Anthropogenic influences on fish assemblages in the Recherche Archipelago.

Ella Rosengart

Supervised by:

Professor Jessica Meeuwig.

School of Biological Sciences and the Oceans Institute, The University of Western Australia

Co-supervisor:

Professor Dirk Zeller

School of Biological Sciences, The University of Western Australia

Journal: Conservation Biology

This thesis is submitted in partial fulfillment of the requirements for a Masters of Biological Science

Masters of Biological Science

BIOL5555 Research Dissertation

School of Biological Sciences

Faculty of Science

University of Western Australia

25th May 2020

Word Count: 5113

THE UNIVERSITY OF WESTERN AUSTRALIA

School of Biological Science

Faculty of Science Assignment Cover Sheet

Name/s and Student Number/s	X Individual ☐ Group
1. Ella Rosengart 21536869	4.
2.	5.
3.	6.

It will be assumed that all group members have equally participated in group assignments, unless other arrangements have been made to notify lecturer of participation levels.

UNIT CODE: BIOL5555	UNIT NAME: Research Dissertation
UNIT COORDINATOR/LECTURER: Mandy Ridley & Jan Hemmi	DAY/TIME DUE: 27th May 2020, 17:00
TITLE/TOPIC OF ASSIGNMENT: Anthropogenic influences on fish assemblages in the Recherche Archipelago	WORD COUNT: 5113
	OFFICE USE ONLY:

The Faculty of Science adheres to the University Policy on Academic Dishonesty which constitutes misconduct and is dealt with under the University's Statute 17 (http://www.governance.uwa.edu.au/statutes/statutes/discipline). These guidelines make reference to the following:

- **Cheating** in tests or examinations, e.g., copying from another student, or taking unauthorized materials into the test or examination room.
- **Plagiarism**, i.e., presenting another's work as though it were one's own, for instance quoting or paraphrasing someone else's opinions, arguments or research findings, whether published or unpublished (e.g., from a book or article, an internet site, or another student's assignment), without clear acknowledgement of the source. You may quote material from another source, but if you do so, the quotation must be word perfect and, in addition to citing the source reference in the usual manner, the beginning and end of the quotation must be clearly indicated by quotation marks. E.g. "quotation"
- **Falsifying results** of experiments or research studies.
- **Collusion**, e.g., writing an assignment jointly and submitting it as the work of one individual. Although discussion and co-operation are valuable in the pursuit of knowledge and understanding, any work submitted for assessment must be the individual's own work unless it is clearly designated a group project.
- **Helping someone else to commit any dishonest act** such as those listed above.

The consequences for misconduct can be severe, including exclusion from the University. All students are expected to make themselves aware of the definitions and policies relating to academic misconduct, (http://www.governance.uwa.edu.au/procedures/policies/policies-and-procedures?policy=UP07%2F21), and with any additional requirements or stipulations that may be provided by individual unit co-ordinators.

Late Assignments
There are penalties for late assignments. Refer to the unit outline for more information.

NO ASSIGNMENT WILL BE ACCEPTED UNLESS THE FOLLOWING DECLARATION IS SIGNED AND DATED

DECLARATION

I/We certify that I have read the University guidelines on Academic Misconduct. I/We certify that the assignment submitted online is my own work and that all material drawn from other sources has been fully acknowledged.

I/We certify that I am aware that the work submitted under this declaration is submitted to an online plagiarism detection service for analysis and that the work may be stored in a database either internal or external to the University. I/We have a photocopy or electronic copy of this assignment in my possession.

Sign: Ella Rosengart	Date: 25/05/2020	Sign:	Date:
Sign:	Date:	Sign:	Date:
Sign:	Date:	Sign:	Date:
Submission date: 25/05/2020			

