanthuridae and subfamily Scarinae) showed relatively consistent trends over the sampling period, with the sizes of most harvested species exceeding the life history milestones of length at maturity and length at sex change. Sizes of harvested species were influenced by fishing effort type. Brief comparisons with prior spear fishery analyses focusing on the Northern Mariana Islands indicated that effectively evaluating the nighttime commercial coral reef spear fishery requires an understanding of fishery dynamics and implementation of a long-term monitoring program.

The status of nearshore coral reef fisheries has received increasing attention as threats to coral reef ecosystems from climate change (Pandolfi et al. 2011; Cinner et al. 2012; Doney et al. 2012), habitat loss (Graham 2014; Pratchett et al. 2014; Rogers et al. 2014), and increased fishing pressure (Friedlander et al. 2010; Brewer et al. 2013; Campbell et al. 2014) have come to the forefront internationally (Hughes et al. 2012; Rogers et al. 2015). To address these threats, jurisdictions have implemented regulations to assure sustainability and productivity. These controls include marine protected areas (Almany et al. 2009; Ban et al. 2011), gear restrictions and modifications, or both (McClanahan and Hicks 2011), implemented while attempting to minimize the impact to local economies (Johnson and Saunders 2014; Thebaud et al. 2014), all with varying degrees of success (Day and Dobbs 2013; Edgar et al. 2014). With these

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concerns for the future comes the need for effective monitoring of coral reef fisheries over the long term in order to ensure sustainability for perpetuation of ecological services and food security (McClanahan et al. 2015).

Historically, the success of coral reef fisheries monitoring programs in the U.S. central and western Pacific regions has been inconsistent due to capacity needs as well as financial and logistical support. As a result, the outer island communities of the Commonwealth of the Northern Mariana Islands (CNMI), Guam, and American Samoa have met with challenges in maintaining consistent and accurate documentation of coral reef fish landings (WPRFMC 2009a, 2009b). In the CNMI, these issues have led to difficulty in accurately assessing nearshore fisheries, subsequent misrepresentations of fishery status, or both.

The island of Saipan, the population center and governmental seat of the CNMI, serves as the center of the nearshore coral reef fishery (Figure 1). Coral reef fish landings in the CNMI are primarily from around Saipan; secondarily from Tinian, Aguijan, and Rota; and, weather permitting, occasionally from Farallon de Medinilla, Anatahan, Sarigan, Alamagan, and Pagan. Harvest methods in the fishery have changed from traditional natural-fiber nets and forged spearfishing to post-World War II use of synthetic fibers for net construction and the use of compressed air breathing (scuba/hookah) with spears, the latter of which began during the Trust Territory of the Pacific Islands period under U.S. jurisdiction (1947–1986). The use of scuba/hookah reached its peak during the mid-1990s (Graham 1994; Trianni 1998), with the CNMI banning its use since 2002. Gill-net, drag-net, and surround-net fishing was restricted in 2003 to approved government exemptions that have been principally requests from annual church-affiliated fiestas. Because of these management measures, both fishing effort and fishing mortality have changed considerably, making this fishery unique in comparison to other U.S. outer islands as well as to other Pacific Island jurisdictions.

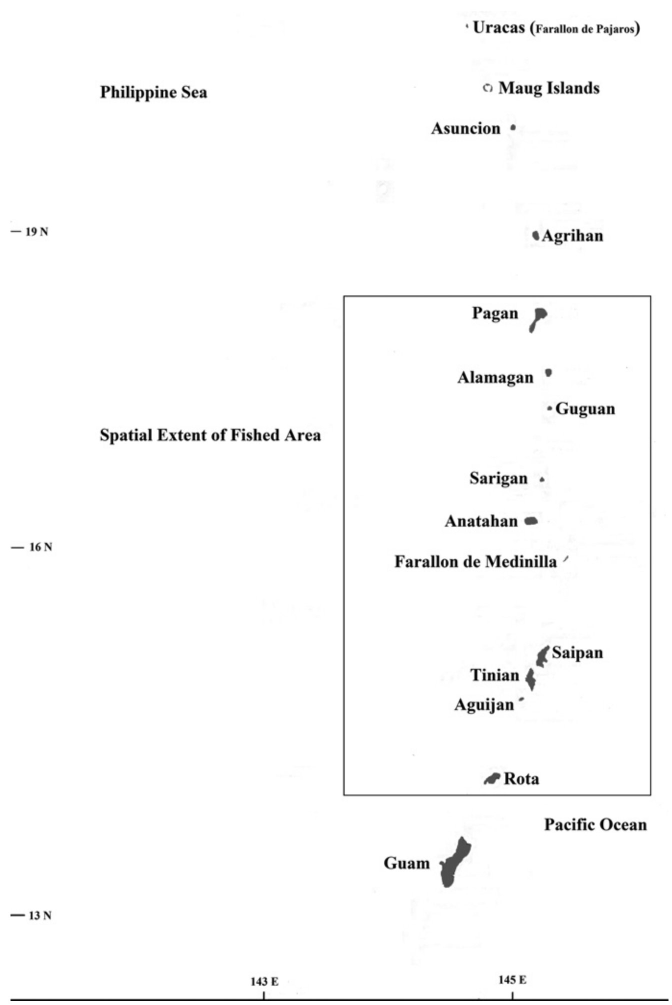

FIGURE 1. Map of the Commonwealth of the Northern Mariana Islands and Guam. Light-blue areas indicate the 100-m depth contour.

In 2009, the National Marine Fisheries Service (NMFS) Pacific Islands Fisheries Science Center (PIFSC) initiated discussions with U.S. outer island management agencies to develop plans to implement commercial coral reef fish market sampling programs based in the major population centers of the CNMI, Guam, and American Samoa. Preliminary market sampling on Saipan began in December 2010, followed by program implementation in January 2011. The NMFS PIFSC-funded biosampling program continues to collect weekly market sampling data along with a complementary, contractor-funded, daily vendor log data collection program. This paper examines data collected from the Saipan-based nighttime commercial free-dive spear fishery (hereafter, "spear fishery") from January 2011 through December 2014. This study has four objectives: (1) to examine intra-annual and interannual trends in shore- and boat-based fishery harvests; (2) to assess the influence of oceanographic conditions on spearfishing patterns; (3) to describe the reef fish composition from shore- and boat-based spear fishery landings; and (4) to evaluate length distributions of key harvested species relative to established life history benchmarks.

METHODS

The Saipan-based nighttime commercial spearfishing PIFSC-funded biosampling program sampled major commercial fish vendors on Saipan. The top-three vendors in landings volume were sampled three times per week (2 weekdays, 1 weekend day); four other vendors, some of which went out of business or started up during the 2011–2014 period, were sampled opportunistically. Sampling of nighttime coral reef fish from commercial vendors on Saipan occurred at the point of sale prior to collation of fish catches into coolers for retail sale. The sampling of catches occurred during early morning hours (0330–0630 hours) for trips made in Saipan waters or upon return of fishing boats from other CNMI islands. Samplers processed a catch directly after vendor purchase to ensure that sampled catches were unique and complete, as mixing of catches took place prior to sale at markets. If two catches were accidently combined or if somehow a partial catch came in, data were not collected. For each sampled catch, individual fish were identified to species, FL was measured to the nearest millimeter, and weight was recorded to the nearest 0.01 g using a top-loading electronic scale.

