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Research Article

Management of a Marine Park: analysis of recreational and illegal fishing pressures on the reef fish assemblage at Los Arcos Reserve in Jalisco, Mexico

Kirsten Stokes[1], Kelly Scammon[2], Darian Double[3], Katie Toon[4], Shelli Hendricks[5], Aldo Alfonso Zavala Jimenez[6], Karla De La Pena[7] and Katherine Comer Santos [8*]

[1]*Kirsten Stokes Orlando County Public School District, 445 W. Amelia St., Orlando, FL 32801*
[2]*Kelly Scammon Roger Williams University, One Old Ferry Road, Bristol, RI 02809*
[3]*Darian Double Ross School of Business, 701 Tappan Street, Ann Arbor, MI 48109*
[4]*Katie Toon Pitzer College, 1050 N. Mills Avenue, Claremont, CA 91711*
[5]*Shelli Hendricks Fielding Graduate University School of Leadership Studies, 2020 De la Vina Street, Santa Barbara, California 93105*
[6]*Aldo Alfonso Zavala Jimenez Centro Universitario de la Costa, Universidad de Guadalajara, Av. Universidad #203, Puerto Vallarta, Jalisco, México 48280*
[7]*Karla De La Pena Boca Divers, Calle Pelicanos 518, Boca de Tomatlán, Jalisco, México 48292*
[8*]*Katherine Comer Santos The Science Exchange Internship Program, a project of the Ocean Foundation, 1320 19th St NW Floor 5, Washington, DC 20036*

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***CORRESPONDENCE**
katherine@thescienceexchange.org

ABSTRACT

Illegal fishing activities are a worldwide threat affecting all ocean basins. At the Los Arcos Marine Reserve, located in Puerto Vallarta, Jalisco, Mexico management problems include overcrowding of tourist boats and illegal fishing activities. There is little enforcement of regulations due to lack of government personnel and resources. We took 30 systematic censuses of reef fish and recreational activities (boating and fishing) over two summer months in 2017 and 2018 to document species richness, fish densities, fish sizes, sea surface temperatures, and threats in the reserve. We identified 67 unique species during the study period, mostly small reef fish less than 81 cm total length. Species richness and densities were significantly higher in 2017 compared to 2018 (richness T=2.37; p=.040 and density T=2.16; p=.047). This could be related to significantly fewer boats and fishers in 2017 with buoys installed by a non-profit group to keep boats away from divers (T=-2.10; p=.045). In 2017, we found the expected significant negative trend between high recreational activity and low fish density (r^2= -0.52; p=0.02) but in 2018 we found the opposite trend (r^2=0.31; p=0.02). Removal of the buoys in 2018 apparently allowed SCUBA and snorkel tour operators to get closer to the Aquarium transect site and attract fish with bread bait. In general, Los Arcos species richness and densities are higher than other nearby areas and reserves. The team recommends education over enforcement to reduce illegal fishing activity and overcrowding of tour boats in this protected area in order to allow fish stocks to flourish, not only for their ecological roles, but also for the economic well-being of the local communities that depend on them for their livelihoods.

INTRODUCTION

Illegal fishing activities are a worldwide threat affecting all ocean basins. The situation is confounded when governments lack resources to monitor and enforce regulations, and when fishers come from low-income communities. Both these conditions exist in our study area. Los Arcos National Marine Reserve is one of the most popular diving and snorkeling sites in Puerto Vallarta, Mexico. The reserve was decreed in 1975 with 3.14 km^2 of protected waters (1 km radius around the arches for which the park is named) where no fishing of any kind is allowed, and violators are subject to sanctions by fisheries authorities (Carabias Lillo *et. al.*, 2000). However, locals complain that it is just a "paper park", and we observed that there is overcrowding of tourist and fishing boats, and illegal fishing activities at Los Arcos. Therefore, interns enrolled in the Science Exchange program took systematic censuses of reef fishes, turtles, octopi and documented recreational activities (boating and fishing) in 2017 and 2018. We recorded species richness and “reef fish” densities (which hereafter also includes turtles and octopi) and explored the relationships with recreational activity and sea surface temperatures. The data can be used to implement adaptive management practices in this reserve and others.

