Effects of the 2016 El Niño on the Galapagos artisanal coastal fin-fish fishery

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El Niño events heavily influence physical characteristics in the Tropical Eastern Pacific and lead to a decrease in nutrient and phytoplankton concentrations and to variation in the composition of the marine trophic chain. However, El Niño events can also provide an opportunity to evaluate the possible effects climate change may have on marine ecosystems. The Galapagos Marine Reserve coastal fin-fish fishery supports approximately 400 fishers that target species that include benthic/demersal predatory fish such as the endemic Galapagos whitespotted sandbass (*Paralabrax albomaculatus*), the regional endemic sailfin grouper (*Mycteroperca olfax*) and mottled scorpion fish (*Pontinus clemensi*), and the misty grouper (*Hyporthodon mystacinus*). The first two species are listed as vulnerable and endangered, respectively, on the IUCN red list of threatened species. Despite their potential effects on the biota, at present it is unclear how El Niño events influence artisanal fin-fish fisheries in the Galapagos. To study the impacts of El Niño events on the fishery, numerical percentage catch composition at the largest dock in Santa Cruz Island was recorded during March and April 2013, 2014 and 2016 and compared. Compositions were significantly different between 2016 and both 2013 and 2014, but not between 2013 and 2014. These differences appear to have been due to the appearance of uncommon demersal/benthic predatory fish such as Grape eye seabass (*Hemilutjanus macrophthalmos*) and Pacific dog snapper (*Lutjanus novemfasciatus*). Size frequency distributions also varied, with significantly larger sizes of several species observed in 2016 when compared to 2013 or 2014. These changes in catch composition and size may be a product of a reduction in nutrient concentration and primary production that led to an increase in water clarity and decrease in prey biomass that forced these benthic fish species to change their feeding behavior and strike at baits that usually would not be easily detected. Because of the conservative life history many of these benthic predatory fish exhibit and the absence of any form of management for fish species in the

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GMR, El Niño events may have profound effects on their populations due to the elimination of the largest individuals. Management actions, such as size and catch limits and closures, directed at reducing the impact of the fishery on these important fish populations in the near- (El Niños) and long-term (climate change) future should be encouraged.

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ABSTRACT

El Niño events heavily influence physical characteristics in the Tropical Eastern Pacific and lead to a decrease in nutrient and phytoplankton concentrations and to variation in the composition of the marine trophic chain. However, El Niño events can also provide an opportunity to evaluate the possible effects climate change may have on marine ecosystems. The Galapagos Marine Reserve coastal fin-fish fishery supports approximately 400 fishers that target species that include benthic/demersal predatory fish such as the endemic Galapagos whitespotted sandbass (*Paralabrax albomaculatus*), the regional endemic sailfin grouper (*Mycteroperca olfax*) and mottled scorpion fish (*Pontinus clemensi*), and the misty grouper (*Hyporthodon mystacinus*). The first two species are listed as vulnerable and endangered, respectively, on the IUCN red list of threatened species. Despite their potential effects on the biota, at present it is unclear how El Niño events influence artisanal fin-fish fisheries in the Galapagos. To study the impacts of El Niño events on the fishery, numerical percentage catch composition at the largest dock in Santa Cruz Island was recorded during March and April 2013, 2014 and 2016 and compared. Compositions were significantly different between 2016 and both 2013 and 2014, but not between 2013 and 2014. These differences appear to have been due to the appearance of uncommon demersal/benthic predatory fish such as Grape eye seabass (*Hemilutjanus macrophthalmos*) and Pacific dog snapper (*Lutjanus novemfasciatus*). Size frequency distributions also varied, with significantly larger sizes of several species observed in 2016 when compared to 2013 or 2014. These changes in catch composition and size may be a product of a reduction in nutrient concentration and primary production that led to an increase in water clarity and decrease in prey biomass that forced these benthic fish species to change their feeding behavior and strike at baits that usually would not be easily detected. Because of the conservative life history many of these benthic predatory fish exhibit and the absence of any form of management for fish species in the GMR, El Niño events may have profound effects on their populations due to the elimination of the largest individuals. Management actions, such as size and catch limits and closures, directed at reducing the impact of the fishery on these important fish populations in the near- (El Niños) and long-term (climate change) future should be encouraged.

Keywords: ENSO, Galapagos, Artisanal fishery, climate change, *Mycteroperca olfax*

INTRODUCTION

The Tropical Eastern Pacific (TEP) is dominated by the El Niño-Southern Oscillation (ENSO) cycle and its effect on inter-annual sea surface temperature variability (Wang & Fiedler, 2006). During El Niño years, Kelvin waves originate in the warm western equatorial Pacific, travel easterly across the equatorial Pacific, bringing unusual warm waters to the west coast of South America. The physical effects of El Niño events include an abnormal increase in sea surface temperature, precipitation and sea surface height, and deepening of the thermocline (Wang & Fiedler, 2006; Liu et al., 2014). These changes in physical characteristics produce a decrease in nutrient and phytoplankton concentrations, and variation in the composition of the marine trophic chain (Wang & Fiedler, 2006). El Niño events have historically occurred at a decadal time scale; however, they appear to have increased in strength in the TEP over the last thousand years, with record temperatures observed over the last half century (Conroy et al., 2009; Edgar et al., 2010; Wang et al., 2017). This pattern is expected to continue as extreme El Niño events are predicted to occur more frequently under future climate change scenarios (Conroy et al., 2009; Edgar et al., 2010; Wang et al., 2017). The variable environmental conditions during El Niño years have been linked with changes in the abundance and distribution of multiple species, many of them of high economic importance for fisheries from pelagic species such as the jack mackerel (Arcos, Cubillos & Núnez, 2001) or the jumbo flying squid (Alabia et al., 2016) to entire coastal fish assemblages (Rojo-Vázquez et al., 2008; Adams & Flores, 2016).