The vendor log data collection program obtained daily reports of fish purchased by vendors, typically grouped as "reef fish," even on days when a vendor did not purchase fish. The voluntary vendor log program provided estimates of total landings on a monthly basis for comparison against and assessment of sampling effort. Support for the data collected from the contractor-funded vendor log program occurred through cash stipends and improvements to vendor facilities, keeping vendors informed of changing federal and local fishing rules, helping vendors sort catches, and collating fish in morning hours for subsequent retail sale.

Data were partitioned three ways: spatially by island and island aspect; temporally by month and year; and by trip type (i.e., fishing done while swimming from shore or from a boat). Analyses within those partitions were performed for fishing effort and reef fish landings composition, number and weight of family/subfamily, and species dominance.

The influence of moon phase on reported vendor log landings was examined based on daily lunar illumination, aggregated over the 4-year period, and tested by categorizing the reported landings into high (gibbous–full) or low (crescent–new) periods of lunar illumination. One-thousand samples were drawn with replacement from each illumination category as described, and the mean difference between the illumination categories was calculated for each draw; mean differences were compared to the original difference between the two categories, recording how many of the randomized mean differences exceeded the original. The percentage of excesses provided an estimate of the significance of the original difference.

The length frequencies of the dominant Acanthuridae and Scarinae in biosampling catches were examined against life history milestone parameters: length of females and males at maturity (L_{50}); and, for hermaphroditic species, length at transition (L_T) from female to male. Life history milestone parameters were obtained from either the Mariana Archipelago or the Federated States of Micronesia (CNMI DFW 2006; Taylor and Choat 2014; Taylor et al. 2014).

The influence of two environmental variables—average daily wind speed and average daily wave height—were correlated against daily reported vendor log landings (kg) by using Pearson's product-moment correlation analyses. Canonical correspondence analysis (CCA) is a multivariate method that elucidates relationships between species assemblages and sites with selected environmental variables, where CCA axes are constrained to be linear combinations of those variables. An extension of correspondence analysis, CCA results depict triplots that are biplots of CA species and site scores, with the additional environmental variables plotted as directional lines of increasing magnitude. We applied CCA to find associations of the top-25 species landed monthly in the nighttime commercial spear fishery (NCSF) with monthly averages for wind speed and wave height. Significance of constrained axes and model terms (environmental variables) were subsequently evaluated using permutation tests. The R package "vegan" was used for CCA (Oksanen et al. 2011). Oceanographic data were obtained from the National Weather Service (National Oceanic and Atmospheric Administration).

Examination of landings from daily vendor log data used the weight of fish purchased as provided by vendors. Derivation of the CPUE per fishing trip (CPUE_T) followed the formula

$$\mathrm{CPUE}_T = \frac{(\text{reported weight, kg})}{(\text{number of hours fished})(\text{number of fishers})},$$

and average monthly CPUE was calculated as

$$\mathrm{CPUE}_M = \frac{\sum_{i=1}^{n} \mathrm{CPUE}_T}{n},$$

where n equals the number of completed vendor logs submitted per month. The CPUE was also calculated monthly by trip type for the 4-year period by island aspect (east, west, north, and south) and by moon phase.

RESULTS

Of the 10,554 NCSF trips documented from vendor logs, swimming from shore and fishing (shore-based) accounted for 87% of the trips, while fishing from a boat (boat-based) accounted for 13%. There were 2,143 NCSF trips sampled; of the boat-based trips, 66% were from Saipan and 25% were from Tinian–Aguijan, followed by Rota and the Northern Islands (Table 1), while all shore-based trips were from Saipan. During the summer months, the number of boat-based trips per month increased up to 30%, coincident with periods of generally calmer seas and greater access to windward and distant fishing grounds.

TABLE 1. Total number of boat-based trips from 2011 to 2014 and the number sampled by the Commonwealth of the Northern Mariana Islands biosampling program.

Location	Number of trips	Number sampled
Aguijan	57	17
Alamagan	2	1
Anatahan	3	0
Farallon de Medinilla	21	0
Pagan	1	1
Rota	72	5
Saipan	808	195
Sarigan	13	6
Tinian	245	63

Landings and CPUE

Monthly reported Saipan NCSF landings (kg) are shown in Figure 2. Shore-based landings dominated the 4-year period, although reported landings per month for boat-based trips equaled or exceeded shore-based landings during annual calm-weather periods, primarily from May to September. The average reported monthly landings for shore-based trips were about 2,400 kg, compared to the boat-based average of about 1,300 kg. Over 77% of landings from Saipan were from the leeward aspect of the island, followed by the windward (eastern) and southern aspects.

The mean fisher catch per month (MFCM) was considerably greater for boat-based trips compared to shore-based trips, although shore-based trips drove the total MFCM, as evidenced by the close proximity of the shore-based time series to that of the total (Figure 3). Boat-based MFCM tended to decline during the winter months and to increase during the summer.

Variability in CPUE was greater in boat-based trips, with average combined CPUE driven by shore-based trips (Figure 4). Boat-based CPUE tended to exceed shore-based CPUE during the summer months. Over the 4-year period, the average CPUE was 2.40 kg/man-hour (SD = 0.16) for boat-based trips and 2.13 kg/man-hour (SD = 0.10) for shore-based trips. As with monthly landings and MFCM, shore-based trips drove CPUE, with boat-based trips generally tending to be greater during spring and summer months; the exception was in 2013, when boat-based CPUE exceeded shore-based CPUE during February–April.

Composition of Sampled Landings

In total, 171 species were identified in the Saipan-based NCSF from market sampling, with five groups dominating landings by number and weight: Acanthuridae, Lethrinidae, Mullidae, Scarinae, and Siganidae (Table 2). These groups accounted for 83–85% of the sampled catches by number and 83–86% by weight. Acanthuridae constituted the greatest percentage by number and weight for all 4 years, although by weight Scarinae were nearly equal to Acanthuridae in 2013 and 2014 (Table 3). Differences in the percentages of reef fishes sampled varied by trip type. Acanthuridae dominated shore-based trips by weight and number of fish sampled, except in 2014, when Mullidae landings by number were greater and Siganidae landings by number were nearly equal (Table 3). Acanthuridae also dominated boat-based trips numerically, but Scarinae comprised a greater percentage of landings by weight for all years (Table 3). The decrease in Acanthuridae during 2014 was due to an unresolved die-off of a primary target species, the Clown Surgeonfish *Acanthurus lineatus*, which resulted in a public warning regarding consumption. Subsequently, vendors were not purchasing fish (Villahermosa 2014). Three acanthurid species (Clown Surgeonfish, Masked Unicornfish *Naso lituratus*, and Bluespine Unicornfish *N. unicornis*) accounted for 73–97% of boat-based landings and 81–91% of shore-based landings by number; these species accounted for 74–94% of boat-based landings and 82–92% of shore-based landings by weight. Of the top-six acanthurids landed during the 2011–2014 period, Clown Surgeonfish and Masked Unicornfish dominated the catch by number, while Bluespine Unicornfish dominated by weight. As previously noted, Clown Surgeonfish declined considerably in 2014, and the Epaulette Surgeonfish *A. nigricauda* was represented primarily in boat-based trips. The top-10 species of Scarinae landed in the fishery displayed notable differences with respect to boat- and shore-based fishing activity. Three species (Bicolor Parrotfish *Scarus rubroviolaceus* [known locally as Redlip Parrotfish], Steephead Parrotfish *Chlorurus microrhinos*, and in most years, Daisy Parrotfish *Chlorurus spilurus*) were primarily landed by boat-based fishing activity in terms of weight and number (Figure 5). Conversely, four species (Bluechin Parrotfish *Scarus ghobban*, Marbled Parrotfish *Leptoscarus vaigiensis*, Pacific Longnose Parrotfish *Hipposcarus longiceps*, and Stareye Parrotfish *Calotomus carolinus*) were representative of shore-based landings. Differences in the percentage of sampled Scarinae by weight and number from boat- and shore-based fishing activity illustrate the greater frequency of boat-based activity during later spring through summer months, when weather conditions in the Marianas are more conducive to harvesting in windward island aspects.

