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Concepts of vulnerability as drivers of conservation priorities: An applied study of fish communities in the Galapagos Marine Reserve

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ABSTRACT:

The protection of marine biodiversity requires the identification of vulnerable species and the creation of marine protected areas (MPAs) to ensure their survival. Different conceptual frameworks of vulnerability based on both intrinsic and extrinsic factors have resulted in a variety of methods for assessing vulnerability, which can yield different conclusions as to which species are of conservation priority. This paper applies two vulnerability assessments, the IUCN red list of threatened species and Fishbase's fuzzy logic expert system, to fish communities in different habitat types of the Galapagos Marine Reserve (GMR). Three habitat types, mangroves, rocky reefs and corals, were assessed on the island of San Cristobal to determine habitats that host vulnerable fish species. When using the IUCN red list of threatened species, rocky reefs had the greatest abundance of vulnerable species, however when applying Fishbase's assessment of intrinsic vulnerability, mangroves had the greatest abundance of vulnerable species. This study recommends that Fishbase's assessment of vulnerability is the more appropriate measure to use in the GMR, but that may not be the case in other areas of the world. Marine managers ought to use both assessments and determine the more appropriate measure for assessing conservation area priorities depending on the specific context of their MPA.

RESUMEN:

La protección de la biodiversidad marina requiere la identificación de especies vulnerables y la creación de áreas marinas protegidas para segurar sus sobrevivencia. Diferentes marcos conceptúales de la vulnerabilidad basados en los factores intrínsicos y extrínsecos han resultado en una variedad de métodos para evaluar la vulnerabilidad que puedan resultar en diferentes conclusiones de que especies son de prioridad de conservación. Este tesis aplica dos evaluaciones de vulnerabilidad, la UICN lista rojo de especies en peligro y el fuzzy lógica experto sistema que esta utilizada en FishBase, a los comunidades de peces en diferentes tipos de hábitats en la Reserve Marina de Galápagos (RMG). Los tres tipos de hábitat, manglares, arrecifes rocosos y corales fueron evaluados en la isla de San Cristóbal para determinar los habitats que acogen especies de peces vulnerables. Cuando usamos la lista roja de UICN de especies en peligro, los arrecifes rocosos tuvieron la mayor abundancia de especies vulnerables, no obstante cuando usamos la evaluación de Fishbase que es la vulnerabilidad intrínsico, los manglares acogen la mayor abundancia de especies vulnerables. Este estudio recomienda que la evaluación usada en Fishbase es mas la medida mas apropiada para usar en la RMG, pero este tal vez no es el caso en otras áreas del mundo. Tomadores de decisiones para la protección de ambientes marinas debe usar los dos evaluaciones y determinar la medida mas apropiada para la evaluación de áreas prioritarias dependiendo en el contexto especifico de la área marina protegida.

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INTRODUCTION:

The conservation of habitat types and specific sites via protected areas is seen as the best approach to maintaining biodiversity and ecological integrity of ecosystems (Bruner et al. 2001; Brooks et al., 2004; Pressey, 2004; Briggs 2011; Fernandes et al. 2005). Protecting biodiversity is the main objective of many successful marine conservation programs (Leslie 2005) and proper implementation of these programs necessitates the identification of species vulnerable to extinction. Vulnerability is defined as species threatened by extinction or extirpation on local and region scales (Dulvy et al. 2003, Cheung et al. 2005); however it is also necessary to include the factors driving a species to extinction in our definition. These extinction drivers may include global climate change, habitat destruction, strong ENSO events, disease, fishing pressure, invasive species or loss of top predators (Polidoro et al. 2012; Myers and Worm 2003; UNEP-WCMC 2008). Alternatively we can conceptualize vulnerable species as possessing biological and ecological characteristics that yield them non-resilient to changes caused by the aforementioned factors (Cheung et al. 2005; Cheung et al. 2007; Dulvy et al. 2004).

The methods used to assess vulnerability vary depending on the conceptual frameworks in which they are founded and as a result the use of different methods may result in inconsistent conclusions about which species and habitats need to be protected. For example some populations may be particularly vulnerable to sudden climatic changes such as strong ENSO events, which could be the primary extinction driver while other species may be more intrinsically vulnerable to fishing pressure due to life-history and ecological characteristics which make them non-resilient (Cheung et al. 2005; Polidoro et al. 2012; Le Quense et al. 2011; Mace et al. 2008). Additionally the method used for assessing vulnerability can include or exclude species with different ecosystem functions, even though ecosystem function is not included as a vulnerability criteria since individual species are assessed, not entire ecosystems or communities. Protecting vulnerable species that play a key role in maintaining ecosystem structures has the dual benefit of preventing species loss and promoting the ecological integrity of the entire ecosystem (Baum et al. 2003; Myers and Worm 2003; Myers et al. 2007; Ferretti et al. 2010).

The primary factors threatening marine fishes in the Eastern Tropical Pacific are overfishing, habitat destruction and strong ENSO events (Polidoro et al. 2012). Many marine species are vulnerable to extinction as a result of fishing pressure, however we lack data necessary to assess current population trends for many species (Mace et al. 2008, Le Quense et al. 2011). Often species of commercial interest are more intrinsically vulnerable to extinction due to life-history characteristics such as a long maximum length, a late age of first reproduction and long generation times, since fisheries frequently exploit larger fish (Pauly et al. 1998; Cheung et. al. 2005; Powels et al. 2000; Reynolds et al. 2005). However, even species of little commercial value are under threat from fishing through by-catch (Walker et a. 2005; Casey et al. 1998), or the disturbance created by fishing activities, particularly in benthic habitats (Jennings et al. 2001; Shurin et al. 2002). Furthermore the loss of species due to fishing can have cascading effects on the ecosystem as a whole (Baum and Worm 2009; Myers and Worm 2003), which threatens biodiversity and the ecological integrity of marine ecosystems (Duffy 2003; Le Quense et al. 2011; Worm et al. 2006).

Cheung et al. 2005 created a method that employs a fuzzy logic expert system to determine species intrinsically vulnerable to extinction based on ecological and life-history characteristics. This fuzzy logic expert system, which is used in a vulnerability assessment on FishBase (Froese and Pauly 2012), allows us to estimate the intrinsic vulnerability even when uncertainty exists for some life-history traits and ecological characteristics, and therefore can be useful in assessing vulnerability when gaps in our knowledge exist. The method is useful in applying the ‘precautionary principle’ (Lauck et al. 1998) because conceptualizes vulnerability intrinsically, or based on inherent characteristics that make species susceptible to fishing pressure, rather than assessing species already on the path to extinction. Though the measure is used to identify vulnerability to fishing pressure, the same attributes used in the assessment can make species susceptible to other threats such as strong El Niño events.

In contrast, the IUCN red list calculates risk for extinction based on data from existing populations, their locations and external threats. It provides valuable information on numerous species and is the most widely accepted method for identifying species as risk of extinction (Hoffman et al. 2008; Rodrigues et al. 2006; Butchert et al. 2005; De Grammot et al. 2006). However many marine species are not assessed on the IUCN red list because we lack data about their existing populations necessary for this assessment. The IUCN red list determines vulnerability by examining population numbers worldwide and prioritizes populations that are declining as well as endemic species with a limited geographic range under threat by various factors (Mace et al. 2008). Though this assessment is comprehensive in that it considers multiple extinction drivers and population attributes, collecting the necessary data for these assessments is costly and time consuming, and frequently marine species are not assessed in tropical developing countries where resources for conservation are low as compared to developed countries (Jennings and Polunin 1996; Johannes 1998). Frequently studies make management suggestions based on the life history cycles and habitat preferences of a few charismatic or keystone species (Bass et al. 2011; Cañadas et al. 2005), however more work needs to be done to assess how vulnerable communities and their structures are to various anthropogenic stressors (Crowder et al. 2008).

A place-based approach is at the cornerstone of emerging efforts to preserve the marine environment. Several studies have attempted to use vulnerability assessments to create conservation priorities in reserve planning. For example, Eken et al. 2004 outline the key-biodiversity area (KBA) concept, which involves identifying areas of global conservation significance using information on vulnerability and irreplaceability of species. Vulnerable sites include areas that host one or more globally threatened species, while irreplaceable sites are areas that host a significant proportion of the global population of a species. KBAs are created using globally applicable criteria (Margules and Pressey, 2000) and use the IUCN red list of threatened species for identifying conservation targets (Eken et al. 2004, Knight et al. 2007). For example, a study by Edgar et al. 2008a applied the KBA criteria, using IUCN data, to sites on several of the islands in the Galapagos Archipelago and recommendations were made for changing the coastline zoning scheme based on their findings. This study was used by Conservation International Marine Management Areas Science program for a work plan called ‘Extinction Resistance’ developed for the Western Pacific and Eastern Tropical Pacific to provide a framework for the conservation of species of global importance and assess the degree to which these species are protected in existing MPAs (UNEP-WCMC 2008). These programs can provide valuable information to decision-makers (Edgar et al. 2008b) and KBA methods are increasingly being employed by marine managers, such as a recent project aimed at improving MPA design in the Philippines (DEF-UNDP 2012). However, these strategies are significantly affected by the conceptual frameworks of vulnerability in which their methods are founded and can be expanded by allowing project managers to decide the most appropriate method based on the specific context of the protected area.