The Galapagos islands, located ~1,000 km west of the coast of Ecuador in the TEP, are at the crossroad of cold and warm water oceanic currents, being mainly influenced by the cold eastward Cromwell or Equatorial Undercurrent that upwells in the western side of the archipelago, and the westward South Equatorial Current (SEC)(Schaeffer et al., 2008; Sachs & Ladd, 2010; Liu et al., 2014). The SEC drives water movement along the whole Galapagos region and transports warm waters from the Panama Current entering from the north, particularly during the wet season (December – May) and cool upwelled waters from the Humboldt Current entering from the south, particularly during the dry/garua season of June-October. The currents provide the waters of the Archipelago with a high input of nutrients and plankton, which can be higher than tropical Pacific open ocean waters even during El Niño events (Schaeffer et al., 2008; Wolff, Ruiz & Taylor, 2012). High levels of production allow for high numbers and biomass of sea life of tropical, temperate, and southern ocean origin to occur, along with a high proportion of endemic species (20%) (Wellington, 1975; Bustamante et al., 2002; Schiller et al., 2013; Salinas de León et al., 2016).

In the past, the Galapagos Islands have been strongly impacted by El Niño events. The 1982/1983 and 1997/1998 EL Niño events exhibited extreme thermal abnormalities that altered intertidal shores and shallow rocky reefs (Robinson, 1982; Glynn et al., 2001); reduced phytoplankton productivity that resulted in a drastic reduction of biomass at the base of the marine trophic pyramid (Robinson & Del Pino, 1985; Wolff, Ruiz & Taylor, 2012); and limited food availability that resulted in population declines of endemic vertebrates such as Galapagos penguins (*Spheniscus mendiculus)* or Galapagos fur seals (*Arctocephalus galapagoensis*) (Trillmich & Limberger, 1985; Vargas et al., 2006). The Galapagos Islands therefore provide a unique opportunity to evaluate the influence of possible impacts of climate change on ecosystems, which will also likely affect ecosystems through increasing intensity and periodicity of extreme events similar to El Niño rather than through a gradual change in ocean climate (Reaser, Pomerance & Thomas, 2000; Boer et al., 2004; Edgar et al., 2010).

The Galapagos Islands were claimed by the Ecuadorian Government in the mid XIX century. Since then, the population on the islands has increased from a few hundred settlers to over 25,000 residents (INEC, 2015), which along with an increasing number of tourists (220,000 in 2015, DPNG, 2014, Lynham et al., 2015), is threatening the islands' unique natural heritage. To protect the islands underwater ecosystems, the Galapagos marine reserve (GMR) was established in 1998 covering an area of ~138,000 km^2 (Heylings, Bensted-Smith & Altamirano, 2002). Since the establishment of the reserve, commercial fishing was banned and artisanal fishing has been permitted only in areas delimited by the GMR zonation scheme approved in 2001 (Castrejón et al., 2014). At present, there are approximately 400 active fishers in the GMR and the lobster (*Panulirus gracillis, P. penicillatus and Scyllarides astori*) and fin-fish fisheries are the most important source of income after the collapse of the sea cucumber (*Isostichopus fuscus*) fishery in the mid to late 2000s (Castrejón et al., 2014; Zimmerhackel et al., 2015). The coastal fin-fish fishery targets species that include benthic/demersal predatory fish such as the endemic Galapagos whitespotted sandbass (*Paralabrax albomaculatus*), the regional endemic sailfin grouper (*Mycteroperca olfax*) and mottled scorpion fish (*Pontinus clemensi*), and the misty grouper (*Hyporthodon mystacinus*) (Schiller et al., 2015; Zimmerhackel et al., 2015). The first two species are listed as vulnerable and endangered, respectively, on the IUCN red list of threatened species (Castrejon et al., 2005; Robertson et al., 2010; Bertoncini et al., 2015). Fishing is mostly conducted using the traditional hook and line method, called "empate", used by most Galapagos fishers during the day-time (Zimmerhackel et al., 2015; Usseglio et al., 2015). Despite sustainability assumptions, this unregulated, multi-species (>60 species caught), small-scale artisanal fishery shows clear signs of over-exploitation, low levels of selectivity and high levels of by-catch, that have had a severe impact on slow growing bottom fish populations such as groupers (Schiller et al., 2015; Zimmerhackel et al., 2015; Usseglio et al., 2015). Landing statistics for this fin-fish fishery are scarce and there is no information on the effect of environmental variability on the population dynamics of the main exploited species (Castrejón et al., 2014; Zimmerhackel et al., 2015; Usseglio et al., 2016). Despite the negative effects of El Niño events on an ecosystem scale in the Galapagos, Nicolaides et al. (2002) found that the abundance and length of *M. olfax* caught in the fishery increased during the 1997-1998 El Niño, while Defeo et al. (2013) found that the biomass of lobsters (*P. penicillatus* and *P. gracillis*) and sea cucumbers (*I. fuscus*) increased considerably after the event. Therefore, there could be an increase in the proportion and size of the benthic predatory fish in the catch composition of Galapagos artisanal fishers during El Niño events.

In the present study, we tested the hypothesis that during El Niño events Galapagos artisanal fishery landing composition changes, with an increase in the proportion of large benthic predatory fish. To test this hypothesis we compared water temperature, chlorophyll *a*, Multivariate ENSO Index (MEI), catch composition, species richness, diversity and length distribution of the most common species landed at the main port of Santa Cruz, Galapagos, during 2013, an average year, 2014, a year of weak warming, and 2016, an El Niño year (McPhaden, 2015; Wang et al., 2017). We also identified species indicative of each year, and correlated variability in the catch composition to the environmental variables mentioned above. We did not compare individual or total catch among years because annual fishing effort variability is unknown.

METHODS

Data Collection

The artisanal catch was identified using Molina et al. (2004) and Stein Grove and Lavenberg (1997), and recorded by an observer at the port of Pelican Bay in Puerto Ayora, the major landing dock of Santa Cruz Island (Fig. 1). Data were collected under permits PC-13-13 through PC-13-18 issued by the Galapagos National Park. The observer recorded all catches landed from 07h30 to 17h00, Monday through Friday during March and April of 2013 and 2016 and in April 2014. Data were collected during these months because they are part of the Galapagos wet season, when the influence of El Niño events are more strongly experienced in the TEP (Wang & Fiedler, 2006; Liu et al., 2014). We excluded pelagic species from further analysis because during 2013 the Galapagos National Park Directorate (GNPD) and local fishers conducted a pilot study to determine the feasibility and impacts of long-line fishing inside the GMR (DPNG, 2014; Lavenberg & Grove, 1997). Pelagic species caught were taken directly to continental Ecuador to be sold, and were therefore poorly represented during this year in our data set. Participation by some fishers in this long-line study also influenced fishing effort during 2013, not allowing us to compare fish catch abundance among years. Besides quantifying the species collected, the observer recorded fork length (FL, 0.1 cm precision) and name of the fishing boat. During 2013 and 2014 fishers also shared their approximate fishing locations (Fig. 1). Species richness and diversity (Shannon's diversity index) were also calculated for the catch.