Acanthuridae represented smaller overall percentages of total landings by number and weight from the west aspect in comparison to the other aspects (Figure 6). Numerically, fishes belonging to Scarinae were comparable among aspects, although they comprised a greater percentage by weight from the east aspect. The west aspect yielded greater percentages of Mullidae, Siganidae, and Lethrinidae, while the south aspect brought in greater percentages of Holocentridae.

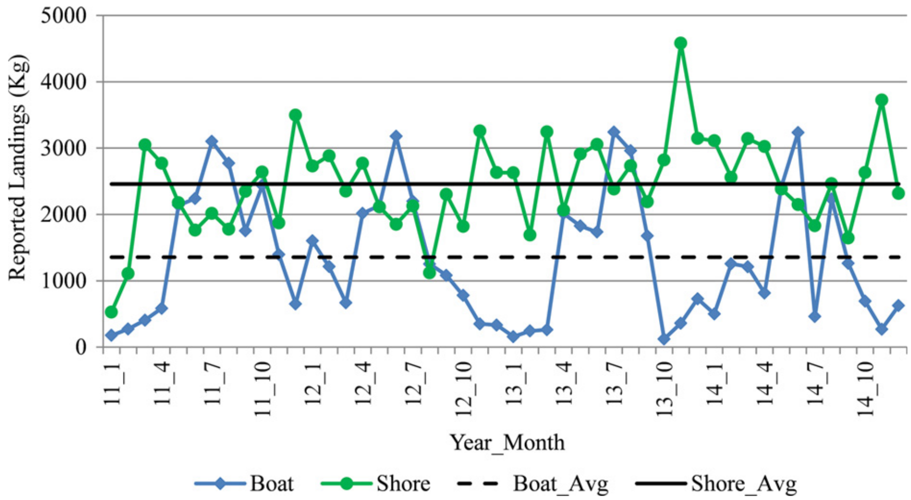

FIGURE 2. Reported landings (kg) of nighttime spear-caught coral reef fish landed on Saipan from 2011 to 2014 by fishing activity type.

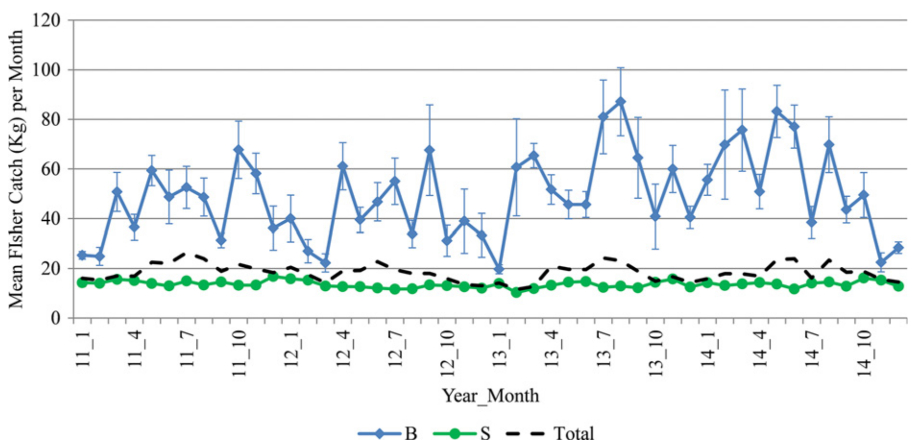

FIGURE 3. Mean fisher catch (kg) per month from reported landings of nighttime spear-caught coral reef fish landed on Saipan from 2011 to 2014 by fishing activity type (B = boat based; S = shore based).

Size

Figures 7 and 8 list the average FLs of the top species in the two dominant groups landed from shore- and boat-based fishing: the Scarinae and Acanthuridae. Available specific lengths at maturity (L_{50}) by sex (L_{M50} for males; L_{F50} for females) were provided for the Acanthuridae (Taylor et al. 2014), with additional available lengths at transition (L_T) for the hermaphroditic Scarinae (Taylor and Choat 2014). Fork lengths of most species of Scarinae were generally above L_{50} for the 4-year period, with the exception of shore-based landings of Pacific Longnose Parrotfish, while an L_{50} was not available for Bluechin Parrotfish. The following species remained above L_T for the 2011–2014 period: Stareye Parrotfish, Daisy Parrotfish, Common Parrotfish *Scarus psittacus*, and boat-based landings of Bicolor Parrotfish. The time series of average monthly FLs for Masked Unicornfish remained above both L_{F50} and L_{M50} during 2011–2014, while Bluespine Unicornfish remained generally above for boat-based trips. Time series FL data remained above L_{F50} for Clown Surgeonfish; an L_{M50} estimate was not available. In general, fish that were landed during boat-based trips were larger than those landed during shore-based trips.

Environmental Factors

Average daily wind speed and average daily wave height for the period 2011–2014 were moderately correlated ($r = 0.31$), with correlation weakest during the calm-weather months from May to September ($r = 0.01$). Pearson's product-moment correlation analysis showed a negative correlation between daily kilograms landed and average daily wave height ($r = -0.16$; $P = 0.000$) and wind speed ($r = -0.28$; $P = 0.000$; Table 4).

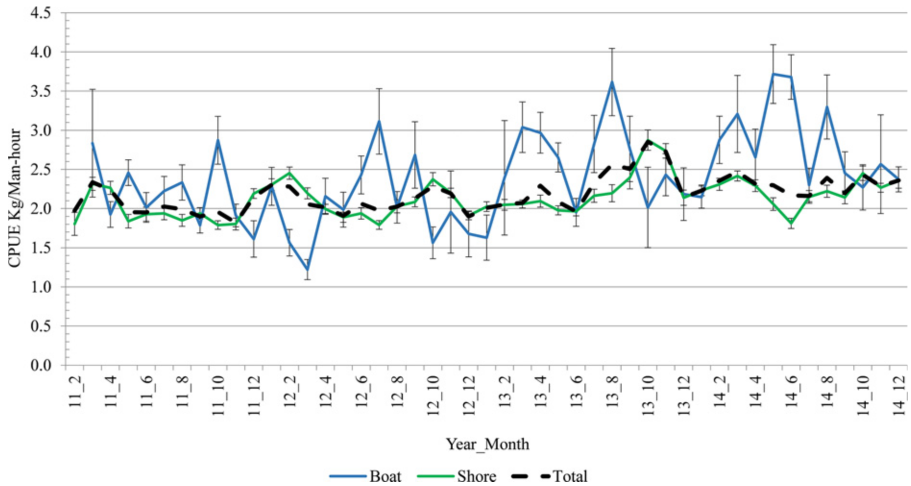

FIGURE 4. Mean CPUE (kg/man-hour) per month from nighttime spear-caught coral reef fish landed on Saipan from 2011 to 2014 by fishing activity type.