MATERIALS AND METHODS

Our study area is in the Tropical Eastern Pacific where approximately 71% of identified fish species are endemic, the highest rate of endemism per unit area in the world (Torres-Hernández *et al.* 2016). Los Arcos Marine Reserve (in Spanish *Zona de Refugio Para La Protección de la Flora y Fauna Marinas “Los Arcos”*) is located about10 km south of Puerto Vallarta, Jalisco, México (20°32’41.6”N 105°17’32.6”6W) in the Bay of Banderas (~1,000 km^2). The topography consists of a group of five 25 to 50 m tall granite islands with several arches surrounded by rocks, coral reefs, sandy bottom, caves, and deep tunnels, as well as a 1,400 m deep wall called the “abyss” (Téllez López and Delgado Quintana, 2011). The reserve harbors many protected species under Mexican law NOM-059-SEMARNAT-2010 including a variety of whales, dolphins, sharks, rays, giant mantas (*Manta birostris*), fish (e.g., King angel (*Holacanthus passer*), Cortez angelfish (*Pomacanthus zonipectus*)), and three turtle species: olive ridley turtles (*Lepidochelys olivacea*), green or black turtles (*Chelonia mydas agazzisi*), and hawksbill turtles (*Eretmochelys imbricata*).

Questions included: What was the species richness of the site? What was the mean density of organisms by size class? What was the mean density by species? How did recreational activities correlate to densities and species richness? How did sea surface temperatures correlate to densities and species richness? Was there a difference in these parameters between 2017 and 2018 and between the Aquarium and East sites? How does Los Arcos Reserve compare to other nearby rocky reefs in terms of species richness and densities?

Two snorkel transect locations were chosen - the popular snorkel spot called the “Aquarium” with an approximate depth of 6 m with large rocks, caves, drop-offs, and corals. The second was the “East” site, east of the inland arch rock with an approximate depth of 3 m and a more uniform habitat with patchy *Sargassum* and no recreation (Fig.1). This allowed a comparison of recreational activities and habitats. In 2017, buoys were placed at the Aquarium site by a local non-profit group (*Bahia Unida, A.C.)* to keep boats away from the arches for snorkel and diver safety (dots in Fig.1). This unanticipated event allowed us to compare a year with buoy management to the following year with no management.

In 2017 and 2018, from June to August we carried out two transects a day when weather permitted between 8 a.m. and 10 a.m. Within the entire reserve, the number of boats (including our own), kayaks, fishing lines, nets, and spears were recorded along with weather and ocean conditions. At the transects, the underwater visibility was estimated and the start and end time of each transect was recorded. A 25-m transect rope was stretched to full length and tied to rocks at the ocean bottom (see Solís-Gil and Escobedo Quintero, 2002). A 4-m wide rope was tied to the arm of each researcher with a buoy in the middle to keep a constant width and center over the transect line (see Roos et al., 2015) and for better visibility by boat captains for safety. For approximately 25 min., at a constant pace of about 1 m per min., we tallied numbers and noted species and size classes of fish (nose to tail) onto dive slates. Each observer had a slightly different line of sight on the same 4-m wide transect from the ocean surface to the bottom. Whenever possible, we avoided recounting an individual animal that had already been recorded. During the swim, we noted any changes in boating and fishing activity.

Species were identified using “Fishes of the California and Western Mexico” (Burgess and Axelrod, 1984), “Reef Fish Identification Baja to Panama” (Humann and Deloach, 2004), and a phone application “Fishes East Pacific” version 3.0 (Allen and Robertson, 2016). Sea surface temperatures were downloaded from the NOAA website (http://coastwatch.pfeg.noaa.gov) and averaged over the reserve area for each day.