FACULTY OF SCIENCE

Abstract

Anthropogenic activities have progressively deteriorated marine ecosystems and fish populations causing visible changes in fish assemblage diversity, abundance, biomass and size. Growing exploitation from fishing has led to global decline in fish catch since 1996. Remote regions can have higher abundances of fish as they are not heavily exposed to anthropogenic influences making them appear “pristine”. The Recherche Archipelago is one such remote region located approximately 700 km south of Perth, Western Australia, and is home to a wide diversity of marine habitats and fishes including high proportions of endemic species. This region is considered to be relatively minimally impacted by anthropogenic activities. Using stereo baited remote underwater videos, fish assemblage was sampled at ten sites located across three regions: West (near Esperance), Middle and East (most remote). Fish size was largest in the most remote region indicating that even in lightly populated region of Esperance, the effects of fishing are observable. Total abundance was highest in the West perhaps indicating a release from fishing and proliferation of smaller fish. Diversity and biomass did not vary across the region with the former being a conservation indicator of impact and the latter the product of abundance and size. Fish assemblage composition varied between all regions, either naturally or as a function of exploitation. The results point to the need for protection in the region despite its remote status, noting that currently no MPAs occur in State waters and the Eastern Recherche Marine Park in Commonwealth waters largely allows extraction of reef fish. The heterogeneity means that protection should be representative across the archipelago and, based on latest scientific advice, should compromise at least 30% in highly protected IUCN II (no-take) zoning. The results also provide a recent albeit confounded-by-exploitation baseline against which change, following protection, can be assessed. Finally, the study confirms, as is the case in other remote areas, remoteness in itself is insufficient protection.

Table of Contents

Abstract 3

Acknowledgements 5

Introduction 6

Methods 9

Fieldwork 9

Image analysis and data preparation 10

Statistical analysis 11

Results 11

Discussion 16

Management implications 19

References: 22

Supplementary Information 31

Acknowledgements

I would like to acknowledge and thank Professor Jessica Meeuwig and Professor Dirk Zeller for their patience, support and guidance during this incredible and daunting experience. Every moment has been a rollercoaster, but you have both taught me so much about the scientific community and what is expected. You have shared a wealth of knowledge that I hope to contribute to in the future.

I would also like to thank Andrew Forrest for supporting the field work on these reefs. Lincoln Hood for her incredible patience, moral support and willingness to help throughout this COVID-19 crisis. You have been so positive and welcoming, and my gratitude is endless. Hanna Jabour Christ, Sean van Elden, Chris Thompson, and Naima Lopez for giving up some of their previous time to explain calculations, help identify fish species, moral support, insights and general moral during a stressful time. Alex McLennan for taking his time to sit and ID check my first video analysis and help organize my metadata coordinates and deployments for my sampling design for my research. Adam Jolly, Nikki De Campe, Claire Raphael and Vyv Summers for helping ID check fish species and spending hours watching videos with me and teaching me how to identify, convert, use and set up the videos and software, without your patience and positive attitudes this experience would not have been the same.

I would also like to acknowledge my family and partner for their continued support during this experience. Without my families continued pestering I would not have agreed to go back to university and push myself to achieve my MSc., so thank you.

Introduction

There are few places left on the planet that are not adversely impacted by anthropogenic activities, although some of these effects of these pressures are difficult to observe in marine ecosystems (Lundeberg & Ripple 2019). The oceans are affected by climate change (Brander 2007; Rijnsdorp et al. 2009; Poloczanska et al. 2016) and are increasingly polluted with harmful plastics (Van Sebille 2015; Xanthos & Walker 2017; Chiba et al. 2018). However, fishing is an immediate and pervasive threat (Friedlander et al. 2010; Pauly & Zeller 2016; Tickler et al. 2018). Declines in fish populations are concerning as fish is a major food source for our planet, prized for its protein (Jadhao et al. 2003; Brander 2007). In addition to an important source of food security, fish can be of high economic value both as food (e.g the bluefin tuna) or as a recreational sport (Parmesan 2006; Brander 2013; Sueiro et al. 2020). For the purpose of this study 'fish assemblages' are fish that can reside between approximately 0-500 meters deep and are closely associated with the seafloor (Hill et al. 2018; Vega-Cendejas & de Santillana 2019).