TABLE 2. Sampled landings (by weight and number) of the dominant groups from the Saipan-based nighttime commercial spear fishery, 2011–2014.

	Annual landings by weight (kg)					Annual landings by number				
Group	2011	2012	2013	2014	Total	2011	2012	2013	2014	Total
Acanthuridae	3,266	2,307	3,568	2,416	11,557	12,957	10,509	14,306	10,906	48,678
Scarinae	2,690	1,646	3,243	2,305	9,884	5,643	3,881	7,033	7,179	23,736
Mullidae	719	657	870	1,074	3,319	4,610	5,220	6,125	7,961	23,916
Siganidae	729	536	976	1,050	3,292	3,571	4,014	7,505	7,576	22,666
Lethrinidae	806	636	907	712	3,061	2,656	2,437	3,327	3,229	11,649
Holocentridae	416	241	434	364	1,455	2,818	1,780	2,981	2,683	10,262
Kyphosidae	316	195	527	209	1,247	504	344	932	392	2,172
Labridae	231	209	336	273	1,048	636	744	765	1,007	3,152
Serranidae	290	174	290	126	880	895	644	733	435	2,707
Carangidae	99	92	176	75	442	183	204	299	129	815
Lutjanidae	71	43	82	65	261	198	178	270	238	884
Priacanthidae	84	91	68	30	272	358	514	361	175	1,408
Caesionidae	32	20	17	12	80	179	106	97	68	450
Mugilidae	28	22	23	32	105	59	47	41	71	218
Other (16 families)	11	9	19	41	80	23	34	47	356	460

Results from CCA showed the explained inertia (eigenvalue sum of constrained axes) from environmental variables was 18% for the top-25 species model by weight and 16% for the model by number. Of the accumulated constrained eigenvalues from both models, over 80% was attributable to the first constrained axis. Average daily wind speed was the strongest environmental correlate, with the permutation tests identifying the first axis as being highly significant ($P = 0.001$ for both models). Species-scaled triplots from both CCA models showed that of the top-25 species (Table 5) landed in the NCSF, the Little Spinefoot *Siganus spinus* and Marbled Parrotfish showed the strongest correlations with increasing wind speed for both models, followed by Bluechin Parrotfish, Orange-striped Emperor *Lethrinus obsoletus*, and Yellowstripe Goatfish *Mulloidichthys flavolineatus* (Figures 9 and 10). Several species were most strongly correlated with decreasing wind speed and wave height, including the Bicolor Parrotfish, Blue Sea Chub *Kyphosus cinerascens*, and Brassy Chub *K. vaigiensis*, followed by the Clown Surgeonfish and Bigeye Barenose *Monotaxis grandoculis*. Species correlated with the second constrained axis in both CCA models in the direction of increasing wave height were the Epaulette Surgeonfish and Daisy Parrotfish. The

TABLE 3. Yearly percentages of the five primary coral reef fish families landed in the Saipan nighttime commercial spear fishery (BB = boat-based fishing effort; SB = shore-based fishing effort).

		Number			Weight		
Family	Year	BB	SB	Total	BB	SB	Total
Acanthuridae	2011	32.9	37.9	36.0	28.0	36.0	33.4
	2012	45.4	33.6	34.3	28.0	34.0	33.5
	2013	38.1	29.2	31.9	31.0	31.0	30.9
	2014	30.8	21.8	25.3	27.0	26.0	27.0
Lethrinidae	2011	9.3	7.0	7.5	10.0	7.0	8.2
	2012	6.2	8.1	8.0	10.0	9.0	9.2
	2013	6.4	7.9	7.4	6.0	10.0	7.9
	2014	7.2	7.7	7.5	7.0	8.0	8.0
Mullidae	2011	5.5	15.4	13.1	3.0	10.0	7.3
	2012	1.7	18.0	17.0	1.0	11.0	9.6
	2013	5.0	17.4	13.7	3.0	12.0	7.5
	2014	10.1	23.3	18.4	8.0	15.0	12.0
Scarinae	2011	25.2	13.2	16.0	38.0	22.0	27.5
	2012	21.9	12.1	12.7	42.0	21.0	23.9
	2013	23.9	12.1	15.7	37.0	20.0	28.1
	2014	22.4	13.4	16.6	32.0	21.0	26.0
Siganidae	2011	12.7	9.3	10.1	7.0	8.0	7.5
	2012	10.9	13.2	13.1	6.0	8.0	7.8
	2013	9.0	20.2	16.7	4.0	12.0	8.5
	2014	12.4	20.6	17.5	9.0	14.0	12.0

correlation of sites and year_month in both CCA model triplots showed seasonal trends in which landings during fall, winter, and spring months were generally associated with increasing wind speed and wave height. Landings during the summer months were generally associated with decreasing trends in the environmental variables.

Aggregated landings for 2011–2014 showed declines in average and total landings for both sampled and reported weights around the full moon period (Figure 11). Randomization testing of reported NCSF trip landings per illumination category was found to be not significant ($P = 0.152$; high illumination: $n = 5{,}325$; low illumination: $n = 5{,}229$).

DISCUSSION

The Saipan NCSF is active primarily around the island of Saipan, the center of the CNMI population (CNMI DOC 2010), and is active to a lesser extent around Tinian. Forays to outer islands, such as Rota and the CNMI Northern Islands, require calm-weather conditions and are therefore infrequent. Fishing trips to the sparsely populated far-north islands, such as Pagan and Alamagan (CNMI DOC 2010), primarily target distinctly different species assemblages, such as deepwater bottom fish, with fishing effort for coral reef species being secondary. Traveling 160.9 km (100 mi) or more from Saipan on fishing trips demands an economic profit that free-dive spearfishing for coral reef species generally cannot provide on its own. Oceanographic conditions, such as wind speed and wave height, also play a role in the spatial extent of Saipan NCSF trips. Therefore, economic and oceanographic factors overwhelmingly restrict commercial coral reef fish harvest to the islands of Saipan, Tinian, Aguijan, and Rota.

As observed from summary and analysis of the 4-year time series, shore-based fishing drives the Saipan NCSF, evidenced comparatively by the number of trips, monthly landings, and CPUE. The effort exhibited by boat-based fishing increases notably during the summer months, when calmer weather generally prevails. This shift in the effort characteristic of the fishery, in turn, alters other fishery components, such as composition of landings as boat-based effort tends to target different families/subfamilies and species within families/subfamilies than shore-based effort.