Densities and species richness were calculated (see Galván-Villa *et al*., 2015). To compare differences between two observers of the same transect, after testing the data for the assumptions of parametric tests using the Shapiro-Wilk normality test and Bartlett test of homogeneity of variances, the differences in observations of species richness and density per size class were calculated via the Welch Two Sample T-test or the Wilcoxon T-test with two tails. With minimal differences, the mean density and species richness between the two observers were calculated per transect, and finally annual means were calculated from all transects. The same T test methods were used to compare the annual study means from 2017 to 2018 and between sites. The relationship between boating and fishing activities and reef fish densities was determined with a linear model and the residuals were assessed for normalcy. Analysis was conducted in the open source statistical software R with an alpha<.05.

Fig.1: Puerto Vallarta location map and close-up of Los Arcos Marine Reserve showing Aquarium and East side transects locations (lines) for both years and buoy locations (dots) for 2017.

RESULTS AND DISCUSSION

In the year 2017 the species richness was 55 and the mean density was 4.41 individuals per m^2. The Aquarium had a higher mean fish density with 4.9 fish per m^2 compared to 3.3 fish per m^2 at the East site. The Aquarium also had higher species richness with 49 species at the Aquarium and 34 at the East site. For both sites, the highest densities were in the smaller size categories with species such as Cortez rainbow wrasse (*Thalassoma lucasanum*). The highest species richness was in the 6-20 cm class dominated by beaubrummel (*Stegastes flavilatus*), tinsel squirrelfish (*Sargocentron suborbitale*), and Acapulco damselfish (*Stegastes acapulcoensis*).

During the year 2018 a 55 unique species were observed, and the mean density was 2.86 individuals per m^2. The Aquarium had a slightly higher density with 3.0 fish per m^2 compared to the 2.7 individuals per m^2 at the East side and it also had higher species richness (50 compared to 36). For the East Site in 2018, the greatest number of individuals and highest species richness was in the smaller size category of 0-15 cm including juvenile Acapulco damselfish (*Stegastes acapulcoensis*). In contrast, at the Aquarium the highest species richness was in the medium size categories of 6-30 cm such as the yellowtail surgeonfish (*Prionurus punctatus*).

Comparison of sites and years

Figures 2 through 5 compare densities per size class between years and species richness between years. From the T tests (see Table 1) we found the Aquarium had significantly higher species richness (T=4.13; p<.001) but not a higher density (T=1.87; p=.080). The year 2017 had significantly higher species richness (T=2.37; p=.040) and densities (T=2.16; p=.047) compared to 2018.

Sea surface temperatures

There was significantly higher sea surface temperatures (SST) in 2017 (T=5.16; p< .001) (Table 1). Using combined data from both years we found a weak but significant positive trend between mean SST on the 15 days we sampled and species richness (r^2=.181; p=.02) as well as density (r^2=.19; p=.02) (Fig. 6 and 7).

Recreational activities

With buoys in place in 2017, we observed a mean of 4.6 boats per hr and 1.3 illegal fishing activities per hr totaling 5.9 recreational activities per hr over 5 days. In 2018, with no buoys we recorded 8.3 boats per hr and 1.3 illegal fishing activities for a total of 10.1 recreational activities per hr over 10 days. There was significantly more activity in 2018 without the buoys (T=-2.10; p=.045).

We found the expected significant negative trend between high recreational activity and fish density in 2017 (r^2= -.52; p= 0.02) and species richness (r^2=-.49; p=.03). However, in 2018 we found the opposite trend (density r^2=.31; p=.02 and SR r^2=0.25; p=.02) (Fig. 8 and 9). This is likely due to the removal of the buoys from the Aquarium transect in 2018 that allowed SCUBA and snorkel tour operators to attract fish with bread bait.

Table 1: Results for mean density, species richness, sea surface temperature, and recreational activities per year and per site, along with a statistical comparison of the differences in means via T tests (alpha< 05).