We obtained water temperature data for the study period measured at the Charles Darwin Research Station located in Academy Bay, Puerto Ayora (Fig. 1, http://www.darwinfoundation.org/datazone/climate/). These data are collected once a day at 06h00 and were used because they have been found to be representative of temperature changes in the archipelago and well correlated with values in the TEP (Wolff, 2010). Monthly sea surface temperature (°C, SST) and Chlorophyll *a* (mg m^{-3}) data for the GMR were derived from MODIS

Aqua satellite data at 4 x 4 km resolution (National Aeronautics and Space Administration, https:\\modis.gsfc.nasa.gov). We averaged data over the month and for the entire GMR because data were not available for all days and precise fishing sites were mostly unknown. The MEI is an index used to monitor ENSO across all El Niño regions, where negative values represent the cold ENSO or La Niña phase and positive values represent the warm or El Niño phase (Wolter & Timlin, 1998). This index is developed using data on sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky, considered the main observed variables over the tropical Pacific (National Oceanic and Atmospheric Administration, Earth System Research Laboratory website, http://www.esrl.noaa.gov/psd/enso/mei/).

Statistical Analysis

To test whether the catch composition varied among years a Multi-Response Permutation Procedure (MRPP) was used. Because annual fishing effort variability was unknown, catch composition data were transformed into numerical occurrence percentages to analyze how the composition varied among years (McCune & Mefford, 2011). Species that were only present in one sample were not included. Our percentage transformed catch composition data met the homogeneity of dispersion assumption, which was tested using multivariate homogeneity of groups dispersion analysis (Oksanen et al., 2013). The averaged percent catch composition of all boats per day was used as the unit of comparison because daily oceanographic conditions would have influenced the catch of all boats similarly and therefore the catch of each individual boat would not have been independent from each other. To conduct the MRPP, we used the Bray–Curtis coefficient to calculate a similarity matrix among samples in multidimensional space, and determined the *P*-value by conducting 4999 permutations. The Bray–Curtis index is recommended when using ecological community data because its sensitivity does not decrease when using a heterogeneous dataset and its sensitivity towards outliers is low (McCune & Mefford, 2011). We corrected the p-value to 0.02 due to multiple pairwise comparisons.

In order to visualize MRPP results and explore the relationship between catch composition and environmental variables, MDS ordination was conducted. The MDS ordination was constructed with the Bray-Curtis distance measure in two-dimensions (stress = 0.17) and numerical percent catch composition. To explore the relationship between landing compositions and oceanographic conditions, Pearson correlations between water temperature at CDRS, SST and chlorophyll *a* in the GMR, and MEI with ordination axes were computed. Assumptions were evaluated visually and using normal probability (quantile-quantile) plots. To account for the fact that the environmental conditions that influenced fish movement might have occurred prior to the day of capture, we also included one day and one month lagged values for these variables, and averaged over the one (2014) or two (2013 and 2016) months surveyed each year.

To determine whether certain species were indicators of each year, we used Indicator Species Analysis (ISA). The ISA combines species information on abundance and frequency of occurrence in a particular group (McCune & Mefford, 2011). This analysis provides indicator values (IV) that express the proportional and relative frequency of a species in a particular group as a percentage (i.e., ranges from 0 – 100). We determined the *P*-value using a Monte-Carlo test and conducting 4999 randomizations. Only species with a *P*-value of 0.05 were considered. The MRPP, MDS and ISA analyses were conducted using the statistical software package PC-ORD 6.0 (McCune & Mefford, 2011).

We ran analyses of variance (ANOVA) and Kolmogorov-Smirnov two-way tests (K-S) to determine if environmental and biological variables, and fish size frequency distributions varied among years, respectively. For SST, chlorophyll-*a* and MEI comparisons we used data from January – May of each year to account for potential lag effects. We used one-way ANOVAs to compare SST, chlorophyll-*a* and MEI among years, included year as a fixed factor, and used data per month as the unit of comparison. To compare water temperature at CDRS, species richness and diversity we used a one-way ANOVA, included year as a fixed factor, nested month within year, and used averaged values per day of all boats as the unit of comparison. We used Tukey´s honestly significant difference test to conduct pairwise comparisons. When necessary, data were $\log_{10}$ transformed to meet parametric assumptions, which were tested using normal probability (quantile-quantile) plots and Bartlett tests (Sokal & Rohlf, 2012). We used K-S tests to compare the size frequency distribution (5 cm bins) of *P. clemensi, P. albomaculatus, M. olfax, Hemilutjanus macrophthalmos* (Grape eye seabass)*, Epinephelus mystacinus* (Misty grouper), *Caulolatilus princeps* (Ocean whitefish) and *Lutjanus novemfasciatus* (Pacific dog snapper). ANOVA and K-S tests were run using the R Core software (v. 2.15.3; http://www.r-project.org).

RESULTS

We recorded a total of 4923 fishes (1886, 676, 1418 in 2013, 2014 and 2016 respectively) on 62 fishing days (37, 15 and 10, respectively) from 43 different fishing boats at Pelican Bay (28 in 2013, 22 in 2014 and 7 in 2016). Interestingly, we recorded more fish during 2016 than in 2014 despite the fact that fishers returned with catch during more days in 2014. During this period, we documented 36 species, of which 16 were caught on more than one day and were benthic/demersal (Fig. 2, Table 1) and were therefore used in further statistical analyses. These species belonged to seven families but most were part of the Serranidae (7 species) and Lutjanidae (5 species, Table

1). The most commonly caught species were *P. clemensi* (31% of fish, Fig. 2), *P. albomaculatus* (31%) and *M. olfax* (27%) in 2013, *M. olfax* (31%), *C. princeps* (24%), and *P. clemensi* (15%) in 2014 and *P. clemensi* (41%), *H. macrophthalmos* (41%) and *P. albomaculatus* (11%) in 2016. These fishes were collected at 54 fishing sites in 2013 and 32 in 2014, located around 10 major islands, mostly in the Central-Southeastern bioregion, including Floreana (50% of 954 catches where location was provided, Fig. 1), Isabela (17%) and Santiago (9%). Collection site data were not available during 2016. During the sampling period, water temperature at Puerto Ayora, sea surface temperature in the GMR and MEI were lowest in 2013 and highest in 2016, while chlorophyll *a* was lowest in 2014 and highest in 2013. (Table 2).