This study applies intrinsic vulnerability data available on FishBase and the IUCN red list of threatened species to assess the vulnerability of fish communities at six sites off the island of San Cristobal, Galapagos, Ecuador. The two vulnerability assessments were applied to fish communities in three ecosystems (rocky, mangrove and coral) to determine if different vulnerability data would draw similar conclusions in terms of locating habitat conservation priorities of vulnerable fish species. Although the two methods use different criteria, it was hypothesized that there would be a high degree of overlap in the number of vulnerable fish species and their habitat preferences between the two assessments and that similar conclusions would be reached as to which ecosystem types host the most vulnerable species. By comparing FishBase and IUCN criteria I demonstrate how dissimilarities in the conceptual framework of vulnerability of species can significantly affect our conservation priorities in terms of protecting vulnerable species' habitats.

MATERIALS AND METHODS:

Study area:

The Galapagos Marine Reserve covers 133,000 km^2 and is the largest marine protected area in Ecuador and one of the largest in the world. The islands are 1000 km from the Ecuadorian mainland (between 01◦40 N–01◦25 S and 89◦15 W–92◦00 W). The climate varies between the cool dry season, which begins around June and ends in December, and a hot wet season, which begins in December and ends in May. The Galapagos is also near the center of the most intense areas impacted by El Niño events, in which unusually warm temperatures up to 5 degrees C above the long-term average are observed during the warm season followed sometimes by unusually cold temperatures, La Niña event, during the cool season (Barber and Chavez 1986). The warming El Niño event can have devastating consequences for marine species, since it reduces the number of dissolved nutrients thereby decreasing the amount of primary production available, which decreases biomass at the base of the food web (Robinson and Del Pino 1985).

During the cool season the colder nutrient rich Humboldt current moves from Antarctica to the equator and reaches Galapagos, while in the warm season the warmer Panama current coming from the north, becomes more dominant bringing warmer water and weather to Galapagos. Additionally, the southern equatorial surface current flows along the western part of the islands, while the Cromwell equatorial sub current from the west flows at 100 m depth along the ocean bottom and then rises to the surface at Galapagos bringing nutrient rich waters, which creates algal blooms (Palacios 2004). This primary production forms the base of the food-web in Galapagos and has enabled many unique species to evolve (Feldman 1986).

The study areas are in six different locations on San Cristobal island (Figure 1). San Cristobal is the eastern most island of the Galapagos archipelago, with an area of 558 km^2 and the capital of Galapagos, Puerto Baquerizo Moreno, is located on this island. Only two coral habitats have been found on this island, which are both included in this study, and four mangrove habitats are on the island, two of which are included in this study, while the rest of the island, and over 90% of Galapagos is dominated by rocky reef ecosystems (Bustamante et al. 2002). The six sites and ecosystem types for this study include: Isla lobos (rocky), Negritas (rocky), Punta Pitt (coral), Rosa Blanca (coral), Rosa Blanca (mangrove), and Tortuga (mangrove, Figure 1).

Fish community survey:

Data were collected over an eight-month period from January 2010 to August 2010 with a total of 181 transects conducted across the six study sites list above. Species abundance and richness data were collected in all transects. In total 67 fish species were observed across all ecosystem types during the study period. The visual transect method of collecting species abundance and richness data consisted of one researcher holding one end of the transect line while another researcher laid the transect line, both researchers then fastened their end of the transect line in place using rocks. Then one researcher would swim toward the other counting species in the water column up to two meters above the benthic habitats including the benthos, along the transect line and collecting data, within the transect area. Fish were counted from one meter on each side of the transect line (2 meter width total) over a 50 meter length, thus each transect area was 100 square meters. Between three to six transects were conducted for each dive survey (at a depth of 5-12 m) or snorkel survey (at a depth of 1-3 m). Data was collected by scuba diving at all sites except the mangrove ecosystems where transects were collected through snorkeling (Tortuga and Rosa Blanca).

Rarefaction for calculating adequate sample size:

The sample size was evaluated to be representative of the entire community of fish species in each ecosystem in terms of biodiversity and species composition. The rarefaction methods used involves calculating the accumulated average and standard deviation of fish species diversity curves using the Shannon index (H') (Krebs 1999). Diversity curves were generated using MATLAB program, which conducts 500 random permutations using the original data while maintaining a margin of error at 0.05. This error is obtained from the data's coefficient of variation and is measured when the accumulated average reaches asymptote, thereby determining the appropriate sample size for characterizing the fish communities in each ecosystem with a 95% confidence interval. Diversity curves reached asymptote (Coefficient of variation=0.05) at 27 for coral, 27 for mangroves, and 21 for rocky, confirming that the sample size (number of transects) obtained for each ecosystem (56 for coral, 67 for mangrove and 58 for rocky) was sufficient to describe the composition of each ecosystem's fish community (Figures 2a, 2b and 2c) with an error lower than 0.05.

Intrinsic vulnerability assessment using fuzzy logic expert system:

The intrinsic vulnerability of each species was obtained from FishBase, which is determined by a method developed by Cheung et al. 2005. The intrinsic vulnerability is the resilience of a species to fishing pressure, which is related to this fish's maximum rate of population growth and strength of density dependence (Cheung et al. 2005). Responses of fish populations to fishing pressure are frequently determined by the life-history and ecological characteristics of the species and these characteristics have been correlated to intrinsic vulnerability rates (Adams, 1980; Roff 1984; Kirkwood et al.1994; Dulvy et al. 2003). This method uses fuzzy logic to estimate the degree of membership in certain categories that determine the species' vulnerability.

Fuzzy logic, originally developed by Zadeh (1965) states that a subject can belong to one or more fuzzy sets with a gradation of membership instead of having membership to a group classified as true or false, as in the classical logic system. Fuzzy logic allows conclusions to be reached from a premise with gradation of truth, and membership can be viewed as a representation of the possibility of association with the particular set. To calculate the intrinsic vulnerability an expert system is used to mimic how experts solve a problem. The rules are operated on when the degree of membership of the premises exceed threshold values, which define the minimum required membership of the premises that an expert would expect for that rule to operate which was set at 0.2 out of 1 (Cheung et al. 2005). The vulnerability data is based on this fuzzy logic system and is validated by correlations with empirical data including the observed rate of population decline of fishes in the North Sea (Jennings et al. 1999a) and Fiji (Jennings et al. 1999b).

The input variables for the fuzzy expert system are maximum length, age at first maturity, longevity, von Bertalanffy growth parameter K, natural mortality rate, fecundity, strength of spatial behavior and geographic range. The outputs are four categories referring to the levels of intrinsic vulnerability to extinction and placed on a scale from 1 to 100 with 100 being the most vulnerable described as follows: Low (0-30); Moderate (30-50); High (50-70) and Very high (70-100).

The equation used to calculate vulnerability is:

$$\text{Membership}_{e} = \text{Membership}_{e-1} + \text{Membership}_{i} \text{ x } (1-\text{Membership}_{e-1})$$

Where Membership_e is the degree of membership of the conclusion after combining the conclusions from e piece of rules, and Membership_i is the degree of membership of the conclusion of rule i. An index of intrinsic vulnerability is calculated at the peak or maximum membership of each 'conclusion' fuzzy membership function weighted by the degrees of membership to each conclusion category (Cheung et al 2005). For this study only species within the highest intrinsic vulnerability category (>70) were used, which is classified as 'very high' vulnerability to identify species of the most pressing concern. Again these species' populations may not be in imminent danger of extinction, but they are nonetheless vulnerable because they possess characteristics, which make them non-resilient to changes, therefore only the most intrinsically vulnerable species were considered.

IUCN Criteria for assessing vulnerable species:

The IUCN red list of threatened species categorizes species into the following: extinct (EX), extinct in the wild (EW), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC) and data deficient (DD) (Mace et al. 2008). There are three categories, which indicate that a species is threatened: vulnerable (VU), endangered (EN) or critically endangered (CR). Species are placed in these categories based on the following parameters: population trends and population size, subpopulations, number of mature individuals, generation length, reduction in the number of mature individuals, continuing decline, extreme fluctuations, severely fragmented populations, extent of occurrence, and area of occupancy (Mace et al. 2008). However, a species whose biology is well known, but the global range and known threats are missing will be listed as data deficient (Mace et al. 2008).

Different criteria are used to determine species vulnerability and a species can only fall into one of the criteria. The first criteria which places a species in these categories, or Criterion A, is a high rate of decline as determined by an estimate of the current population size in comparison of an estimate from the past or a projection for the future and change over a specific time measured in as percentage of loss. This population size is then adjusted with the measure of "mature individuals" (IUCN 2001), which reflects the actual or potential breeding population. Since mature individuals of different species have different generation times, the period over which a decline is assessed is measured in generation length, which acts as a turnover rate within the population. Assessments in the rates of change of threatening processes can be applied for criterion A such as loss of habitat, levels of direct or indirect exploitation, the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites; though assessors are advised to use indirect evidence cautiously. Nonetheless the shape of the decline curve is based on the threatening processes. Vulnerable is listed as a decline of >30%; endangered is listed as a decline of >50% and critically endangered is a decline of >80% before extinction occurs.