	Density (fish/ m^2)	SR	SST (C)	Recreational Activities
Mean 2017	4.11	2.09	30.1	5.9
Mean 2018	2.90	1.42	29.4	10.1
T-test	T=2.16; p=.047	T=2.37; p=.040	T=5.16; p< .001	T=-2.10; p=.045
East site	2.92	1.22		
Aquarium site	3.98	2.05		
T-test	T=1.87; p=.080	T=4.13; p< .001		

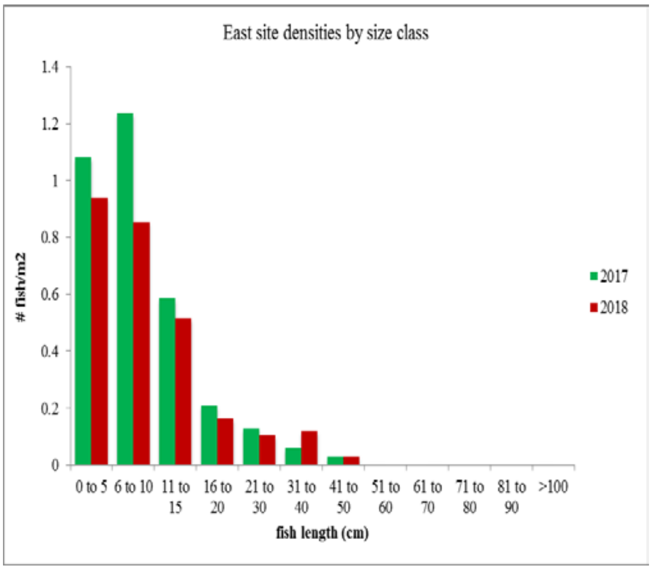

Fig. 2: Annual mean densities by size class (total length) per site and per year.

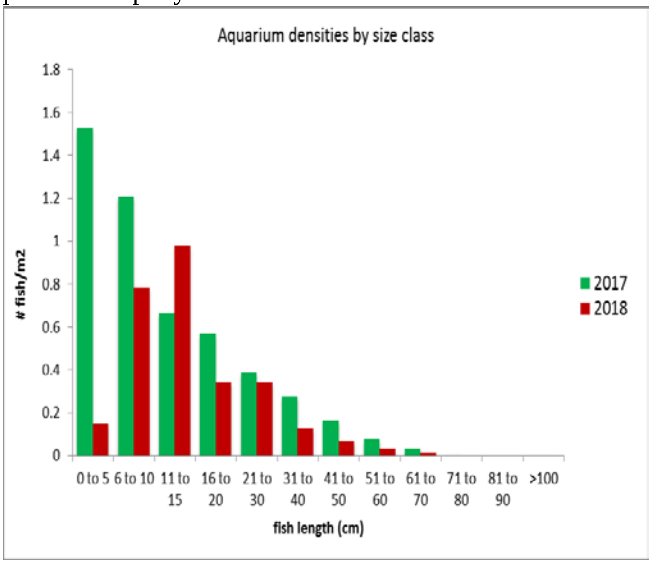

Fig. 3: Annual mean densities by size class (total length) per site and per year.

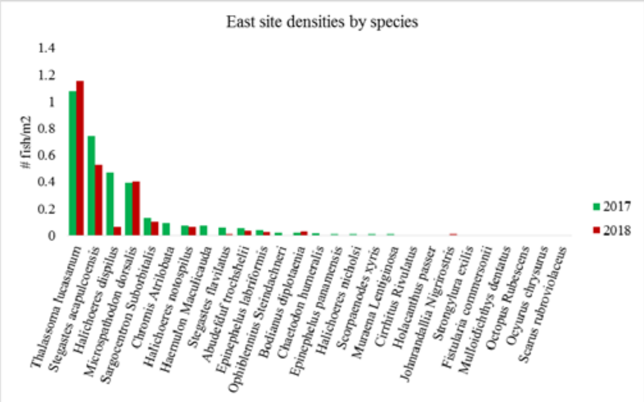

Fig. 4: Annual mean densities by species per site and per year. Densities less than 0.02 are not shown in the graphs.