Fishing dates back over thousands of years and was one of the first anthropogenic pressures on the marine ecosystem (Roberts 2007; Jackson & Alexander 2011). Currently, fish populations are in trouble with growing exploitation from fishing resulting in global declines in fish assemblages with peak catch in 1996 (Pauly & Zeller 2016). Over 33% of global fisheries have been overfished and 60% of global fisheries have been fished to their maximum capacity as of 2015 (FAO 2016). Fisheries are more often than not, unsustainable, with ongoing depletion even in advanced economies such as Australia. For instance, Edgar et al. (2018) estimated that Australian Fisheries declined by 31% between 2005 and 2015 with both Australian fish showing a 33% decrease in abundance and 36% decrease in biomass of exploited fish species and a 16% decrease in unexploited fish populations resulting in an overall decline (Edgar et al. 2018). Exploitation at higher trophic levels leads to a cascading phenomenon or "fishing down the food web" (Pauly et al. 1998). Overfishing, has shown to affect fish assemblage diversity, abundance, biomass and size (Novaglio et al. 2016). A paper by Pauly et al. (2002) The 'March of the folly' was coined, to describe deliberate overexploitation of fish stocks to gain monetary success with potential knowledge of the negative ramifications (Pauly et al. 2002).

Declines in fish population abundance impacts marine food webs and associated trophic structures, destabilizing predatory-prey relationships and ultimately marine ecosystems (Baum & Worm 2009; Barley et al. 2017; Meekan et al. 2018). Ecologically, fish assemblages also have numerous functions within a marine ecosystem including nutrient cycling (McIntyre et al. 2007) and habitat maintenance and are thus ecosystem indicators (Dorman et al. 2012; Edgar et al. 2018). Fish are also a major source of protein globally and are considered by some to be one of the most sustainable ways to feed humanity (Brander 2007; Hilborn et al. 2019). However, sustainable practices are a controversial topic of debate, with different perceptions on what constitutes as sustainable (Hilborn et al. 2004; Edgar et al. 2018). Ultimately if fisheries management is able to regulate food production without compromising future production, seafood can become sustainable (Hilborn et al. 2004, 2015, 2018; Edgar et al. 2018). This is particularly important in developing countries and coastal communities who depend heavily on their surrounding waters for food and livelihoods (Valmonte-Santos et al. 2016).

Recreational fishing contributes an estimated 1.81 billion AUD to the Australia economy with approximately 3.5 million recreational fishers annually (Lee 2013; Griffiths et al. 2014). In Western Australia, recreational fishers have substantially increased in number since the 1980s, with approximately 600,000 recreational fishers reportedly active statewide with 140,000 boat based licenses in 2014 (Industries & Development 2015). Most recreational fishing is either shore-based targeting school whiting (*Sillago bassensis, S. vittata and S. schomburgkii*), and Australian Herring (*Arripis georgianus*) or in small boats (< 3 m deep) targeting reef species such as dhufish (*Glaucosoma hebraicum*) and snapper (*Pagrus auratus*); 57% of boat based fishing occurs between 5-20 m deep and 27% in the "inshore demersal zone" greater than 20 m deep between (Ryan et al. 2019).

The historical and ongoing impact of humans on marine fishes is difficult to quantify. Prior to the 1880s, fish records were seldom recorded making it difficult to estimate or reconstruct catch data before the 19th century (Lajus et al. 2005). The lack of historical data prior to 1950 means that the reduction in fish diversity, abundance, biomass and size, relative to non-exploited periods is masked. First applied to fisheries by Pauly (1995), the concept of "shifting baselines" means declines are underestimate when measuring them from an already-exploited state. Fundamentally, scientists accept the current baseline data on species diversity, abundance, biomass and size and use it to assess changes during their own careers and not through history. Despite the lack of historical data, there are visible and significant differences in organisms today in comparison to 60 years ago due to increased fishing pressure (Genner et al. 2010; Pauly & Zeller 2016), interpretations of the significance of these declines is debated by ecologists and fisheries scientists (Edgar et al. 2018; Gaughan et al. 2019).