The next criterion, B, is used to classify threatened species when the geographical range is very restricted and when other factors suggest that it is at risk. This applies when a species is restricted to small areas or to habitat remnants that are being diminished. This criterion uses two measures: extent of occurrence (EOO) and the area of occupancy (AOO). The EOO is defined as the area within the shortest continuous boundary that can be drawn to include all known, inferred or projected sites of occurrence of a species. The AOO is the area within the EOO area in which the species is found. It is the smallest area essential at any stage of survival of existing populations of a species. Criterion B has encountered some difficulties because the choice of critical thresholds is uncertain since no framework exists to associate given range areas with different levels of risk of extinction. A constant ratio was maintained with cut-off values for EOO and AOO in the categories of critically endangered (100 km^2), endangered (5,000 km^2) and vulnerable (20,000 km^2). To qualify in this criteria there must be evidence that the population is or projected to decline, severely fragmented, limited to a few locations, or subject to extreme fluctuations.

Criterion C is related to small population size and decline. The thresholds are selected by the number of mature individuals and are derived by theoretical values for minimum viable populations adjusted to reflect timescales appropriate for the species. The population must be fewer than 10,000 mature individuals for vulnerable, 2,500 for endangered, and 250 for critically endangered. Criteria D involves very small population sizes without evidence that there has been or will be a decline because small populations can have high extinction risks from internal processes such as demographic stochasticity meaning the process whereby random variation among individuals in certain demographics such as sex ratios can lead to extinction. To be classified as vulnerable in criterion D a species must have less than 1000 mature individuals, for endangered less that 250, and for critically endangered less than 50. There is a subcriterion D2 from criterion D, which allows a species to qualify solely on the basis of a very restricted distribution as evidence that the species is threatened. Criterion E uses any kind of quantitative analysis for assessing risk of extinction, which is then compared to the extinction-risk thresholds, which are expressed as the probability of extinction within a given time frame. Essentially it is any case where a robust estimate of extinction risk can be determined. This might be done without detailed information on population dynamics.

Data Analysis:

The diversity measures of richness and Shannon's diversity index were calculated for each habitat type. A Two-Way ANOVA was used to test differences in abundance, richness and the Shannon diversity index between habitat types (mangrove, coral and rocky) and between seasons (cool and warm). Normality was tested using Shapiro-Wilks test.

Total abundance of vulnerable especies per transect (using both IUCN and FishBase assessments) were also calculated. Because these data did not follow normal distribution, Kruskal-Wallis test was performed to test differences between habitat types (mangrove, coral and rocky) and between seasons (cool and warm). All statisitical analyses were performed using R statisitical software packages.

Additionally, mean trophic levels per ecosystem were calculated using IUCN vulnerable species abundance and FishBase vulnerable species abundance by summing the total abundance for all transects per ecosystem and weighting species' trophic levels by their abundance to obtain a final weighted average.

RESULTS:

A comparison of criteria for assessing vulnerability:

A comparison in the criteria used in each vulnerability assessment was made showing the population parameters used by the IUCN and the life-history characteristics used by FishBase, geographic range, natural mortality rate, fecundity and age at first maturity are consider on the IUCN red list only as they relate to population trends and predictions whereas they are considered using FishBase's assessment independently (Table 1). Furthermore, ten of the 67 species were not evaluated or data deficient and therefore not given an assessment on the IUCN red list, though all species had a vulnerability score on FishBase. On the IUCN red list, population trends were known for 20 of the 67 species found in this study.

Distribution of FishBase's intrinsically vulnerable species across ecosystems:

Using FishBase's vulnerability criteria, across all three ecosystems five species encountered had life history and ecological characteristics that placed them in the highest intrinsic vulnerability category (>70) which is described as 'very high' according to the fuzzy logic expert system on a scale ranging from low (0-30), moderate (30-50), high (50-70) to very high (70-100, Table 2). These species include: the spotted eagle ray (*Aetobatus narinari),* the diamond ray *(Dasyatis brevis),* the pacific dog snapper (*Lutjanus novemfasciatus,* vulnerability: 74), the marbled ray (*Taeniura meyeni,* vulnerability: 77), and the white tip reef shark *(Triaenodon obesus,* vulnerability: 83*)*. The average number of highly vulnerable species per transect were significantly greater in mangroves as compared to corals and rocky reef habitats (Table 2). In addition to being very highly vulnerable, three of the five species are also top predators (*Triaenodon obesus*, *Taeniura meyeri,* and, *Lutjanus novemfasciatus)* and the other two are predatory rays (*Dasyatis brevis, Aetobatus narinari*; Table 2). Mangroves had the greatest abundance of very highly vulnerable species per transect revealed by a Kruskal-Wallis test. ($\chi^2(2) = 32.61$, $p<0.05$), and there was a significant effect of season ($\chi^2(1)= 5.27$, p-value = 0.022), with the cool season having a greater number of vulnerable species than the warm season (Figure 3a).

Distribution of IUCN vulnerable species across ecosystems:

A total of eight species out of the 67 species encountered in the study were found to be vulnerable according to the IUCN red list criteria (Table 3). Rocky reef ecosystems hosted the greatest number of IUCN vulnerable species followed by corals and lastly mangroves (Table 4, Kruskal-Wallis $\chi^2(1) = 5.27$, $p<0.05$) and there was no significant difference between seasons (Kruskal-Wallis $\chi^2(1) = 5.27$, $p=0.412$; Figure 3b). The species found in this study on the IUCN red list include: the endemic Galapagos barnacle blenny (*Acanthemblemaria castroi*); the Pacific sea horse (*Hippocampus ingens*) threatened by habitat degradation, targeted catch and incidental capture; the white salema (*Xenichthys agassizi)* an endemic species; the bravo clinid (*Labrisomus dendriticus*) endemic to the Galapagos and Malpelo islands; the sailfin grouper (*Mycteroperca olfax*) endemic to Galapagos, Cocos and Malpelo islands; the Galapagos ringtail damsel fish (*Stegastes beebei*) endemic to Galapagos, Cocos and Malpelo islands; the marbled ray (*Taeniura meyeni*) which is not endemic and is vulnerable due to intense fishing pressure in southeast Asia; and the endemic black stripped salema (*Xenocys jessiae*) (Table 3).

The majority of the abundance of IUCN vulnerable species are represented by the Galapagos ring-tail damsel fish, *Stegastes beebei* (65% in rocky habitats, 90% in corals and 34% in mangroves), and the black-striped salema (33% in rocky, 3% in corals and 54% in mangroves, Table 4). Only one of the species, the marbled ray (*Taeniura meyeni*), overlaps as vulnerable on the IUCN red list and is very highly vulnerable FishBase (Table 2,4). The trophic levels of IUCN vulnerable species can be used to make inferences about the functional ecology of these species (Table 4, Table 5). The mean trophic levels were higher for FishBase species as compared to IUCN species which demonstrates that the vulnerable species from each vulnerability measure are functionally different in terms of their trophic position (Table 5).

Biodiversity analysis:

Although mangroves were shown to host the most vulnerable species, a two-way ANOVA demonstrated that the ecosystem with the highest richness ($F= 19.85_{2,56}$ $p<0.05$, Figure 4a) and abundance (Kruskal-Wallis $\chi^2(2) =15.71$ $p<0.05$, Figure 4b) was corals, followed by rocky and lastly mangroves. The richness showed a significant difference between seasons ($F=6.651_{1, 56}$ $p<0.05$), with El Niño conditions having higher richness, however no significant difference was detected between seasons for abundance ($p>0.05$, Figure 4b). Furthermore significant differences were detected for the Shannon index among ecosystem types ($F=6.929_{2, 56}$ $p<0.05$) with the corals and rocky ecosystems having higher diversity than mangrove ecosystems, but no significant effect was observed between seasons ($p>0.05$, Figure 4c). An interaction effect was observed in a two-way ANOVA between season and ecosystem ($F=3.346_{2,56}$ $p<0.05$) for the Shannon index, though no trend was detected for this interaction (Figure 4c). The data was normally distributed for richness and the Shannon index (Shapiro-Wilks test $p>0.05$ both), but not for abundance (Shapiro-Wilks test $p<0.05$).

DISCUSSION:

Habitats that host intrinsically vulnerable species:

The highest concentration of intrinsically vulnerable species (>70 from FishBase), were found in the mangrove habitats followed by the coral habitats and lastly the rocky reef habitats (Table 2, Figure 3a). The intrinsically vulnerable species encountered in this study include: the spotted eagle ray (*Aetobatus narinari),* the diamond ray *(Dasyatis brevis),* the pacific dog snapper (*Lutjanus novemfasciatus)* the marbled ray (*Taeniura meyeni*), and the white tip reef shark *(Triaenodon obesus,* Table 2*).* In addition to being highly vulnerable, these species may also play a significant role in structuring the ecosystem, because they occupy high trophic levels (Estes et al. 2011; Myers and Worm 2005; Duffy 2003; Tables 2 and 5). These findings demonstrate the importance of mangroves as habitat types that host intrinsically vulnerable species. Mangroves serve as juvenile breeding grounds for many species including vulnerable elasmobranches, because they serve as a habitat refuges due to their structural heterogeneity (Blaber 2000; Laegdsgaard and Johnson 2001) and therefore may serve as refuges from artisanal fishing pressure.