The catch composition varied significantly among years (MRPP, A = 0.10, p = 0.0002). Pairwise comparisons found differences between 2016 and 2013 or 2014 (p = 0.001 and 0.0003, respectively) but not between 2013 and 2014 (p = 0.05). In the MDS ordination, data were divided by year on axis 1 with 2016 catch on the right side, and 2013 and 2014 towards the left hand side of the axis (Fig. 3). Axis 1 was most strongly correlated with MEI values per month (r = 0.53, p < 0.01) followed by MEI values that were lagged by 1 month (r = 0.50, p < 0.01). *H. macrophthalmos*, which was present in all 2016 samples, and *L. novemfasciatus*, present only in 2016, were indicator species for 2016 (IV = 99.3 and 28.6, p = 0.0002 and 0.02).

Water temperature at the CDRS, average monthly SST and chlorophyll *a* in the GMR did not vary significantly among years (p > 0.25) but MEI did ($F_{2,9}$ = 189.3, p < 0.0001). Pair-wise comparisons found that 2016 was significantly different than 2013 and 2014 (p = 0.0001 and 0.0001) but that 2013 and 2014 were not (p = 0.85). Species richness and diversity of the catch were not significantly different among years (p = 0.62 and 0.99) and were on average 2.88 ± 1.72 (mean ± SD) and 0.73 ± 0.36 in 2013, 3.25 ± 2.38 and 0.71 ± 0.35 in 2014, and 3.86 ± 2.41 and

0.70 ± 0.33 in 2016. There were significant differences in the size frequency distribution of all species analyzed (Fig. 4). Size frequency distribution of *P. clemensi*, *H. macrophthalmos, E. mystacinus* varied between 2016 and 2013, with larger sizes observed in 2016, while size distribution of *P. albomaculatus, M. olfax, , C. princeps, L. novemfasciatus* varied between 2016 and both 2013 and 2014, with larger sizes always observed in 2016 (Table 3). We were not able to compare *P. clemensi*, *H. macrophthalmos, E. mystacinus* sizes from 2016 with 2014 as not enough individuals were recorded. We were not able to compare size frequency distribution of *L. novemfasciatus* among years because they were only recorded during 2016 but during this year they varied between 58 and 102 cm FL (77.5±15 cm FL).

DISCUSSION

The present study is one of the first to analyze the impact of El Niño events on artisanal fisheries catch composition (also see Godínez-Domínguez et al., 2000; Rojo-Vázquez et al., 2008; Adams & Flores, 2016), and provides the first evidence of El Niño effects upon the Galapagos fin-fish fishery composition. As we hypothesized, our results provide evidence that the catch composition of the Galapagos artisanal coastal fin-fish fishery changed during 2016, an El Niño year. This change was mainly driven by an increase in size and uncommon demersal/benthic predatory fish species present in the catch during the 2016 El Niño year.

In particular, the appearance of larger groupers and snappers during the 2016 El Niño year produced a distinct catch composition. Grouper and snapper species can exhibit size-depth distribution (Aburto-Oropeza et al., 2009; Misa et al., 2013; Lindfield, McIlwain & Harvey, 2014), suggesting fishers may have been catching larger fish because these were moving to shallower waters where production can be higher than in deeper waters in the Galapagos even during El Nino events (Wolff, Ruiz & Taylor, 2012). However, very little evidence of such size-depth partitioning has been reported in Galapagos for adult Groupers such as *M. olfax* (Coello & Grimm, 1993; Nicolaides et al., 2002), or snappers such as *L. argentiventris* (Aguaiza, 2015; Fierro Arcos, 2017). Furthermore, the fact that species such as *H. macrophthalmos* and *L. novemfasciatus*, two relatively shallow water species (10 – 50, and <30 m in depth, Lavenberg and Grove, 1997; Smith-Vaniz et al., 2010), which rarely appear in fisheries catch (Zimmerhackel et al., 2015) were common in 2016 suggests vertical movement did not drive the larger size of fish in the catch. Instead, common catches of *H. macrophthalmos* and *L. novemfasciatus* in 2016 points to the fact that fish may have been hungry and forced to attack bait presented by fishers. Changes in feeding behavior due to hunger, leading to an increase in bait attacks has been found to occur in other marine fish species (Stoner, 2003, 2004). In Pacific halibut, *Hippoglossus stenolepis*, a benthic predatory species, hungrier individuals were found to more easily and quickly detect and attack bait (Stoner, 2003). This effect could have been magnified by the higher temperatures we observed in 2016 which would have required more food intake. Therefore, the El Niño event may have reduced prey production and increased water temperature, leading fish to be hungrier, and making them more likely to attack bait and consequently more vulnerable to the fishery.

Variation in visibility among years could have also influenced catch composition because higher water clarity can enhance adult fish feeding (Brodeur, 1992; Stoner, 2003; De Robertis et al., 2003). Lower phytoplankton production may have increased visibility, allowing fish to more easily locate and attack baits, increasing the probability of them being caught. Stoner (2003) and De Robertis et al. (2003) conducted laboratory studies and found that prey detection, attack time and capture success of Pacific halibut (*H. stenolepis)*, and sablefish (*Anoplopoma fimbria*), increased with water visibility produced by lower levels of phytoplankton. Higher water clarity was reported in the GMR during the 1998 El Niño event (Wellington, Strong & Merlen, 2001) and during the peak of the 2016 El Niño (Salinas-de-León, personal observation). We were not able to compare water clarity or visibility but we were able to compare MEI, with higher values during 2016 than 2013 or 2014. Calculation of this index includes sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky, variables that influence water clarity and biological production. Therefore, El Niño events may increase water clarity and the probability that fish locate baits, making these predators more available to the fishery.