To understand the human “footprint”, scientists have also explored remote regions that are sufficiently distant from humans to reflect relatively unexploited or “pristine” environments (Graham et al. 2010; Letessier et al. 2019). Global analyses focused on remote regions have found that such areas tend to be dominated by apex predations (Friedlander et al. 2010) and are more resilient than areas close to humans (Graham et al. 2010; Perry et al. 2015; Juhel et al. 2018; Sala et al. 2018; Letessier et al. 2019). However, remoteness may not be a panacea given the global reach of fisheries (Juhel et al. 2018; Letessier et al. 2019). Even in remote areas, declines occur as seen in the Chagos Archipelago (Indian Ocean) where there was a reported 90% decline in reef sharks between 1975 and 2006 (Graham et al. 2010).

Improving our understanding of unexploited fish assemblages is helpful as it provides a window into what past ecosystems may have looked like prior to exploitation (Friedlander et al. 2010) which in turn can provide a more realistic estimate of fish declines due to extraction and build a strong case for extending Marine Protected Area (MPAs) coverage. MPAs increase biodiversity abundance, biomass and fish size (Lester et al. 2009; Graham et al. 2010; Koldewey et al. 2010) and build resilience (Bates et al. 2014; Mellin et al. 2016; Roberts et al. 2017). MPAs also often enhance fisheries productivity through the spillover effect (Goñi et al. 2010; Stamoulis & Friedlander 2013; Buxton et al. 2014; Di et al. 2016). Spillover is a process where as species population recovery increases, abundance of a species within an ecosystem of a species exceeds the size of the reserve and eventually ‘spills’ out of the MPA (Stamoulis & Friedlander 2013). Today MPAs are increasingly used to rebuild overexploited fisheries (Claudet et al. 2008). However, currently less than 3% of the global oceans are closed to fishing (Costello & Ballantine 2015; Roberts et al. 2017) and MPAs remain an underappreciated form of protection for fish populations (Roberts et al. 2017).

Commented [JM1]: Replace marine parks with MPAs throughout and check capitalisation so you don’t up with MPAS rather than MPAs. BUT CAREFULLY see comment below on name of ER park

The Recherche Archipelago is a remote location on Australia’s south west corner and is part of the Great Southern Reef (Bennett et al. 2016) and offers an opportunity to explore the status of reef fishes in a “pristine” region. More than 700 km from the state capital of Perth, the Recherche Archipelago’s regional population centre of Esperance numbers ~14000 people (Statistics 2020). The Recherche Archipelago is a 230 km network of 105 islands and ~ 1500 islets with high levels of endemism in its fish community (Kendrick et al. 2005). The archipelago has a long history of fishing dating back to the 1800s when sealers exploited seals for their skins and oil with, devastating impacts on the regional population (Ross Anderson et al. 2013). The waters of the Recherche Archipelago continue to experience both commercial and recreational fishing, although the effort is considered low by the WA Department of

Primary industries and Regional Development (Gaughan, D.J. & Santoro 2019). Currently there are no MPAs in the State waters (within 3 nautical miles of the coast), but within Australia's Commonwealth waters, the Eastern Recherche Archipelago Marine Park, includes a Special Purpose Zone (IUCN VI) and a National Park Zone (IUCN II). The Special Purpose Zone (the majority of the MPA) allows some forms of extraction from its waters whereas the National Park Zone does not permit any form of extraction. Coastal state waters surrounding islands and coastlines are currently unprotected and are a target for management protection.

Commented [JM2]: Do not change to MPA, this is the name.

Using stereo baited remote underwater video systems, we documented the fish diversity, abundance, biomass, size and composition across three regions of the Recherche Archipelago representing degrees of remoteness. Our hypotheses were that diversity, abundance, biomass and size would increase with distance from the population centre, Esperance. As a first baseline, albeit already likely shifted, this research will also provide data on the state of fish assemblages in the Recherche Archipelago to assist in the region's future management.

Methods

Fieldwork

The data were collected using stereo baited remote underwater videos (BRUVS) over a 20 day period during the Austral summer of 2019, from the 28th of January and the 16th February. Stereo BRUVS consist of a tripod galvanized steel frame that supports two high definition GoPro cameras on either side of a baited arm from which a cage with approximately 1 kg of pilchard (*Sardinops sagax*) is suspended. The cameras are 80 cm apart and each inwardly angled by 4 degrees to face the bait cage which is extended 1.2 m in front of the cameras. Stereo BRUVS are a non-lethal, method to sample and document diversity, abundance and size of fishes across habitats and depths (Harvey et al. 2013; Langlois et al. 2018). They are cost effective and can cover a broad sample area (Dorman et al. 2012). Stereo BRUVS are also valuable tools used to collect data on impacts of anthropogenic activities and inform management and conservation policies (Letessier et al. 2015). Standard procedures were followed in their deployment (Langlois et al. 2018; Przeslawski 2018).