Like previous coral reef fish NCSF surveys on Saipan (Graham 1994; Trianni 1998; Houk et al. 2012), the current study showed that Acanthuridae and Scarinae dominated sampled landings by weight. The dominance of Acanthuridae in Saipan NCSF catches from this study by weight (27–33%) corresponded to previous

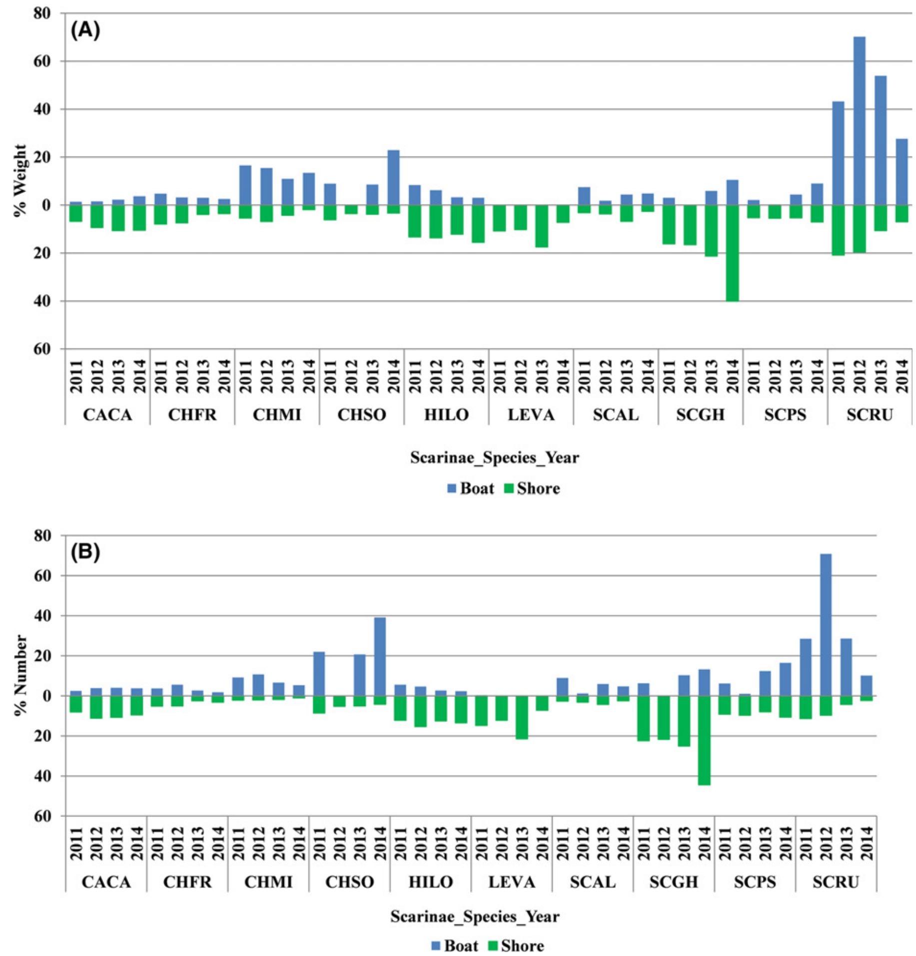

FIGURE 5. Percent composition of the top-10 species from the subfamily Scarinae (species codes are defined in Table 5) sampled from nighttime commercial spear fishery landings on Saipan from 2011 to 2014, comparing shore- and boat-based fishing activity by **(A)** weight and **(B)** number.

NCSF sampling by Graham (1994; 43% by weight) and Trianni (1998; 41% by weight). For Scarinae, the percent landings by weight were 22–28% for the 2011–2014 period; 20% from Graham (1994); and 15% from Trianni (1998). In contrast, Houk et al. (2012) reported percent landings by weight as 38% for Scarinae and 33% for Acanthuridae. Houk et al. (2012) sampled primarily from June to September and over 2 weeks from December to January. The discrepancy is attributable to the primary period in which Houk et al. (2012) sampled on Saipan (i.e., June–September). The 2011–2014 sampling period showed boat-based fishing to be most active during the summer months, with greater percentages of scarines landed. The constricted sampling period conducted by Houk et al. (2012) further illustrated the seasonal shift from shore-based to boat-based fishing by reporting that the Bicolor Parrotfish was the most frequently sampled scarine, totaling 15% by weight of all landings. In this study, landings of Bicolor Parrotfish from the shore-based effort accounted for 3% of total landings by weight compared to 16% from boat-based effort.

The changes in the top species resulting from shore- and boat-based fishing effort reflect the differences between leeward and windward habitats on Saipan as well as habitats on other islands. Saipan Lagoon is the prominent habitat on the leeward aspect of Saipan, dominated by soft sediments but also supporting seagrass and coral habitats. Shore-based fishing is conducted predominantly on leeward aspects, where entry into the water occurs by walking off a beach. Conversely, habitats on the windward aspect of Saipan are defined by steep, heterogeneous structures overlain with greater wave heights. They are generally susceptible to greater wind speeds than leeward aspects, with less-accessible points of entry.

These habitat characteristics showed in the greater percentages of Mullidae and Siganidae in shore-based trips, groups that are more readily harvestable in Saipan Lagoon. Scarinae species showed considerable differences in landings between the trip types: one example is the

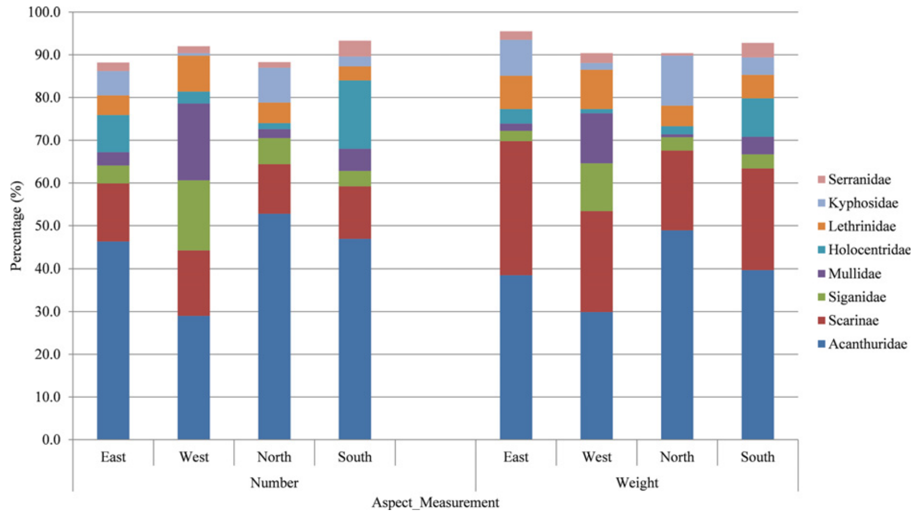

FIGURE 6. Percent composition of the eight most dominant groups sampled from nighttime commercial spear fishery landings (by weight and number) on Saipan from 2011 to 2014, comparing island aspect.

Marbled Parrotfish, which is found in shallow seagrass habitats and is nearly exclusively landed from shore-based trips. Greater percentages of Scarinae sampled from boat-based trips—notably the Bicolor Parrotfish, which favors steep, heterogeneous habitat typical of exposed island aspects—demonstrated effort-based influences on the composition of landings.

These compositional differences show that the Saipan NCSF includes essentially two distinct fisheries, boat based and shore based, that harvest different species assemblages. The relative aspect of where fishing occurs also supports the separate targeting of boat- and shore-based effort. Landings from south, north, and east island aspects were more similar in family/subfamily composition by number and weight compared to west aspect landings. Evaluating the NCSF, therefore, requires recognition of this bipartite characteristic of the fishery for accurately assessing fishery targets.