Along with our results, previous studies suggest El Niño events may reduce prey biomass production (Wang & Fiedler, 2006; Vinueza et al., 2006; Edgar et al., 2010), thus forcing fish, particularly larger individuals, to modify their feeding behavior, increasing the probability of being caught by fishers. This effect has ramifications for fisheries management as the elimination of larger individuals may influence stock productivity and stability, and have evolutionary consequences (Berkeley, Chapman & Sogard, 2004; Enberg et al., 2012; Hixon, Johnson & Sogard, 2014). These effects may occur in all species caught in the Galapagos artisanal fishery with phenotypic traits potentially being expressed earlier in life (Enberg et al., 2012), and the elimination of *big old fat fecund females* (Berkeley, Chapman & Sogard, 2004). In particular, the effects may be especially detrimental for the vulnerable *M. olfax*. This species is a protogynous hermaphrodite (i.e., largest individuals are males) whose population in the Galapagos has a highly skewed sex ratio (<0.025 males:1 female) and has suffered sharp declines due to over-fishing, including the direct targeting of spawning aggregations, over the last century (Reck, 1983; Coello & Grimm, 1993; Salinas-de-León, Rastoin & Acuña-Marrero, 2015; Usseglio et al., 2015, 2016).

These characteristics makes the Galapagos population of *M. olfax* especially vulnerable to fishing effects, particularly during El Niño events.

CONCLUSIONS

Our results suggest Galapagos artisanal fishers catch a different assemblage composition of larger individuals during El Niño events, potentially because a reduction in prey biomass forces fish to change their feeding behavior and strike at baits they usually would not be easily able to locate. The 2016 El Niño was similar to those that occurred in 1983 and 1998 (Wang & Fiedler, 2006; Wang et al., 2017), suggesting the results we observed occur regularly during these events. Because El Niño events provide a unique opportunity to evaluate the influence of possible impacts of climate change on ecosystems, future work should focus on evaluating regulations that could alleviate fishery pressure on these iconic benthic/demersal predatory fish species in the short- (El Niño events) and long-term (climate change) in the Galapagos Archipelago.

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Tables and Figures:

Table 1. List of all fish species recorded at Pelican Bay dock in Puerto Ayora, Santa Cruz Island, Galapagos Archipelago during March and April 2013, April 2014, and March and April 2016. *Species considered in statistical analysis.

Table 2. Results of Kolmogorov-Smirnov two-sample test comparing size frequency distribution of fish species caught by Galapagos artisanal fishers in 2013, 2014 and 2016.

Table 3. Satellite derived mean (±SD) sea surface temperature (°C), Chlorophyll a concentration (mg m-3) in Galapagos Archipelago, and Multivariate El Niño Index (MEI) during March and April 2013, 2014 and 2016. See text for data sources.

Fig. 1. Map of Galapagos Archipelago with locations where fishers collected fish catch. Insert (A) details Darwin and Wolf Islands, the farthest in the Archipelago.

Fig. 2. Numerical percent catch composition of Galapagos fin-fish fishery recorded during March and April 2013, April 2014, and March and April 2016.

Fig. 3. Multidimensional scaling ordination of Galapagos artisanal fisheries catch composition recorded during 2013, 2014 and 206 (stress = 0.17).

Fig. 4. Size frequency distribution (%) of six species of benthic/demersal fish species caught by Galapagos artisanal fishers during 2013, 2014 and 2016. Statistical comparison was conducted with K-S test and is detailed in text and Table 2.

Figure 1

Map of fishing locations in Galapagos Islands

Fig. 1. Map of Galapagos Archipelago with locations where fishers collected fish catch. Insert (A) details Darwin and Wolf Islands, the farthest in the Archipelago.