During the survey, BRUVS were deployed at 300 stations, randomly stratified across two depth strata: the first between 5 and 20 m and the second between 21 and 40 m. The sampling effort was also stratified by region (West, Middle and East) and by sites within these regions, with sites typically associated with rocky reefs (Table 1; Figure 1). The BRUVS were also deployed a minimum of 200 m apart to reduce movement of animals between BRUVS

(Langlois et al. 2018). For the purpose of this study, a subsample of 222 deployments were selected across the sites and the three regions (Figure 1).

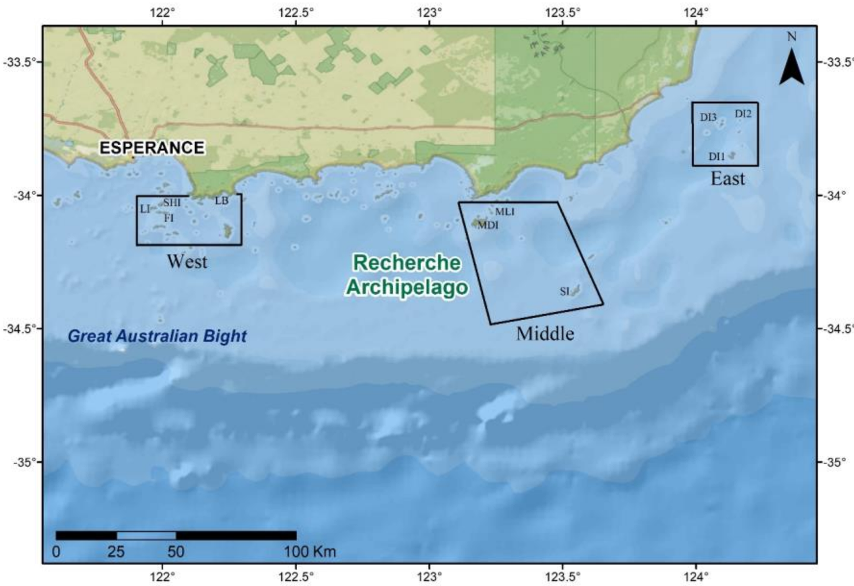


Figure 1. Map of the Recherche Archipelago by region West, Middle and East with sites labelled within regions.

Image analysis and data preparation

Stereo BRUVS were calibrated prior to deployment in the field in an enclosed swimming pool (Langlois et al. 2018). In the field, all imagery was saved on external hard drives in duplicates after which it was returned to the lab for conversion and image analysis. Xilisoft Ultimate converter software (Xilisoft Corporation 2019) was used to convert each individual GoPro video to a single continuous hour-long video. EventMeasure™ software (SeaGIS Pty Ltd 2014) was then used to analyze each individual video. Videos where a single camera were corrupt, obstructed or missing were processed through the single camera video available for taxa identification and abundance purposes only (n=22). Also excluded were videos with less than 45 minutes of footage (n=4) and those that were tipped over within the first 5 minutes (n=20). EventMeasure™ software was used to identify each individual fish to its lowest taxonomic level possible and to generate a conservative estimate of relative abundance Max*N*, the maximum number of individuals of the same taxa per frame (Harvey & Shortis 2014).

Fork length (FL) was estimated and mean weight (W) was based on the mean FL of each species on each deployment, using the length-weight relationships (LWR). The LWR relationship, **$W=a(FL)^b$** was used where 'a' is body shape parameters and 'b' indicates isometric growth in body proportions (Froese et al. 2014). Species-specific LWR were sourced from FishBase (Froese R. & Pauly D. 2019). Biomass was then estimated as the product of the mean weight and Max*N*.