The only study area near a no-take zone is the most northeastern point near the coral habitat Punta Pitt (Figure 1). However, this study highlights the necessity to protect mangroves as at least equally important for preventing further extinctions because of their role as hosts of intrinsically vulnerable species. Many fish species inhabit mangroves for part of their diurnal cycles because mangroves may be unavailable during times of the day when the tide is out, their habitat changes forming an interconnective mosaic of habitats, which helps form complex trophic structures, and highlights the need for biological connectivity between habitat types to protect fish species (Mumby et al. 2004; Sheaves 2005; Unsworth et al. 2008).

While mangroves hosted more vulnerable species in this study, corals had the highest biodiversity in terms of richness and abundance, closely followed by rocky habitats. In comparison, mangroves had considerably lower richness and abundance per transect (Figures 4a and 4b, $p<0.05$). Moreover, mangroves also had the lowest biodiversity per transect using the Shannon diversity index, when compared to rocky and coral ecosystems (Figure 4c,

$p<0.05$). Numerous studies have documented the immense biodiversity of coral reef ecosystems and as a result managers have recognized these areas as being of high conservation priority (Mora et al. 2006; Hughes et al. 2003; Bellwood et al. 2004). However, the value of mangroves, and connectivity between mangroves and adjacent habitats, particularly corals, has been overlooked in many management plans (Mumby et al. 2004).

Additionally, the vulnerability information gained by the fuzzy logic expert system has a potential use in studying species responses to climatic variables because there is overlap in the intrinsic characteristics that make species vulnerable to fishing pressure and to sudden climatic changes such as strong El Niño events. The frequency and intensity of strong El Niño events are expected to increase with climate change, which can have devastating effects on many Galapagos species and ecosystems (Valle and Coulter et al. 1987; Glynn 1988; Edgar et al. 2010). Life history traits such as low reproductive capacity, late maturation, slow growth and long generation time (Sadovy and Cheung 2003; Jager et al. 2008; Reynolds et al. 2005), would yield a population less likely to recover after an extreme climatic event that significantly diminishes the population. Thus, factors used to calculate intrinsic vulnerability can also be used when studying resilience of species and predict how populations might respond to sudden climate changes. This vulnerability data can be combined with IUCN red list data to create a more comprehensive assessment of species for which other information is lacking and can be used to model population responses to climatic events, though further research is needed to show the efficacy of using intrinsic vulnerability data to model responses to extreme climatic events. Additionally future research can use the FishBase methodology and concept of intrinsic vulnerability to apply to other marine species such as marine mammals, reptiles and invertebrates.

Habitats that host fish species on the IUCN red list

Of the 67 fish species encountered in this study, eight were classified as vulnerable on the IUCN red list of threatened species and none were classified as endangered or critically endangered. Rocky habitats had significantly more IUCN abundant species followed by corals and lastly mangrove ecosystems (Table 3, Figure 4b). The eight species from the IUCN red list would trigger KBA criteria indicating that all six sites analyzed are necessary for protection primarily due to endemism and the threat of strong El Niño events as well as the abundance of vulnerable species, which was greater than 30 individuals at all sites (Table 2, 3; Eken et al., 2004; Langhammer et al., 2007). In fact, most likely the majority of marine habitats in Galapagos would trigger KBA criteria because many sites have an abundance of more than 30 vulnerable species on the IUCN red list. When creating KBAs it is important to consider the functional ecology of the species being recommended for protection and the niches they occupy in the ecosystem, which can be inferred from information on trophic levels of the species.

Of the species on the IUCN red list, the sailfin grouper, the bravo clinid and the marbled ray are top predators (Table 2). The majority of the abundance of IUCN vulnerable species is represented by the Galapagos ring-tail damsel fish, (90% in corals, 65% in rocky reefs, and 34% in mangroves), and the black-striped salema (3% in corals, 33% in rocky reefs and 54% in mangroves, Table 3). The Galapagos ring-tail damsel fish and the black-striped salema are ubiquitous in Galapagos, but have been placed on the IUCN red list due to endemism, or their limited geographic range, and the threat of strong El Niño events. The Galapagos ring-tail damsel fish also occupies a comparatively low trophic-level of 2.95 and the black striped salema is higher at 3.4, but neither are top predators and may not play as significant of a role in structuring ecosystems as the species listed as vulnerable according the FishBase criteria (Table 3). FishBase vulnerable species have a higher mean trophic level than the IUCN red list species because the IUCN mean is heavily weighted by abundant lower trophic level species like the Galapagos ring-tailed damsel fish (Table 5). Thus, FishBase's vulnerable species may have a more significant role in structuring an ecosystem, as higher predators, as compared to the very abundant low-trophic level species on the IUCN vulnerable species list (Ferreti et al. 2010; Baum et al. 2003; Myers and Worm 2005; Myers et al. 2007).

A comparison between FishBase and IUCN methodologies for assessing vulnerability:

It is important to note that only one of the 67 species found in this study, the marbled ray (*Taeniura meyeni)*, overlaps as vulnerable on both the IUCN red list and FishBase 'very highly' vulnerable species (Table 2), which is contrary to my hypothesis that there is a high degree of overlap between the two measures. This indicates that the ecological and life history characteristics, which make a species intrinsically vulnerable are not necessarily the species with declining populations from extrinsic extinction drivers or there is a lack of data on many populations making it impossible to determine the degree of overlap. In contrast to Cheung et al.'s (2005) fuzzy expert system of assessing vulnerability, the IUCN red list of threatened species lists the spotted eagle ray, (*Aetobatus narinari)* , as near threatened with populations decreasing; the diamond ray (*Dasyatis brevis)* is listed as data deficient with population trends unknown; the pacific dog snapper (*Lutjanus novemfasciatus)* is of least concern with population trends unknown; the marbled ray (*Taeniura meyeni)* is listed as vulnerable with population trends unknown and the white tip reef shark (*Triaenodon obesus)* is listed as near threatened with population trends unknown (Table 2, IUCN 2011.2).

For only one of these five species, the spotted eagle ray, is the population trend known on the IUCN database and one species, and the diamond ray is too data deficient to make an assessment, which demonstrates that many species without sufficient data may be in need special conservation efforts. The lack of data is also exemplified by the fact that ten of the 67 species encountered in this study were not assessed on the IUCN red list, which highlights the necessity for more research to assess population trends and legitimizes the use of vulnerability measures that do not require as extensive data sets, such as FishBase's intrinsic vulnerability assessment for which all species found in this study were given a vulnerability score. In the Eastern Tropical Pacific half of the 16% of bony fishes listed as data deficient on the IUCN red list are threatened by heavy overfishing, but lack demographic and catch statistics to determine their threat status (Polidoro et al. 2012). Furthermore, approximately 45% of marine mammals and cartilaginous fishes in the tropical eastern pacific are classified as data deficient (Polidoro et al. 2012). In this study population trends were known for only 20 of the 67 species encountered therefore, our lack of knowledge on declining marine populations may not be adequate to fully define priority areas through IUCN criteria alone.

In comparison to the rays, shark and predatory fish listed as having 'very-high' intrinsic vulnerability by FishBase, the species identified as vulnerable by the IUCN red list appear to be less of a concern due to their ubiquity, and the fact that they have more prevalent habitats since rocky reefs are over 90% percent of Galapagos subtidal habitats (Bustamante 2002). For example, the Galapagos ring-tail damsel fish and the black-striped salema have both been given a low intrinsic vulnerability rating (both 32 on the 1-100 scale, Table 3) by

FishBase's fuzzy logic expert system because they possess life history traits that make them not intrinsically vulnerable including small maximum lengths and relatively short generation times (Hutchings and Reynolds 2005; Reynolds et al. 2005; Cheung et al. 2005). However, the black striped salema has been observed to be sensitive to strong El Niño events, since the species disappeared from many study sites after the 1987/88 El Niño event for a period of two years before populations recovered (Allen et al. 2010a). Also, the Galapagos ring-tailed damsel fish's habitat is restricted to less than 2000 km^2 globally and Galapagos is thought to be the only viable self-sustaining population. The population declined by 50% following the 97-98 EL Niño event, though it recovered within one year (Allen et al. 2010b). Endemism is an important variable to factor in when creating marine protected areas, however efforts should evaluate the abundance of endemic species in conjunction with availability of habitat.