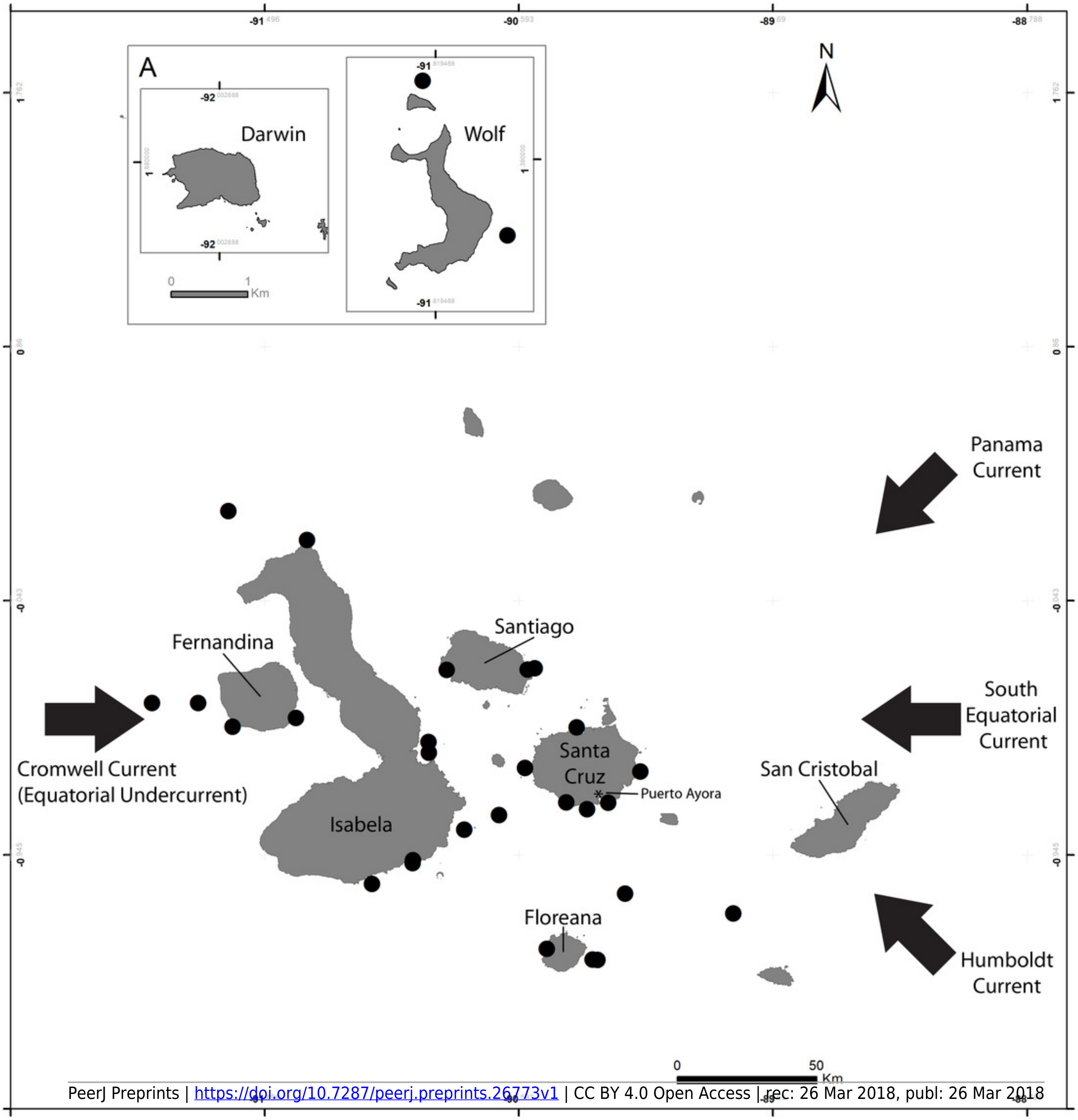

Figure 2

Galapagos fin-fish fishery catch composition

Fig. 2. Numerical percent catch composition of Galapagos fin-fish fishery recorded during March and April 2013, April 2014, and March and April 2016.

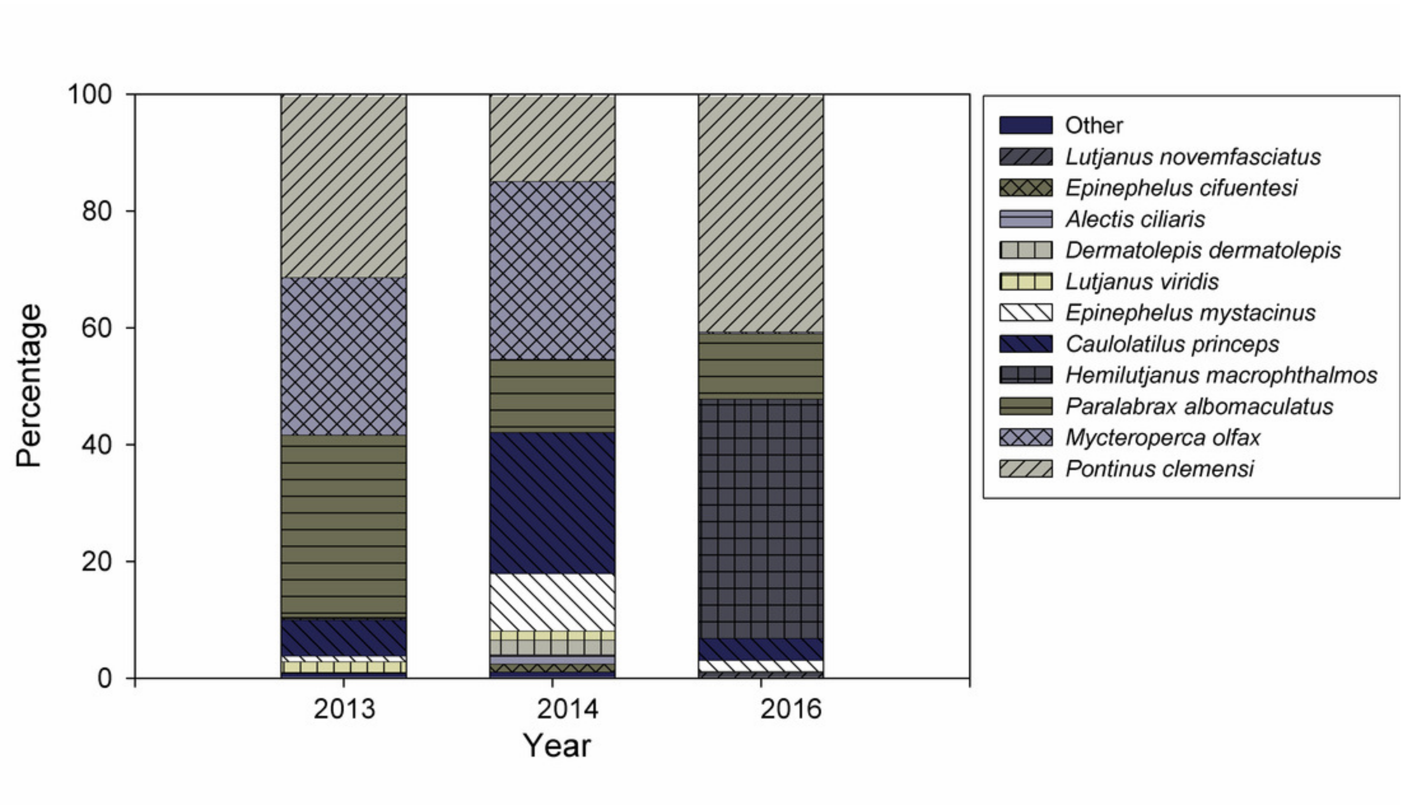

Figure 3

Multidimensional scaling ordination of Galapagos artisanal fisheries catch composition recorded during 2013, 2014 and 206 (stress = 0.17)

Fig. 3. Multidimensional scaling ordination of Galapagos artisanal fisheries catch composition recorded during 2013, 2014 and 206 (stress = 0.17).