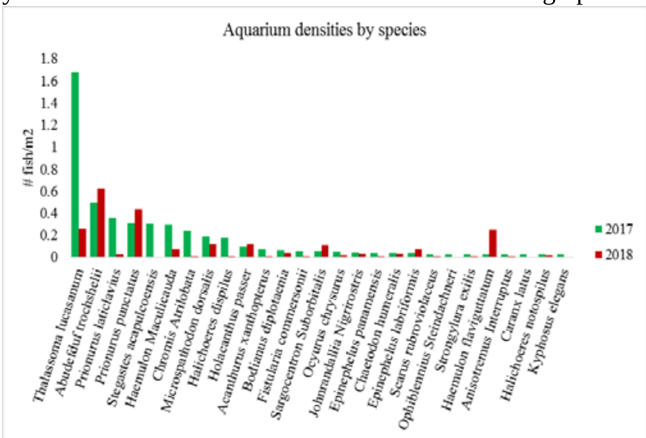

Fig. 5: Annual mean densities by species per site and per year. Densities less than 0.02 are not shown in the graphs.

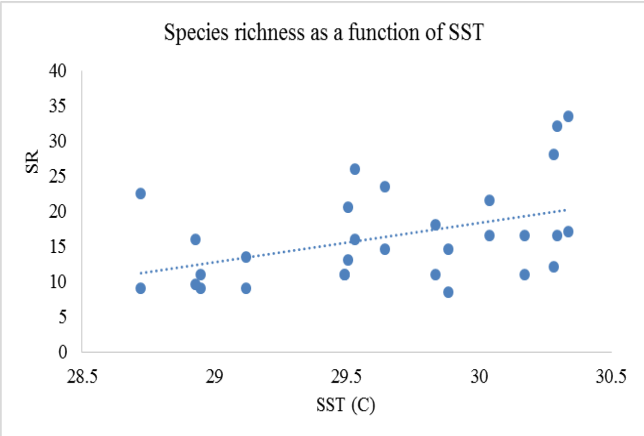

Fig. 6: Linear regression of species richness and densities versus sea surface temperature (SST).

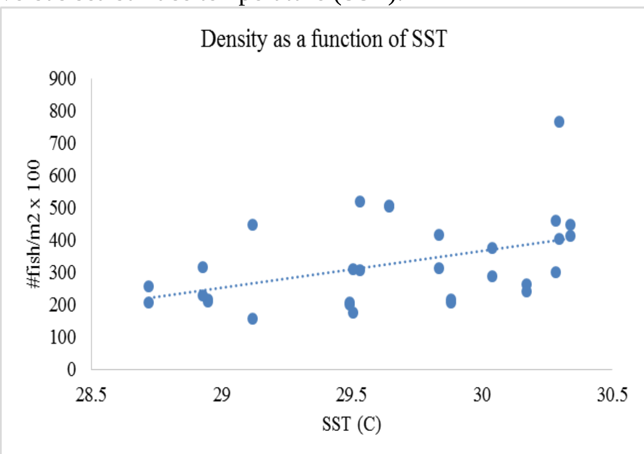

Fig. 7: Linear regression of species richness and densities versus sea surface temperature (SST).

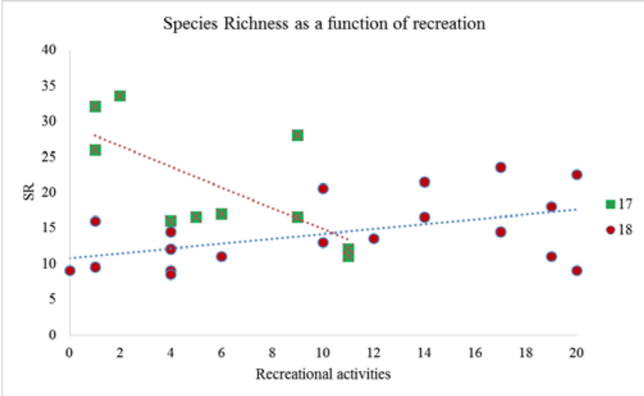

Fig. 8: Linear regression of mean species richness and fish densities versus total activities from boats and fishers.