While the IUCN red list criteria allows for some uncertainty, many of these parameters require extensive research on threats and an understanding of the specific populations of these species (Mace et al. 2008). The IUCN red list therefore provides information about species of the most pressing concern based on actual population numbers or perceived threats, whereas FishBase's fuzzy expert system provides information on the likelihood of these species to be unable to recover from natural and anthropogenic pressures due to life history and ecological traits (Table 1). If we apply the precautionary principle to marine management, the fuzzy expert system can provide a useful analysis in protecting species before populations are on the decline or under threat, at which point the IUCN red list would detect these species. Edgar et al. 2008a applied the KBA criteria in the Galapagos Marine Reserve and demonstrated several sites which should be protected because they host species on the IUCN red list that were listed as either vulnerable, endangered or critically endangered. However, these sites are selected on pre-existing knowledge about areas that had been known to host vulnerable species and the study also demarcates areas based on presence or absence rather than a distribution of vulnerable species' abundances. Additionally, there was no connectivity suggested between the recommended KBAs, toward which further investigation is necessary since many vulnerable species such as elasmobranches and large bony fishes utilize multiple habitats throughout their life cycles (Hooker et al. 2011; Ferreti et al. 2010; Mumby et al. 2004; Nagelkerken et al. 2009).

Nonetheless these studies are necessary to provide decision-makers with adequate information based on scientific research to take appropriate action in preventing biodiversity loss. Recently this year, an over 45 million dollar conservation project was approved in the Philippines with the objective of improving MPAs using KBA methodologies as a basis for identifying areas in need of protection (GEF 2012). This project is co-funded by the Global Environmental Facility (GEF) via the United Nations Development Programme (UNDP) in conjunction with private investors and several NGOs including Conservation International (GEF-UNDP 2012). These programs are examples of ecosystem-based management strategies that could be facilitated by incorporating various methodologies for assessing vulnerable species, such as the fuzzy logic expert system, which requires fewer data, in order to ensure more timely and precautionary management strategies. The fuzzy logic expert system can be applied to non-fish species such as marine reptiles, mammals and invertebrates to make a more comprehensive assessment.

MPAs are selected based on habitat preferences of vulnerable species and several other attributes such as biogeographic representation, habitat availability, and socioeconomic factors among others (Hooker et al. 2011, Leslie 2005). For the intrinsically vulnerable species identified in this study, further research could focus on species maps divided into age-structured and behavioral categories to link demographic studies with monitoring and modeling population trends to use a more accurate space-based approach to ensure the protection of these species, even if their populations are not currently declining (Hooker et al. 2011; Ashe et al. 2010). From a socioeconomic perspective, intrinsically vulnerable species are also species that are attractive to tourists. For example of the species observed in this study, the white tip reef shark, the eagle ray, the marbled ray, and the diamond ray are among the most appealing fish in Galapagos for divers and snorkelers. In Galapagos tourism is particularly important since it generates over 100 million dollars yearly, thus, the interests of the tourism industry and conservationists overlap providing further reason to protect the habitats of these species (Epler 2007). The effective implementation of conservation programs depends on the ability of stakeholders to minimize the tradeoffs between conservation and economic objectives to determine the optimal planning strategy (Cheung and Sumaila 2008).

FishBase's fuzzy expert system or the IUCN red list may be the more appropriate assessment to use in MPA design depending on the context of the conservation sites and the specific objectives of the institutions and stakeholders creating protected areas. Decision makers should be aware of the scope of their objectives to determine the degree to which they want to integrate the different vulnerability criteria, since the scope of our conservation objective can greatly influence vulnerability assessments and prioritization of conservation areas. The FishBase assessment can be useful in identifying species that play an important ecological role such as top predators, which protect the ecological integrity of ecosystems. At the same time the IUCN criteria provide a more global perspective and identify vulnerability with emphasis on endemism and world-wide population numbers. If we use the IUCN criteria, most likely all of Galapagos will trigger the threshold for identification of KBAs, which highlights the importance and uniqueness of Galapagos from the global perspective. From this global perspective the IUCN criteria would be more appropriate to use in suggesting that all areas of Galapagos be protected as no-take zones. However, it is not realistic to prohibit fishing in all of Galapagos due to local political and socio-economic interests in maintaining fisheries (Davos et al. 2007, Baine et al. 2007; Ruttenberg 2001). Therefore, in the context of Galapagos the FishBase vulnerability assessment is more useful in identifying local habitat hosts of vulnerable species important for maintaining trophic structures.

Because management strategies are more effective when there is cooperation between socio-economic objectives and ecosystem based strategies (Arkema et al. 2006, Slocombe 1993, Imperial 1999), intrinsic vulnerability measures are more appropriate for Galapagos as a unique case with high levels of endemism and conflicting interests (Davos et al. 2007; Heylings and Bravos 2007; González et al. 2008). Intrinsic vulnerability measures can be incorporated into KBA methodologies, which would provide greater time and cost efficacy in identifying KBAs, due to lower data input requirements, and would operate under the framework of the precautionary principle and ecosystem-based management. For conservation programs elsewhere, decision-makers can create more comprehensive management strategies by employing various conceptual frameworks of vulnerability, depending on the local context and resources available for the development of conservation areas.

CONCLUSION:

The methods by which vulnerability are assessed can yield entirely different conclusions as to which areas or habitat types host the most vulnerable species. The fuzzy logic expert system used on FishBase employs life-history and ecological traits and can potentially be extended to determine vulnerability to climatic variables such as increasingly strong EL Niño events, though long-term research is necessary to determine the efficacy of using this method for that purpose. Additionally the concept of intrinsic vulnerability and the methodology used to assess species on FishBase can be extended to include other marine species such as mammals, reptiles and invertebrates to make a more comprehensive assessment. The two vulnerability assessments discussed, coupled with biodiversity data can help managers make better-informed decisions when identifying conservation priorities. Furthermore the prevalence of habitat types is important to consider, for example corals and mangroves are a relatively small portion of the coastal habitat types available on the islands, yet mangroves have the greatest concentration of intrinsically vulnerable species, and corals host the greatest biodiversity. Therefore, although rocky reef habitats were shown to have the greatest abundance of IUCN vulnerable species due to the presence of two very abundant endemic species, protection efforts may be better directed toward mangroves and corals due to their low prevalence on the islands and their capacity to host species that structure ecosystems such as top predators as in the case of mangroves, or corals as habitats that contain a high level biodiversity.

Ultimately, the vulnerability assessment employed depends on the scope and objective of the conservation project. Both FishBase's intrinsic vulnerability assessment and the IUCN red list has applicability in the conservation of marine species, as long as objectives are clear and various stakeholders' needs are incorporated into the management strategy. KBA methods can be extended to include other vulnerability measures when IUCN assessment is unavailable or there is a site-specific reason that FishBase criteria is more applicable, as in the case of the GMR. The use of a combination of conceptual frameworks defining vulnerability according to both external threats and intrinsic characteristics can aid decision makers in effectively minimizing biodiversity loss from the perspective of local, regional or global conservation objectives.

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APPENDIX

TABLES:

Table 1. A comparison of criteria analyzed by FishBase and IUCN vulnerability assessments. X* indicates these factors are considered as they relate to population trends, therefore these factors are dependent on other information.

Criteria:	IUCN red list	FishBase's fuzzy expert system
Population trends	X	
Number of mature individuals	X	
Limited geographic range/distribution	X	X
Small population size	X	
Population viability/habitat degradation projections	X	
Maximum length		X
Age at first maturity	X*	X
Von Bertlanaffy growth parameter (K)		X
Natural mortality rate	X*	X
Maximum age	X*	X
Fecundity	X*	X
Spatial behavior strength		X

Table 2. Percent composition, IUCN assessment and trophic levels of very highly vulnerable species (>70) calculated from fuzzy logic expert system. Vulnerability and trophic level information was taken from FishBase. IUCN assessments: NT (near threatened), DD (data deficient), LC (least concern) and VU (vulnerable).

Intrinsically vulnerable species	**Mangrove**	**Rocky**	**Coral**	**IUCN assessment**	**IUCN population trend**	**Trophic Level**
Aetobatus narinari	1%	-	-	NT	decreasing	3.24
Dasyatis brevis	6%	-	50%	DD	not assessed	3.85
Lutjanus novemfasciatus	59%	-	-	LC	unknown	4.1
Triaenodon obesus	31%	-	-	NT	unknown	4.19
Taeniura meyeni	3%	100%	50%	VU	unknown	4.2
Total abundance per transect	1.55 (+/- 0.548)	0.028 (+/- 0.028)	0.141 (+/- 0.102)			

Table 3. IUCN vulnerable species range, population trends, threats and endemism (IUCN 2011.2). Trophic level information obtained from FishBase.

IUCN Vulnerable species	**Range**	**Population trends**	**Threats**	**FishBase vulnerability score**	**Trophic Level**
Acanthemblemaria castroi	Galapagos	unknown	El Niño events Restricted range Habitat alteration	10	3.43
Hippocampus ingens	Not endemic	decreasing	By-catch Habitat degradation	27	3.26
Labrisomus dendriticus	Galapagos and Malpelo islands	unknown	El Niño events Restricted range	10	3.98
Mycteroperca olfax	Galapagos, Cocos and Malpelo islands	unknown	Overfishing Restricted range	56	4.5
Stegastes beebei	Galapagos	unknown	El Niño events Restricted range	32	2.95
Taeniura meyeni	Not endemic	unknown	Fishing By-catch	77	4.2
Xenichthys agassizii	Galapagos	unknown	El Niño events Restricted range	25	3.36
Xenocys jessiae	Galapagos	unknown	El Niño events Restricted range	32	3.4

Table 4. IUCN vulnerable species and percent of species abundance out of total abundance of vulnerable species counted per ecosystem. Average abundance per transect per ecosystem +/- 1 S.E.M.