Abiotic factors had varying influences on fishery CPUEs and landings. Rhodes and Tupper (2007) reported that low lunar illumination resulted in a significantly greater volume of reef fish purchased in Pohnpei. For data collected from a Saipan-based hookah spear fishery, Graham (1994) found that CPUE was positively correlated with periods of lower lunar illumination. In a multiple regression analysis, Houk et al. (2012) determined that periods of low lunar illumination had a significant positive effect on landings in the Saipan-based NCSF. This study showed decreased total landings during high lunar illumination, specifically around the full moon. In comparison to total landings, declines in average landings were even more restricted, specifically to days on and around the full moon. Although declines in landings were apparent around the full moon, the lack of a difference between the aggregated periods of high and low lunar illumination indicated that Saipan commercial fishers continued to work regardless of the lunar period. From a fishery operational standpoint, these findings were not surprising given the oceanographic conditions that typify the Mariana Archipelago. During most of the year, trade winds emanate from east–northeast, decreasing access to the northern and eastern aspects of Saipan and other CNMI islands. Given this prevailing pattern of weather, fishing would occur more frequently on leeward island aspects. With limited spatial fishing grounds during such conditions, fishers would tend to be less likely to limit effort during lunar illumination phases in order to maintain income levels.

The life history milestones for size at maturity and size at transition tracked over the 4-year study period showed that, in general, fish caught during boat-based trips were larger than those caught during shore-based trips, as boat-based trips were able to access the weather-limited fishing grounds where larger fish of a given species tend to be found. Of the species for which size was evaluated against L_{50}, Pacific Longnose Parrotfish and Bluespine Unicornfish were generally smaller than L_{50}, mostly with respect to $L_{\mathrm{F}50}$ in the latter species. For both species, the fish that were smaller than L_{50} were primarily landed from shore-based fishing effort. Recent studies have used L_{50} as a measure to use in management (McClanahan and Hicks 2011; Clements et al. 2012; Bejarano et al. 2013), and others have suggested incorporating the additional measure of size at transition (L_T) for hermaphroditic species (Alonzo and Mangel 2004; Carter et al. 2014; Taylor 2014). The estimation of L_{50} and L_T is important in the

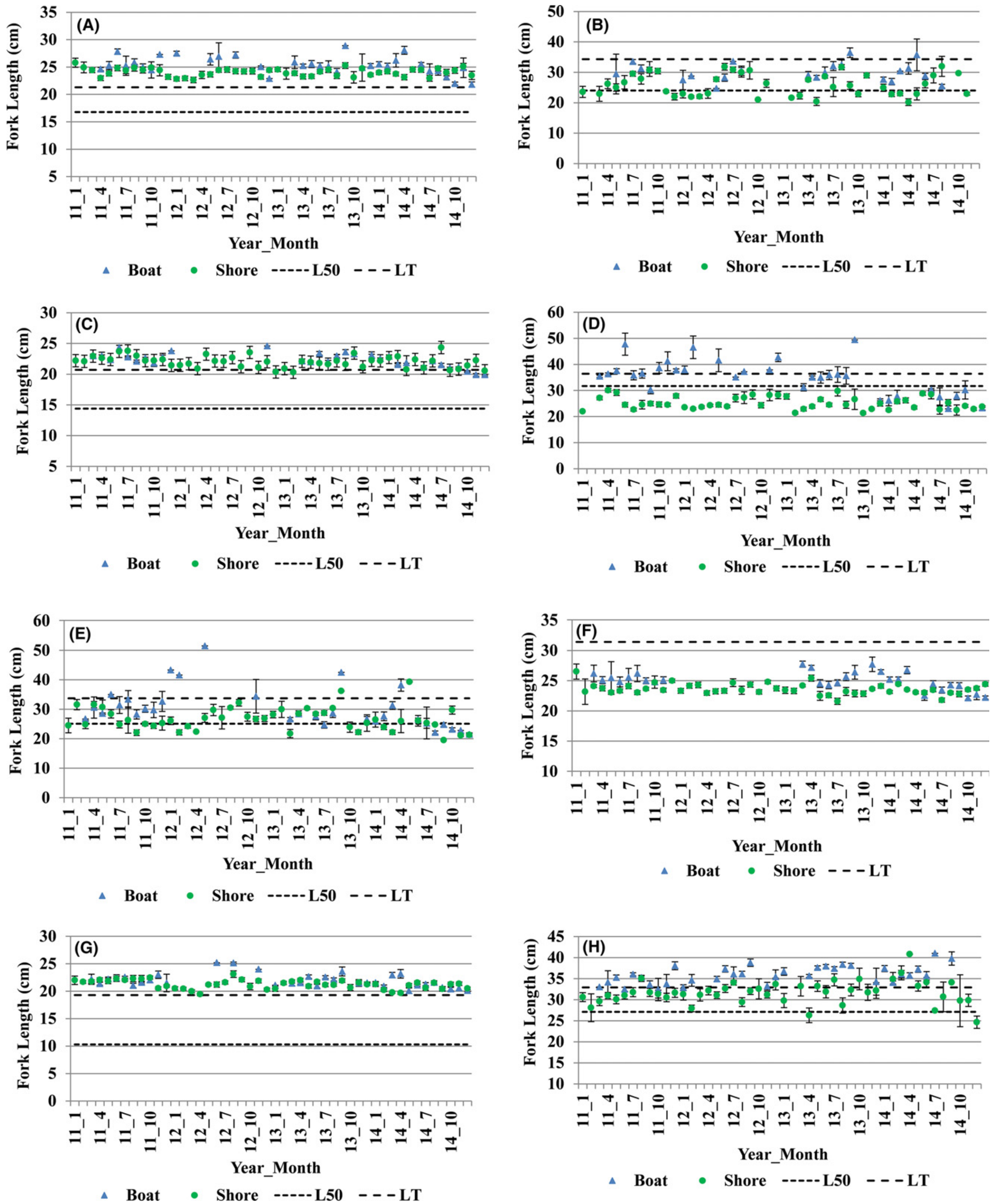

FIGURE 7. Length at female maturity (L_{50}) and size at transition (L_T) versus average monthly length for the dominant parrotfish species landed in the nighttime commercial spear fishery on Saipan from 2011 to 2014: **(A)** Stareye Parrotfish *Calotomus carolinus*; **(B)** Pacific Slopehead Parrotfish *Chlorurus frontalis*; **(C)** Daisy Parrotfish *Chlorurus spilurus*; **(D)** Pacific Longnose Parrotfish *Hipposcarus longiceps*; **(E)** Filament-finned Parrotfish *Scarus altipinnis*; **(F)** Bluechin Parrotfish *S. ghobban*; **(G)** Common Parrotfish *S. psittacus*; and **(H)** Bicolor Parrotfish *S. rubroviolaceus*.