Statistical analysis

For each BRUVS sample, species richness (SR) and total abundance (TA) were calculated as the total number of species recorded and the total number of individuals respectively. Mean length (FL) per BRUVS sample was calculated as the average weighted by Max*N*. Total biomass (TB) was calculated as the mean weight multiplied by the abundance of each species and summed for all species on the sample.

To test the hypothesis of regional differences in species richness, total abundance, total biomass and fork length a permutational analysis of variance (ANOVA) were conducted with site nested in region (Zar 2009). All variables, except species richness, were $\log_{10}(x+1)$ transformed to homogenize variance. Where there was a significant effect of region, a pairwise test was applied to determine where these regional differences occurred. To test for regional differences in species composition, the data were square root transformed to balance abundant and rare species. A Bray-Curtis similarity matrix was then calculated to address joint absences between species. As with the univariate analyses, site was nested in region to test for regional differences. A canonical analysis of principle coordinates (CAP) was then applied to visualize regional differences in species composition and determine which taxa most contributed to these differences. All univariate and multivariate analyses were completed in Primer 7 (Clarke & Gorley 2015).

Commented [JM3]: Only refer to restulst in results.

Results

The analysis is based on 222 samples across ten sites and three regions in the Recherche Archipelago (Table 1). A total of 22,690 individuals was recorded, representing 116 species in 89 genera and 58 families, with a collective biomass of 36.8 tonnes. Individual size ranged from a 1.72 cm siphon fish (*Siphamia cephalotes)* to a 3.04 m great white shark (*Carcharodon carcharias).* Per sample, the mean richness was 13 species, ranging between zero (2% of samples) and a maximum 28 species. There mean abundance was 102 fish, ranging from zero to a maximum1, 786 individuals. Thirteen families made up 94.8% of the

Commented [JM4]: Total is singular

Commented [JM5]: Round up

Recherche Archipelagos fish diversity: hulafish (Plesiopidae 36.96%), leatherjackets (Monacanthidae 12.48%), wrasses (Labridae 11.58%), trevallys (Carangidae 7.36%), scalyfins (Pomacentridae 6.46%), rock & sweep fish (Kyphosidae 4.89%), bullseyes (Pempheridae 3.72%), herrings (Clupeidae 3.46%), Australian herrings (Arripidae 2.14%), pikefish (Dinolestidae 1.86%), cods (Serranidae 1.78%), morwongs (Cheilodactylidae 1.08%) and silverbellys (Gerreidae 1.02%).

The most abundant species found was the small schooling hulafish (*Trachinops noarlungae*) with over 8,359 individuals observed. Moreover, 55% of the hulafish were found in the Middle region. The ocean leatherjacket (*Nelusetta ayraud*) was the second most common species with 2,420 individuals observed, 95% of which were found in the West region. Shark species found throughout the Recherche Archipelago included 22 Port Jackson sharks (*Heterodontus portusjacksoni*), 20 varied carpet sharks (*Parascyllium* sp.), 15 gummy sharks (*Mustelus antarcticus*), five whaler sharks (*Carcharhinus* sp.), three grey nurse sharks (*Carcharias* taurus), two great white sharks (*Carcharodon Carcharias;* only found in the East region), and two wobbegongs (*Orectolobrus* sp.).

Region had a statistically significant effect on abundance and fork length of fish (Table 2, Figure 2). Abundance declined with distance from Esperance and mean size increased. Species richness and total biomass did not vary with region. There was generally very little variability among sites within regions in terms of these attributes (Supplementary information Figure 1).

Table 1. Summary of 222 samples by region, West, Middle and East and site.