IUCN Vulnerable species	**Rocky reefs**	**Mangroves**	**Coral**
Acanthemblemaria castroi	0.06%	0%	0%
Hippocampus ingens	0%	0.38%	0%
Labrisomus dendriticus	1.00%	0.38%	1.01%
Mycteroperca olfax	0.25 %	1.53%	0.93%
Stegastes beebei	65.07%	34.87%	90.87%
Taeniura meyeni	0.03%	1.15%	0.23%
Xenichthys agassizii	0%	7.66%	3.87%
Xenocys jessiae	33.59%	54.02%	3.09%
Total abundance per transect	59.96 (+/-13.23)	26.61 (+/- 4.34)	4.31 (+/- 1.51)

Table 5. Trophic level comparison of vulnerable of species from FishBase and from the IUCN, calculated based on relative abundances of fish species for all transects summed over study period.

Ecosystem	FishBase vulnerable species mean trophic level	IUCN vulnerable species mean trophic level
Rocky	4.2	3.11
Coral	4.02	3.02
Mangrove	4.1	3.27

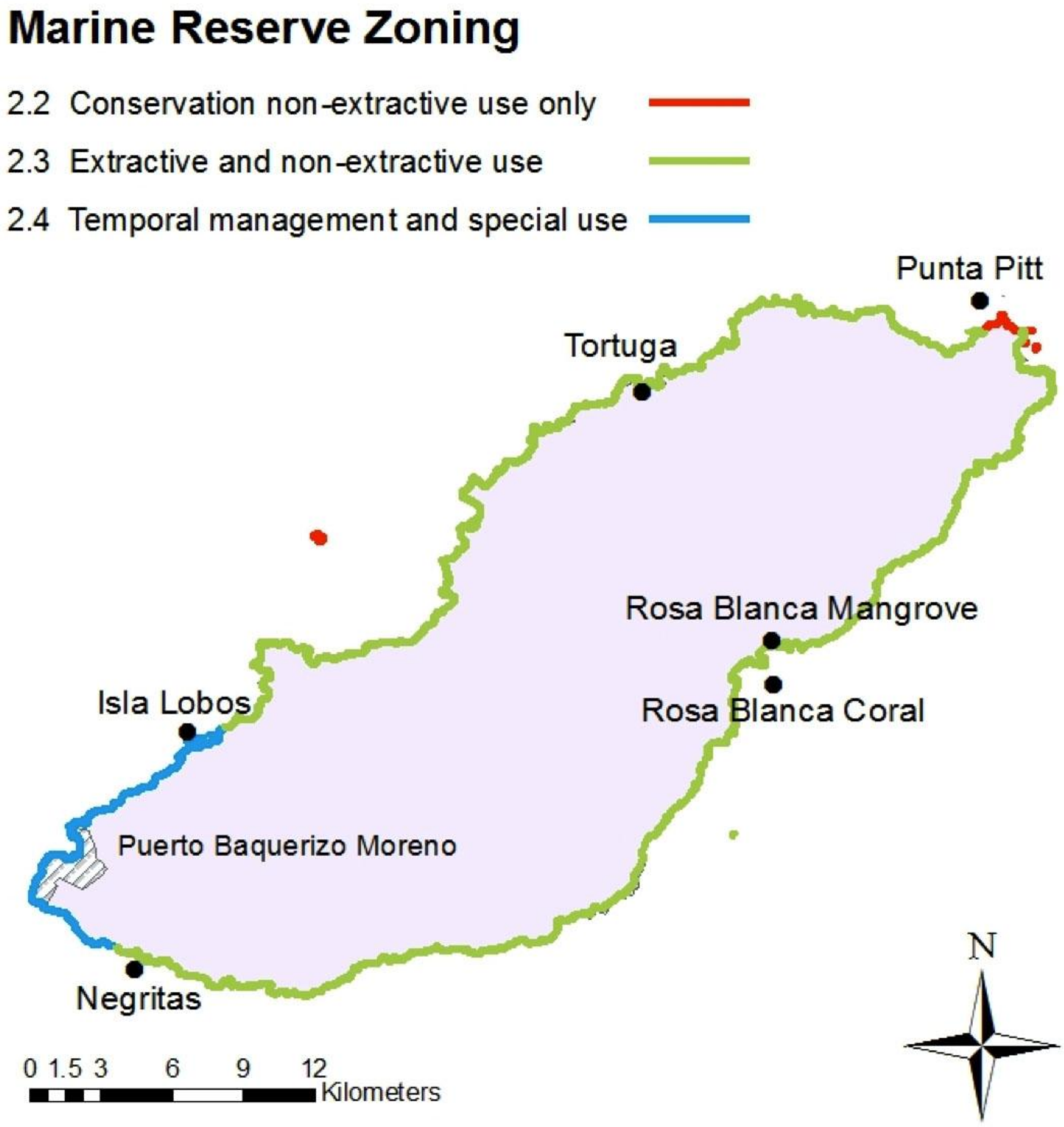

Figure 1. Map of San Cristóbal island, The six sites where the study was conducted are at the following coordinates: Negritas (Rocky) 0º56’29.74” S and 89º35’07.84” W; Isla Lobos (Rocky) 0º51’34.07” S and 89º33’42.69” W; Rosa Blanca (Coral and Mangrove) 0º48’29.50” S and 89º20’32.00” W; La Tortuga (Mangrove) 0º42’28.12” S and 89º24’28.39” W; Punta Pitt (Coral) 0º41’58.99” S and 89º14’42.24” W (Galapagos National Park Marine Reserve Zoning).

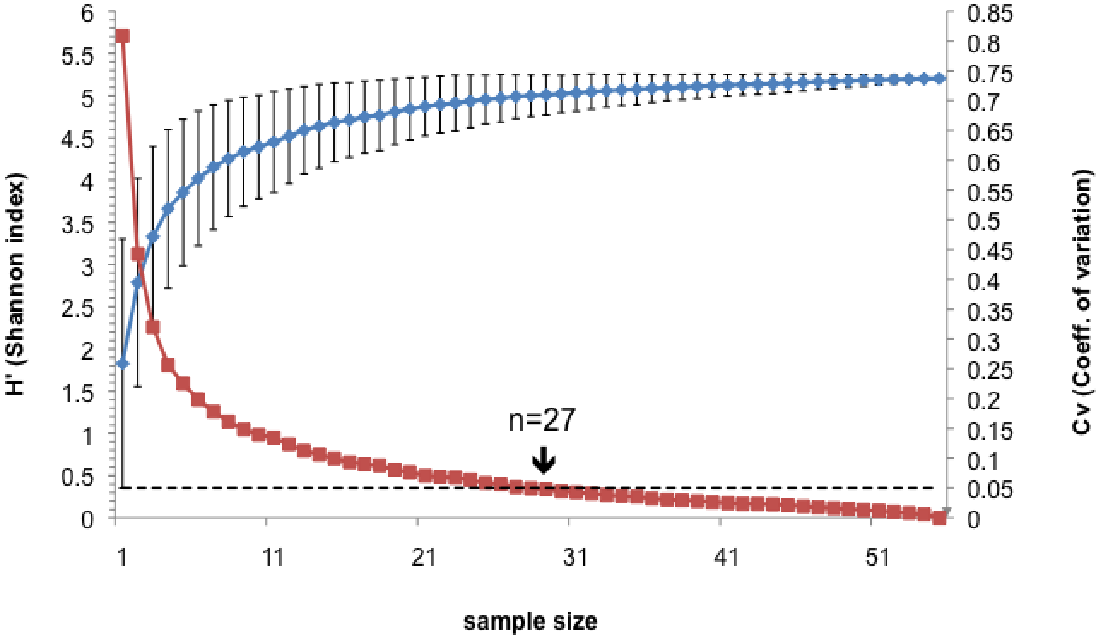

Fig. 2 a. Mean cumulative fish diversity curves and SD based on samples collected at two coral ecosystems, Punta Pitt and Rosa Blanca. Cumulative diversity is based on Shannon index (H'). n=optimum sample size, 27