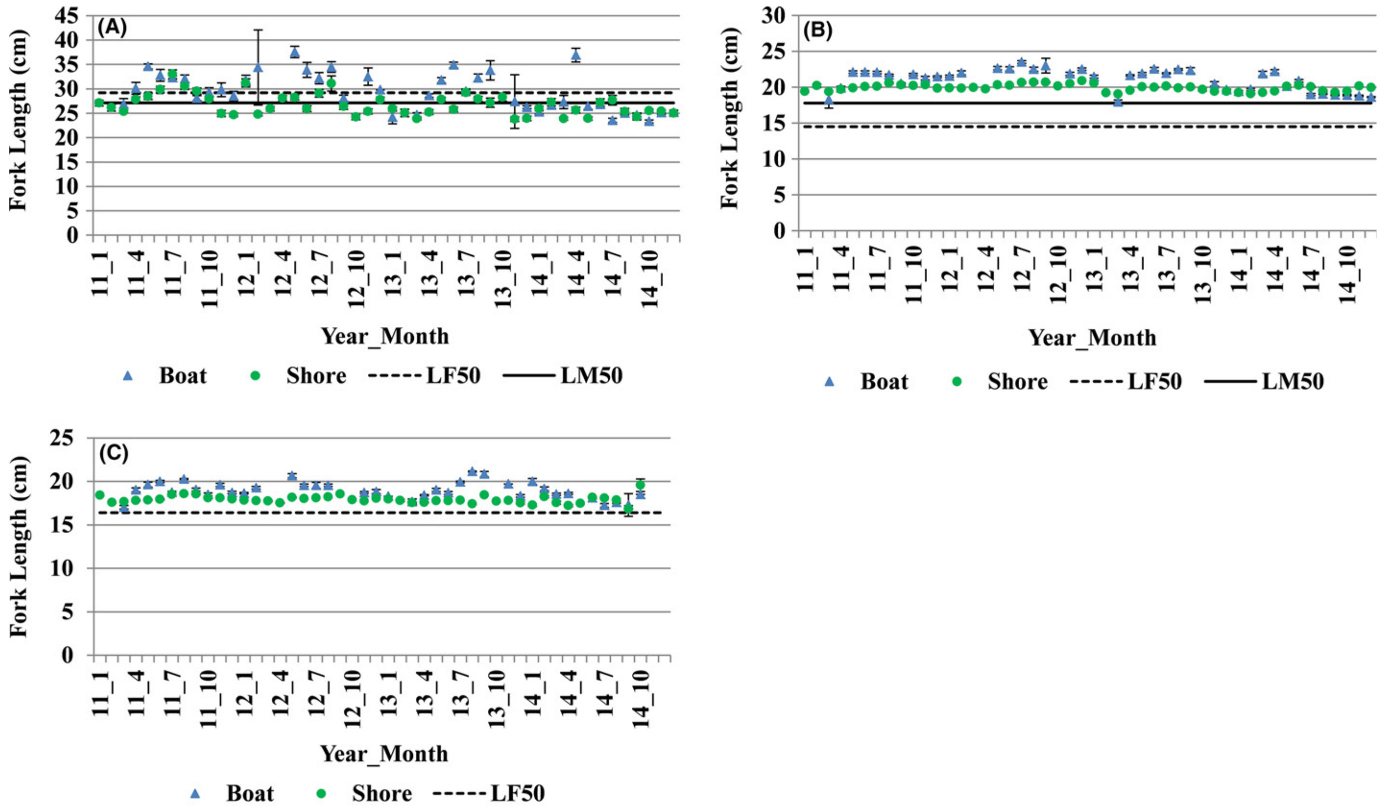

FIGURE 8. Length at female maturity (L_{F50}) and length at male maturity (L_{M50}) versus average monthly length for the dominant Acanthuridae species landed in the nighttime commercial spear fishery on Saipan from 2011 to 2014: **(A)** Bluespine Unicornfish *Naso unicornis*; **(B)** Masked Unicornfish *N. lituratus*; and **(C)** Clown Surgeonfish *Acanthurus lineatus*.

TABLE 4. Pearson's product-moment correlation results for daily comparisons of the weight (kg) of reef fish landed from commercial nighttime free-dive spearfishing and estimates of wave height and wind speed for Saipan (95% CI = 95% confidence interval for the correlation coefficient *r*).

Variable	*t*	df	*P*	*r*	95% CI
Wave height	−6.31	1,427	0.000	−0.16	−0.21 to −0.11
Wind speed	−11.14	1,427	0.000	−0.28	−0.33 to −0.23

tracking of size over time as well as in stock assessments (Alonzo et al. 2008). However, those parameters alone cannot provide a clear indication of fishery status. As shown in these analyses, considerable variability existed in landings, depending upon whether harvest was shore based or boat based. Tracking size over time against L_{50} and L_T in the Scarinae and Acanthuridae indicated that smaller fish came from shore-based fishing effort, reflecting the spatially restricted nature of the fishery. On Guam, Marshall et al. (2011) found that larger Bluespine Unicornfish on reef flats had home ranges that extended into deeper outer-reef slope areas, suggesting a probable ontogenic shift in habitat preference for that species. Linfield et al. (2014) reported larger individuals of acanthurid and scarine species on deep reef areas (depth ≥ 30 m) in CNMI (Saipan and Tinian), where the use of scuba-spearfishing has been banned, in comparison with Guam, where scuba-spearfishing is allowed. Linfield et al. (2014) concluded that depth refugia created by the ban on scuba-spearfishing resulted in larger individual acanthurids and scarines at depths not accessible by spearfishing without scuba. It is therefore important to consider species-specific size differences between shore- and boat-based fishing effort when evaluating species statuses.

The variability in MFCM and mean monthly CPUE from reported landings demonstrates the temporal influence of shore-based effort in comparison to the corresponding mean totals. These results show that shore-based fishing, which occurs primarily on the leeward aspect of Saipan, drives this fishery. For effectively tracking changes over time, future monitoring of this fishery needs to ensure a statistically robust sampling effort, and appropriate

TABLE 5. List of the top-25 species landed from the commercial nighttime free-dive spear fishery, with species codes used in Figures 9 and 10, which present the results of canonical correspondence analysis.

Species name	Code	Species name	Code
Clown Surgeonfish *Acanthurus lineatus*	ACLI	Bigeye Barenose *Monotaxis grandoculis*	MOGR
Epaulette Surgeonfish *Acanthurus nigricauda*	ACNI	Yellowstripe Goatfish *Mulloidichthys flavolineatus*	MUFL
Stareye Parrotfish *Calotomus carolinus*	CACA	Yellowfin Goatfish *Mulloidichthys vanicolensis*	MUVA
Tripletail Wrasse *Cheilinus trilobatus*	CHTR	Masked Unicornfish *Naso lituratus*	NALI
Steephead Parrotfish *Chlorurus microrhinos*	CHMI	Bluespine Unicornfish *N. unicornis*	NAUN
Pacific Slopehead Parrotfish *Chlorurus frontalis*	CHFR	Dash-and-dot Goatfish *Parupeneus barberinus*	PABA
Daisy Parrotfish *Chlorurus spilurus*	CHSO	Filament-finned Parrotfish *Scarus altipinnis*	SCAL
Pacific Longnose Parrotfish *Hipposcarus longiceps*	HILO	Bluechin Parrotfish *Scarus ghobban*	SCGH
Blue Sea Chub *Kyphosus cinerascens*	KYCI	Common Parrotfish *Scarus psittacus*	SCPS
Brassy Chub *K. vaigiensis*	KYVA	Bicolor Parrotfish *Scarus rubroviolaceus*	SCRU
Marbled Parrotfish *Leptoscarus vaigiensis*	LEVA	Roman-nose Spinefoot *Siganus argenteus*	SIAG
Pacific Yellowtail Emperor *Lethrinus atkinsoni*	LEAT	Goldspotted Spinefoot *Siganus punctatus*	SIPU
Orange-striped Emperor *Lethrinus obsoletus*	LEOB	Little Spinefoot *Siganus spinus*	SISP