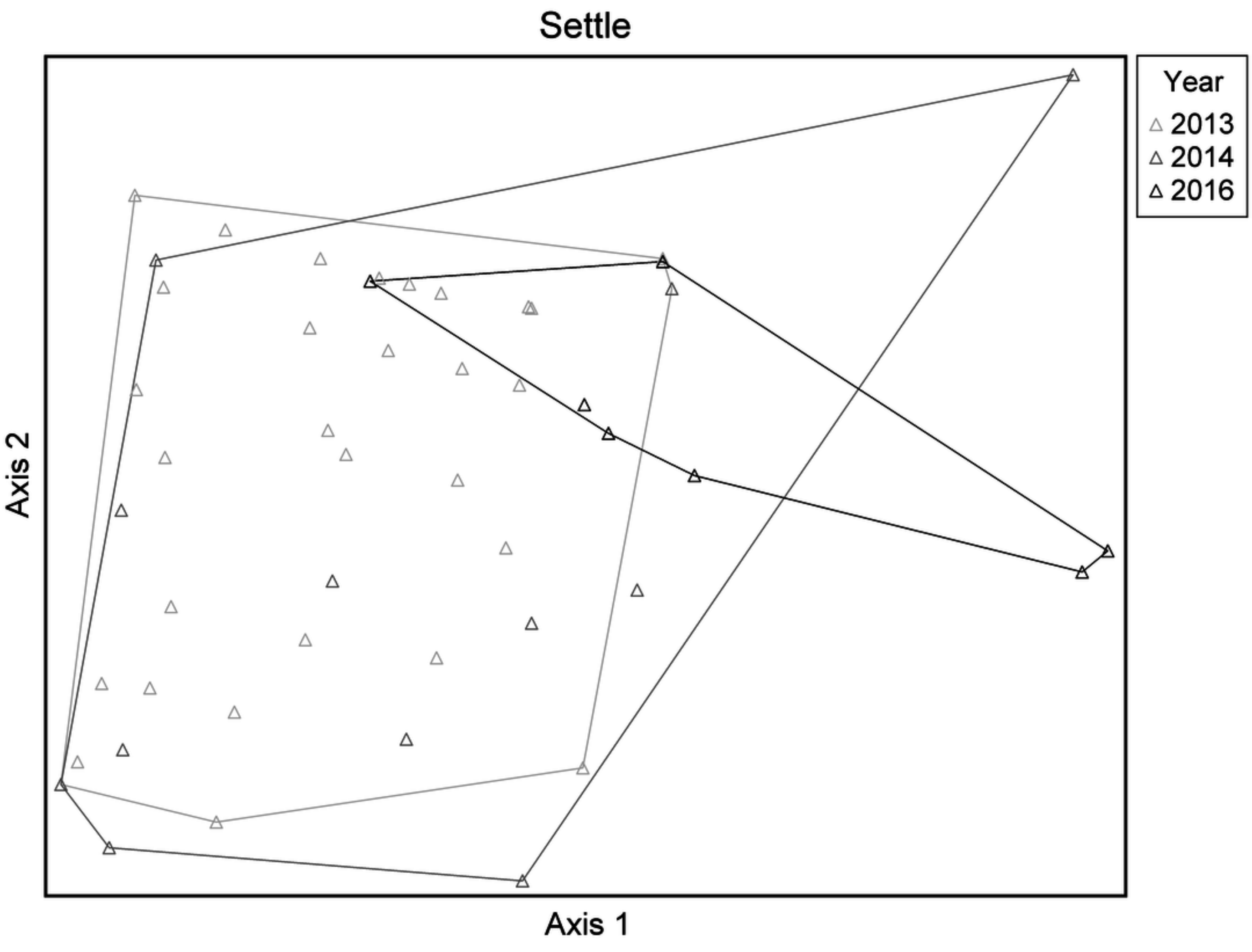

Figure 4

Comparison of size frequency distribution of six commercially important species collected in Galapagos during 2013, 2014 and 2016

Fig. 4. Size frequency distribution (%) of six species of benthic/demersal fish species caught by Galapagos artisanal fishers during 2013, 2014 and 2016. Statistical comparison was conducted with K-S test and is detailed in text and Table 2.