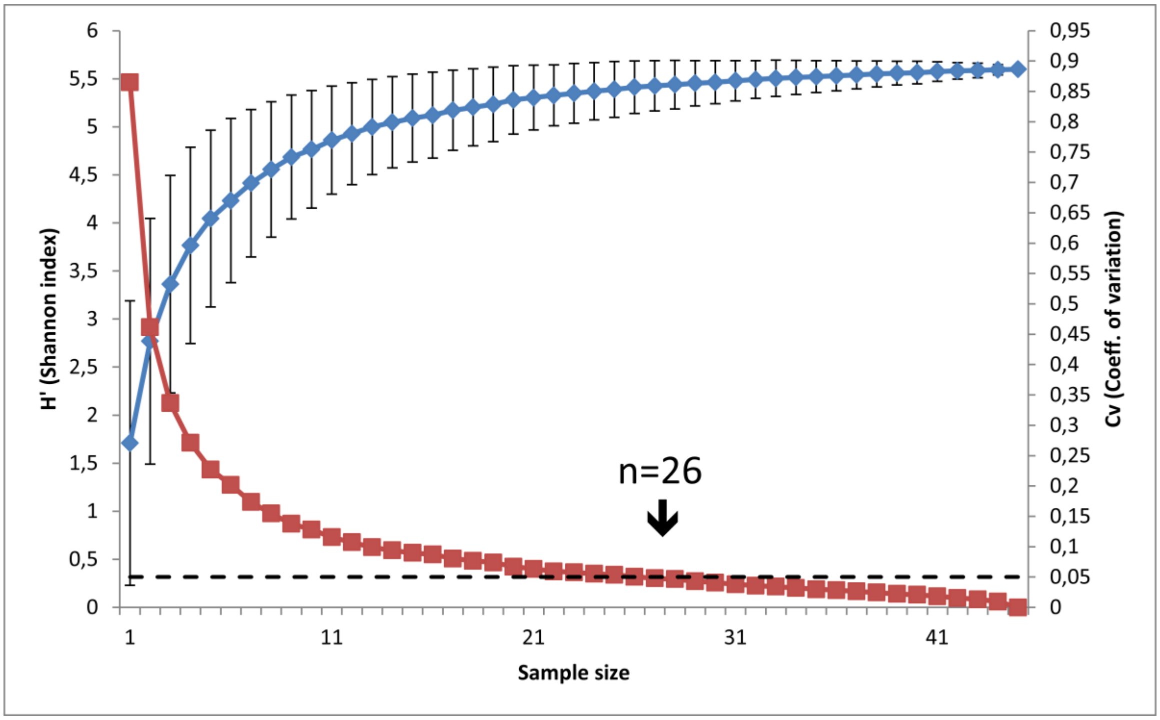

Fig 2.b. Mean cumulative fish diversity curve and SD for mangrove ecosystems based on transects conducted at two mangrove ecosystems, Tortuga and Rosa Blanca Mangrove. Cumulative fish diversity based on Shannon index (H'). n=optimum sample size, 26

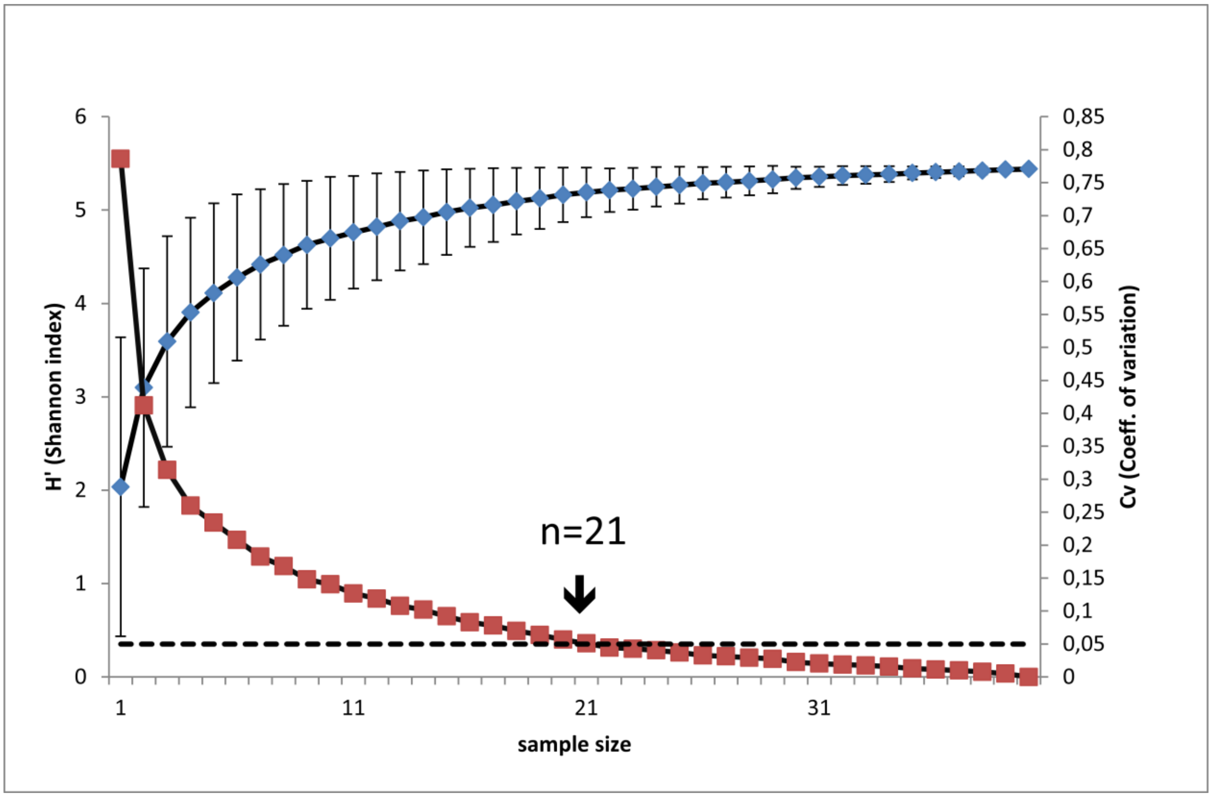

Fig 2.c. Mean cumulative fish diversity curve and SD for rocky ecosystems based on transects conducted at two rocky ecosystems, Negritas and Isla Lobos. Cumulative fish diversity based on Shannon index (H'). n=optimum sample size, 21

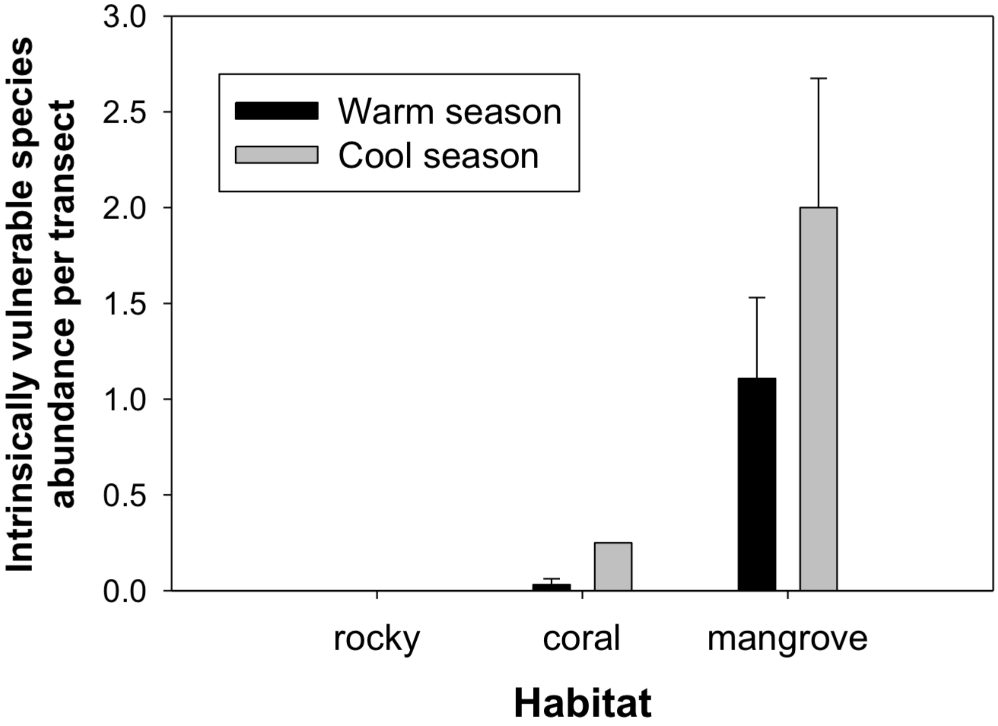

Figure 3.a. Abundance per transect of FishBase's 'very high' intrinsically vulnerable species in habitat type and season. +/- 1 S.E.M

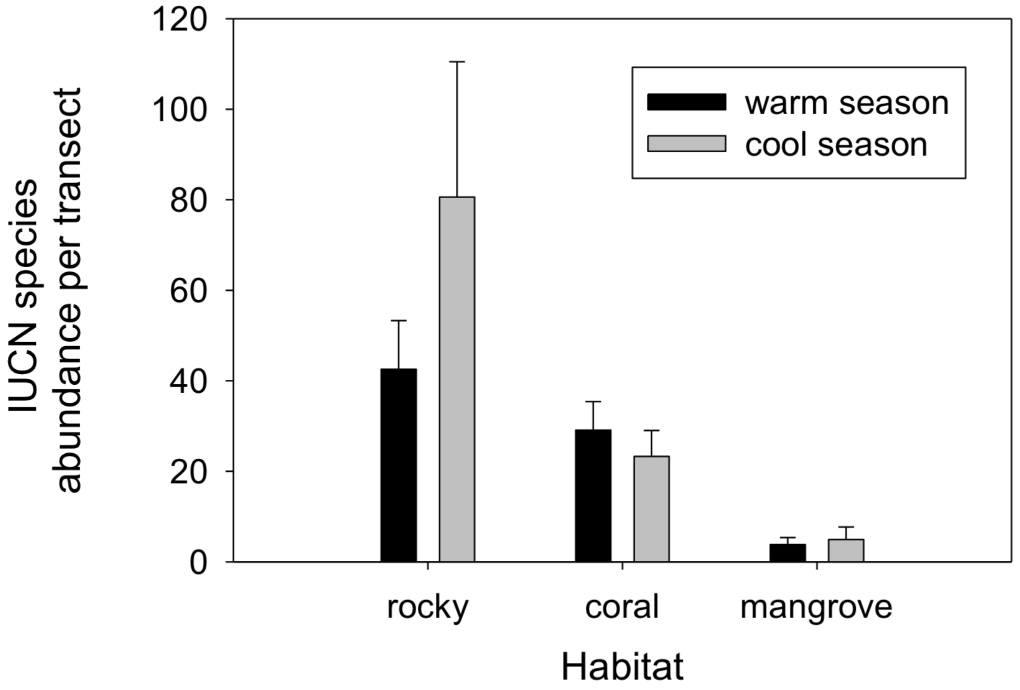

Figure 3.b Average abundance per transect of IUCN vulnerable species in habitat types and season. +/-1 S.E.M