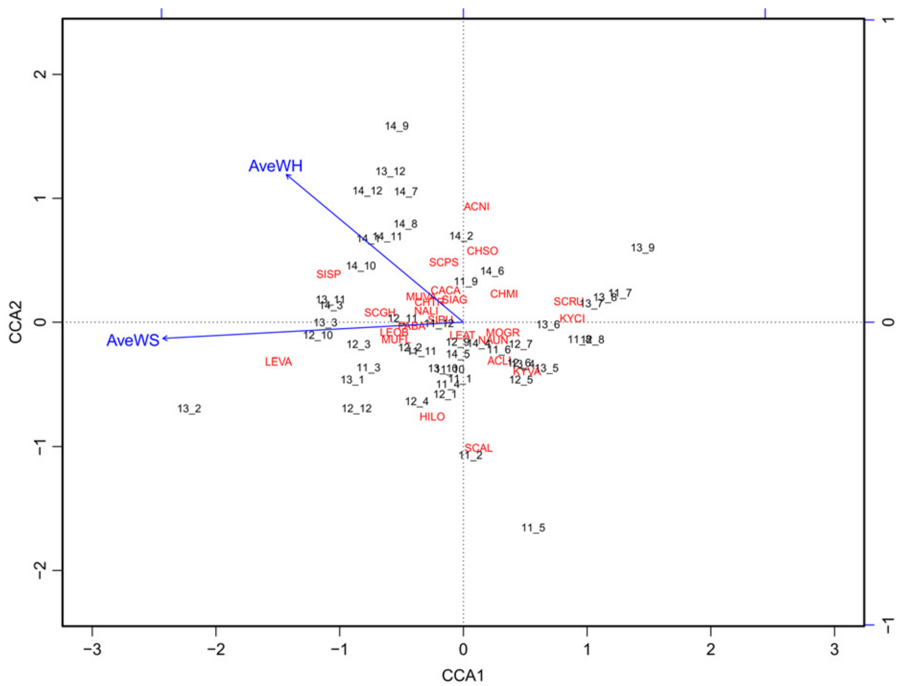

FIGURE 9. Canonical correspondence analysis triplot of the 25 most common species (species codes are defined in Table 5) landed by weight on Saipan from the nighttime coral reef spear fishery, with sites as year_month and monthly averages of environmental variables for average wind speed (AveWS) and average wave height (AveWH).

tracking of shore-based landings will enable detection of significant fishery changes.

The CNMI biosampling program sets the standard for future monitoring of the Saipan NCSF. The analysis reported here contradicts a recent attempt to describe the Saipan NCSF, as the sampling protocols used by that study (Houk et al. 2012) did not capture the effort structure of the fishery and led to results that indicated a biased sampling effort toward the sampling of boat-based trips. Although Houk et al. (2012) claimed that their data supported "anecdotal information that illegal scuba supplied the majority of marketed fish," this claim was unsubstantiated. There was no evidence of illegal scuba-spearfishing during the period of this study (2011–2014), and given the results provided here, the assertion by Houk et al. (2012) that scuba-spearfishing supplies the majority of marketed fish on Saipan cannot be considered valid. This raises an important if not critical issue regarding

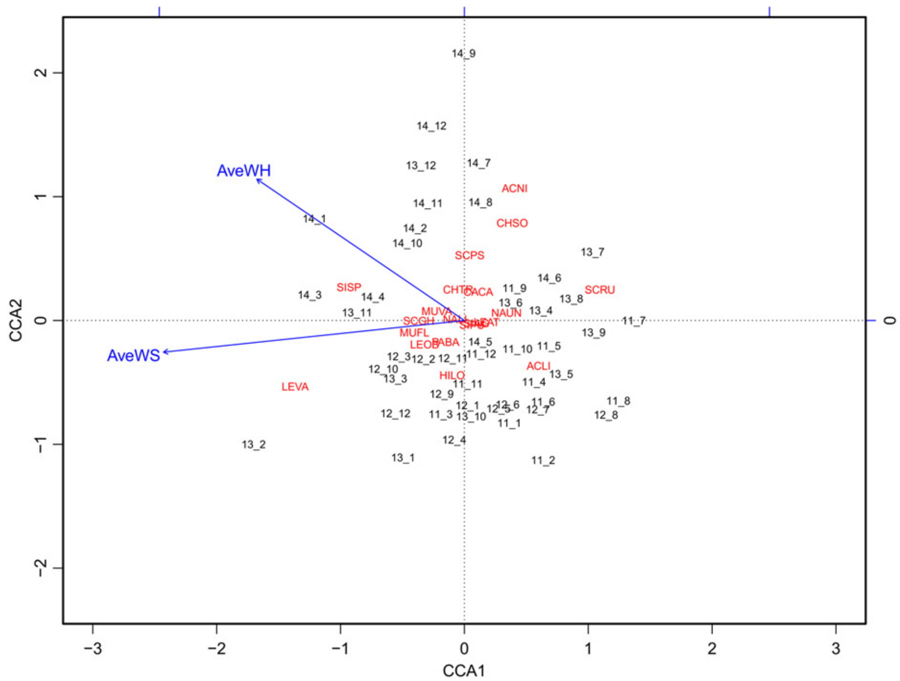

FIGURE 10. Canonical correspondence analysis triplot of the 25 most common species (species codes are defined in Table 5) landed by number on Saipan from the nighttime coral reef spear fishery, with sites as year_month and monthly averages of environmental variables for average wind speed (AveWS) and average wave height (AveWH).

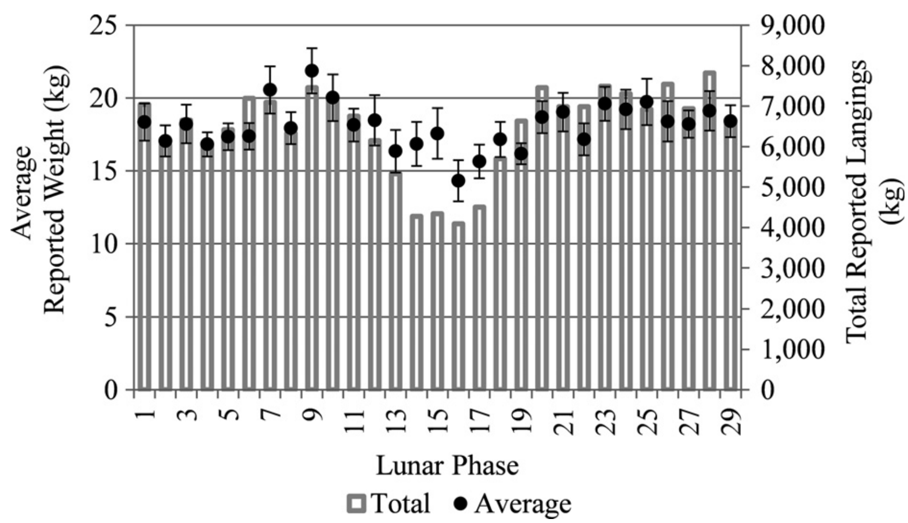

FIGURE 11. Average (±SE) sampled and reported weights (kg) of coral reef fish landed by the nighttime commercial spear fishery on Saipan from 2011 to 2014 against lunar phase.

coral reef fisheries studies: specifically, the recommendation of management measures based on conclusions derived from the analysis of data sets that are limited by any combination of spatial, temporal, or sampling design deficiencies. Objective recognition and subsequent declaration of such deficits would contribute to the application of appropriate rigor in future research, which would in turn strengthen management implementation.

The degree of detail available from the CNMI biosampling database provides a unique opportunity to track and observe a variety of fishery and species metrics over time. This database will provide a solid foundation for future coral reef fish status assessments in the CNMI and will give managers an exceptional source of detailed fishery information that will be useful in implementing science-based management decisions. Similarly detailed fishery data collection programs would enhance coral reef fish assessments and management in the western Pacific region.

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