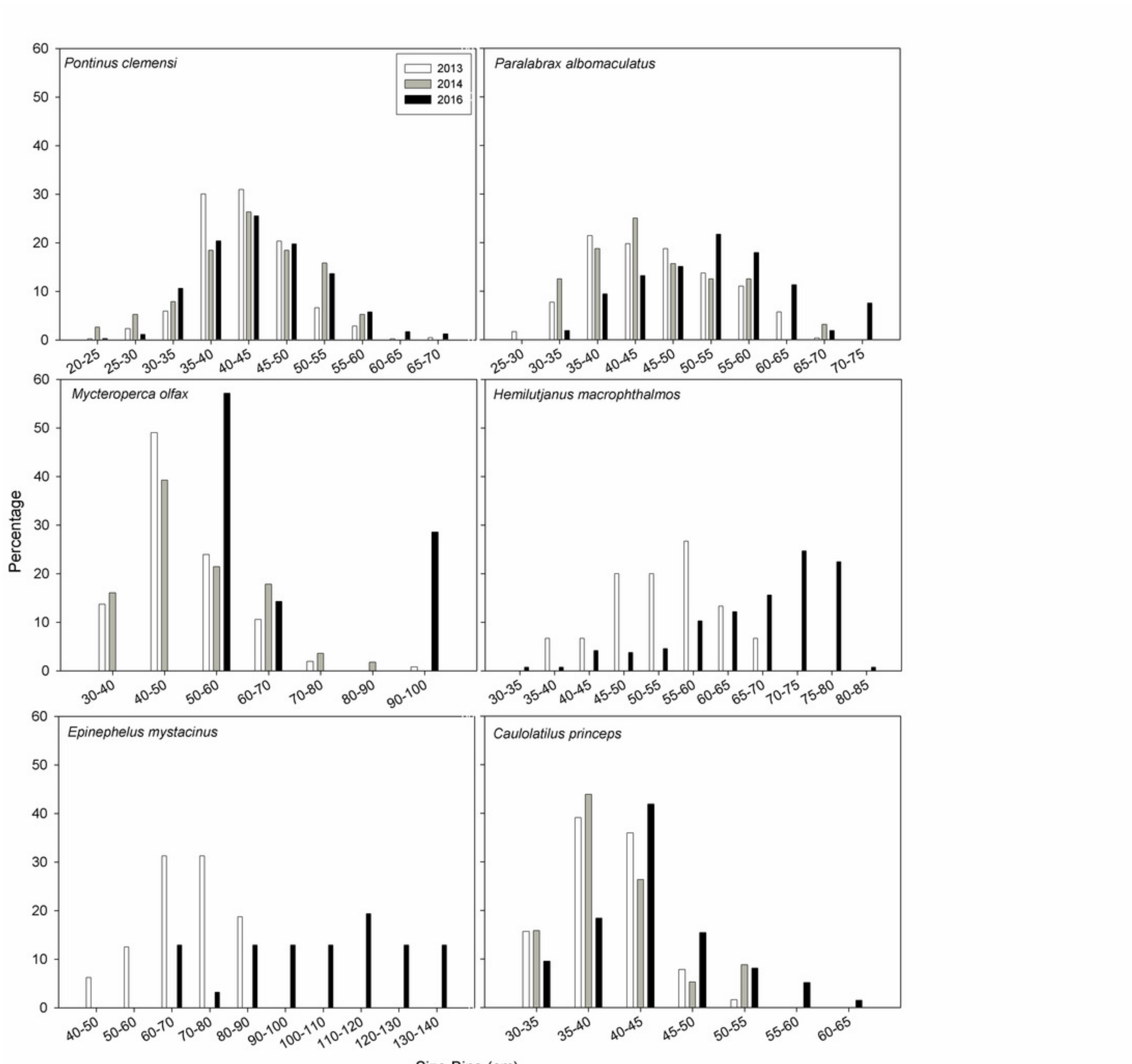

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Table 1(on next page)

Species caught in Galapagos fin-fish fishery during 2013, 2014 and 2016

Table 1. List of all fish species recorded at Pelican Bay dock in Puerto Ayora, Santa Cruz Island, Galapagos Archipelago during March and April 2013, April 2014, and March and April 2016. *Species considered in statistical analysis.

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Table 1. List of all fish species recorded at Pelican Bay dock in Puerto Ayora, Santa Cruz Island, Galapagos Archipelago during March and April 2013, April 2014, and March and April 2016. *Species considered in statistical analysis.

Species	Family
Acanthocybium solandri	Scombridae
*Alectis ciliaris**	Carangidae
*Bodianus diplotaenia**	Labridae
*Caulolatilus affinis**	Malacanthidae
*Caulolatilus princeps**	Malacanthidae
Coryphaena hippurus	Coryphaenidae
*Cratinus agassizii**	Serranidae
*Dermatolepis dermatolepis**	Serranidae
*Epinephelus cifuentesi**	Serranidae
*Epinephelus labriformis**	Serranidae
*Epinephelus mystacinus**	Serranidae
Euthynnus lineatus	Scombridae
*Haemulon scudderii**	Haemulidae
*Hemilujanus macrophthalmos**	Serranidae
*Lutjamus guttatus**	Lutjanidae
*Lutjanus argentiventris**	Lutjanidae
*Lutjanus novumfasiatus**	Lutjanidae
*Lutjanus viridis**	Lutjanidae
*Mycteroperca olfax**	Serranidae
Makaira mazara	Istiophoridae
Mugil galapagensis	Mugilidae
*Paralabrax albomaculatus**	Serranidae
Paranthias colonus	Serranidae
*Pontinus clemensi**	Scorpaenidae
Sarda orientalis	Scombridae
Scomberomorus sierra	Scombridae
Scorpaena mystes	Scorpaenidae
Semicossyphus darwini	Labridae
Seriola peruana	Carangidae
Seriola rivoliana	Carangidae
Sphyraena idiastes	Sphyraenidae
Thunnus albacares	Scombridae
Thunnus obesus	Scombridae
Xenichthys agassizi	Haemulidae
Xenocys jessiae	Haemulidae
Thunnus alalunga	Scombridae

Table 2(on next page)

Statistics of size frequency distribution comparison of six species of fish collected in Galapagos during 2013, 2014 and 2016

Table 2. Results of Kolmogorov-Smirnov two-sample test comparing size frequency distribution of fish species caught by Galapagos artisanal fishers in 2013, 2014 and 2016.

Table 2. Satellite derived mean (±SD) sea surface temperature (°C), Chlorophyll *a* concentration (mg m^{-3}) in Galapagos Archipelago, and Multivariate El Niño Index (MEI) during March and April 2013, 2014 and 2016. See text for data sources.

Variable	Month	2013	2014	2016
Temperature	March	26.9 (0.8)	27.3 (1.0)	28.1 (0.7)
	April	26.2 (1.1)	26.3 (0.7)	26.3 (1.3)
Chlorophyll a	March	0.31 (0.15)	0.31 (0.22)	0.27 (0.14)
	April	0.30 (0.18)	0.23 (0.12)	0.32 (0.35)
MEI	March	-0.128	0.032	1.96
	April	0.069	0.248	2.07

Table 3 (on next page)

Satellite derived sea surface temperature and chlorophyll *a* in Galapagos archipelago, and Multivariate El Niño Index during 2013, 2014 and 2016

Table 3. Satellite derived mean (±SD) sea surface temperature (°C), Chlorophyll *a* concentration (mg m^{-3}) in Galapagos Archipelago, and Multivariate El Niño Index (MEI) during March and April 2013, 2014 and 2016. See text for data sources.

Table 3. Results of Kolmogorov-Smirnov two-sample test comparing size frequency distribution of fish species caught by Galapagos artisanal fishers in 2013, 2014 and 2016.

Species	2013 vs. 2014		2013 vs. 2016		2014 vs. 2016	
	D	n	D	n	D	n
Caulolatilus princeps	0.12	127	0.37***	193	0.41***	206
Epinephelus mystacinus	n/a	n/a	0.77***	48	n/a	n/a
Hemilujanus macrophthalmos	n/a	n/a	0.65***	279	n/a	n/a
Mycteroperca olfax	0.15	313	0.77***	262	0.67**	65
Paralabrax albomaculatus	0.09	331	0.3***	405	0.37**	138
Pontinus clemensi	0.21	462	0.17***	1244	0.11	860

*$p<0.05$

**$p<0.01$

***$p<0.001$

n/a = comparison not possible