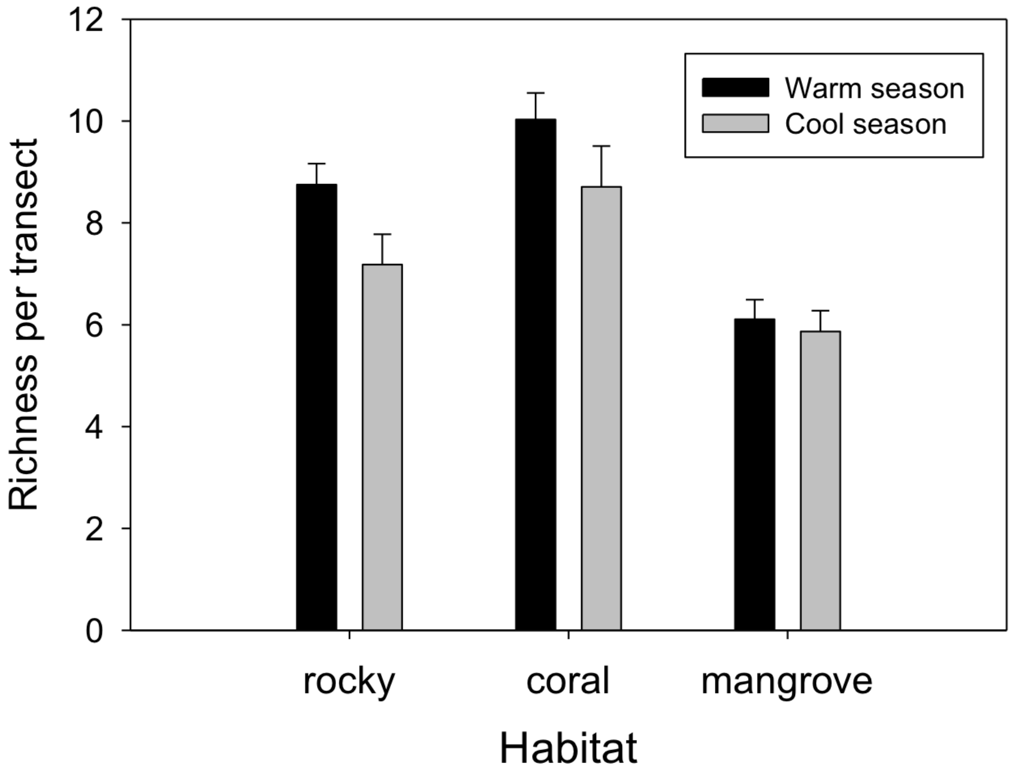

Fig. 4 a. Richness per transect in habitat types and season. +/- 1 S.E.M.

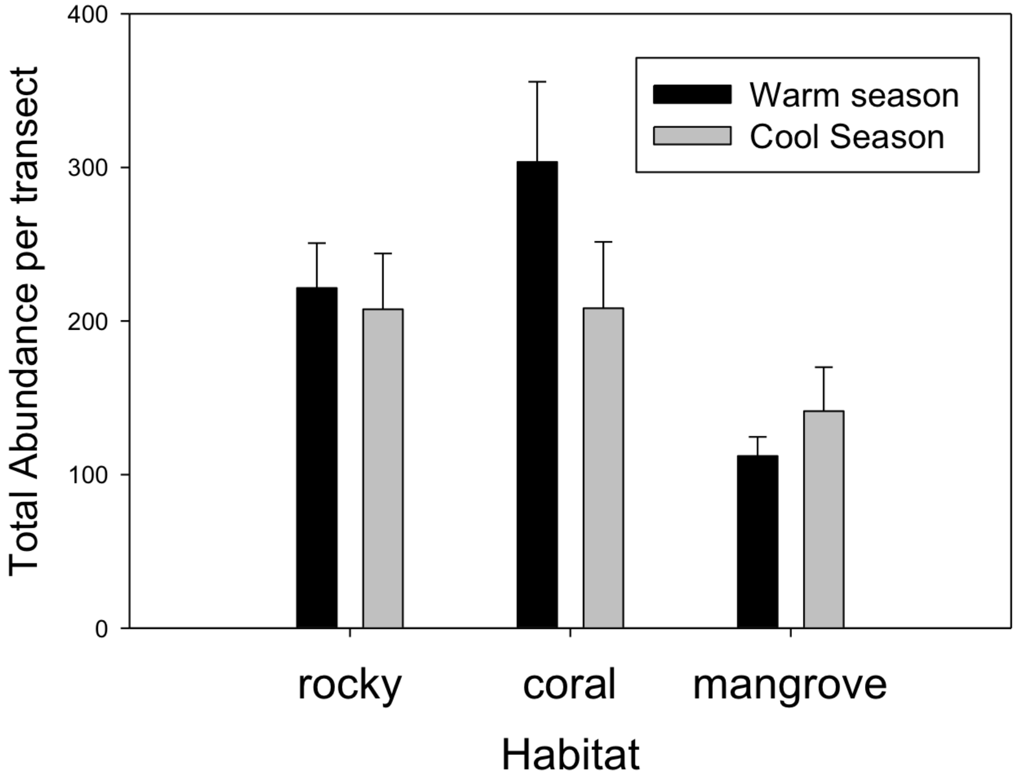

Fig. 4 b. Average total abundance per transect in habitat types and season. +/- 1 S.E.M.

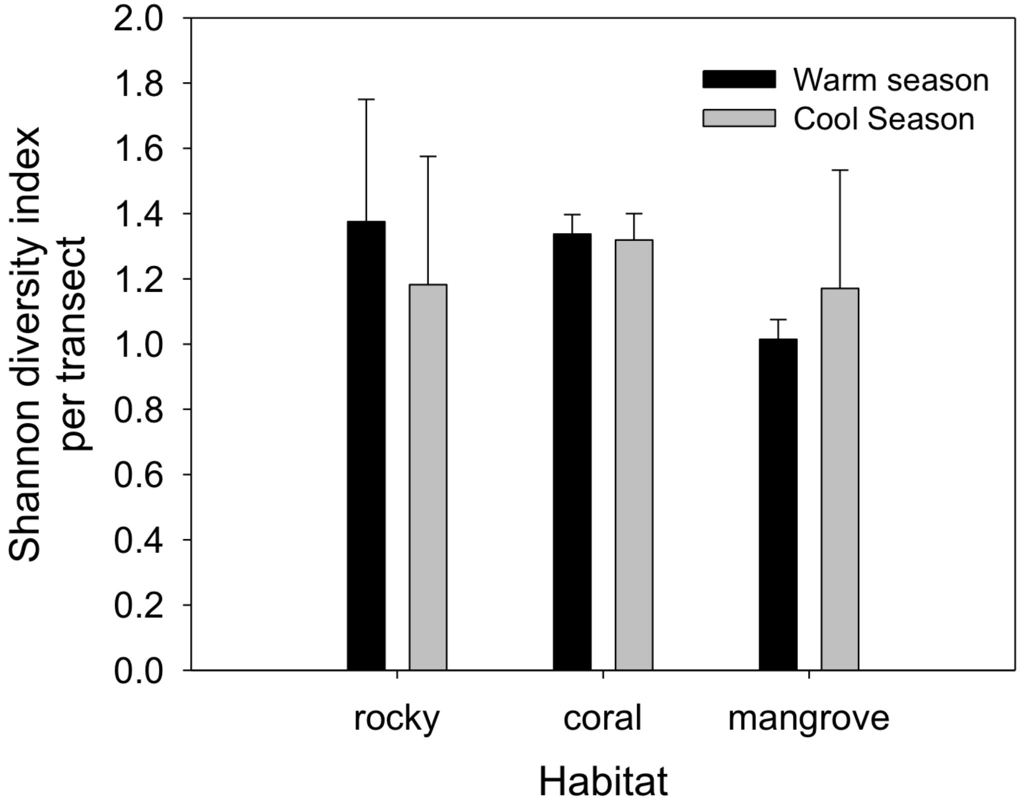

Fig. 4 c. Average shannon diversity index per transect by habitat and season. S.E.M. +/-1