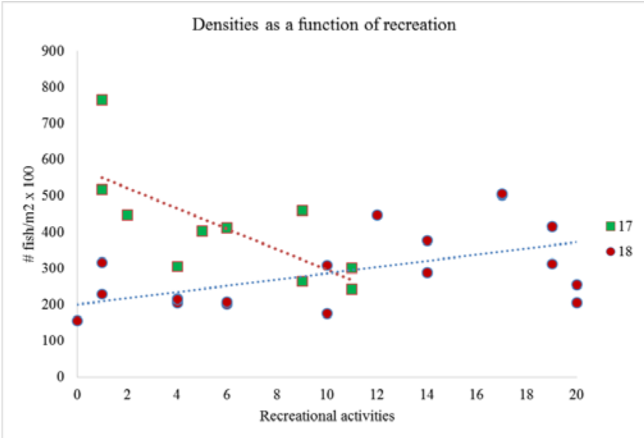

Fig. 9: Linear regression of mean species richness and fish densities versus total activities from boats and fishers.

DISCUSSION

It is an alarming observation that there were lower species richness and densities after one year of our study. One may jump to the conclusion that the fish stocks are going down due to overfishing or overcrowding by boats. Indeed, our study site had mainly small fish; we saw no commercial fish over 81 cm in either year. However, the trend we saw over two years could also be due to the buoys in 2017 which limited bread bait, higher sea surface temperatures in 2017, as well as other oceanic factors not measured here.

Compared to other areas in the region, Los Arcos species richness and densities are higher. Over the two-year study period (30 transects), we recorded 67 unique species. Miranda-Sánchez (2016) recorded 27 unique species at nearby Yelapa, Jalisco using the stationary point count method for 10 min. At Tehuamixtle and Islas Marietas, a protected area, García-Hernández et al. (2014) recorded 38 species along a 2 x 50 m belt transects during 4 to 5 min. dives and found species richness and abundance were higher at the protected site. Solís-Gil *et al.* (2003) found lower densities than we did at 0.51 organisms per m^2 with a species richness of 12 at Playa Manzanillo beach in north Bay of Banderas and 0.75 organisms per m^2 with 11 species at Careyes beach, Nayarit (sampling areas 50 m^2 and swim times unknown). Solís-Gil and Escoveda (2002) found densities at Los Arcos between 0.91 and 0.96 individuals per m^2 and species richness between 41 and 51 depending on the season. The higher densities and species richness in our study indicates that Los Arcos is a haven for biodiversity that should be better protected.

This study offers an interesting comparison between a year with active management (buoys) and a year with no management. From our data (Fig. 8 and 9) it appears that active management can help improve densities and species richness by limiting recreational pressures like fishing. Better management of the reserve would also help to protect local livelihoods from the threats of over fishing which could reduce the region's stock in the long-term. It would also help improve the tourist experience for operators by limiting overcrowding of snorkelers and boats.

A growing theory among scientists is that marine conservation may be 10% biology and 90% management of people (Nichols, 2003). We recommend education over enforcement to reduce illegal fishing activity and overcrowding this protected area. Residents who are a part of the decision-making process may be willing to change their behaviors and take part in conservation efforts. All conservation efforts, including placement of buoys, educational outreach, signs, patrolling, enforcement, etc. should be well documented, including dates, locations, and effort. This is important to see if there is a subsequent change in reef fish assemblage from our baseline surveys presented here. If documented properly, lessons learned can facilitate adaptive management here and be shared with other marine reserves in this region and around the world.

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