Region	Site	Mean Latitude	Mean Longitude	Mean Depth (m)	Mean Distance from Esperance (km)
West	Sandy Hood Isl	-34.04º	122.01º	23.4	22.4
	Long Isl	-34.04º	121.98º	22.2	21.0
	Frederick Isl	-34.07º	122.00º	24.9	24.2
	Lucky Bay	-34.00º	122.22º	20.5	34.5
Middle	Middle Isl	-34.10º	123.17º	23.4	120.7
	Miles Isl	-34.10º	123.27º	20.8	129.7
	Salisbury Isl	-34.34º	123.51º	22.4	158.4
East	Daw Isl 1	-33.85º	124.13º	21.3	207.2
	Daw Isl 2	-33.74º	124.16º	24.9	210.5
	Daw Isl 3	-33.73º	124.09º	22.5	204.3

Commented [JM6]: Single sig fig for all of these i.e. 204.3 not 204.25

Table 2. Analysis of variance (ANOVA) examining the difference in species richness (Diversity), total abundance, total biomass and fork length (size) as a function of regions (Re) and site nested in region (SiRe) and a multivariate analysis examining species composition. Each test was run with 999 unique permutations.

Analysis of Variance	df	SS	MS	Pseudo-F	P-Value
Species Richness					
Re	2	0.30516	0.15258	1.4141	0.303
Si(Re)	7	0.80358	0.1148	1.9295	0.067
Res	212	12.613	0.059495		
Total	221	14.128			
Log Total Abundance					
Re	2	4.9622	2.4811	12.127	0.003
Si(Re)	7	1.4531	0.20759	1.1307	0.367
Res	212	38.923	0.1836		
Total	221	45.007			
Log Total Biomass					
Re	2	0.84974	0.42487	1.2422	0.341
Si(Re)	7	2.5415	0.36307	1.8682	0.086
Res	212	41.202	0.19435		
Total	221	44.149			
Log Fork Length					
Re	2	0.93417	0.46708	6.3629	0.016
Si(Re)	7	0.54837	0.078339	2.0195	0.052
Res	212	8.2238	0.038792		
Total	221	9.5769			
Species Composition					
Re	2	39788	19894	2.3598	0.0304
Si(Re)	7	47269	6752.7	2.6121	1.00E-05
Res	212	5.48E+05	2585.1		
Total	221	6.35E+05			

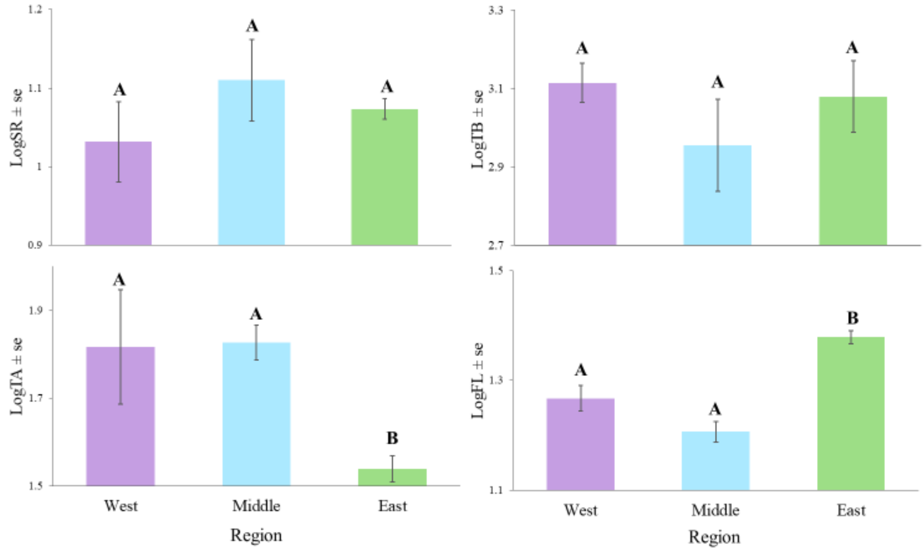


Figure 2. Mean value with standard errors (se) of log transformed species richness (SR), taxonomic abundance (TA), fork length (FL) and total biomass (TB) of fish assemblages by region, West, Middle and East. A and B represent statistically significant differences between regions.

A comparison of species richness, abundance, fork length and biomass were subsequently undertaken for fished and non-fished species within the Recherche Archipelago. There was no statistically significant effect of region on species richness, biomass or fork length for either fished or non-fished species. For total abundance, the same pattern was observed as with the combined data for fished species (p=0.02), driven by large numbers of juvenile ocean leatherjackets (mean FL = 12.9 cm; length at maturity = 35 cm) (Froese & Pauly 2019). There was no effect of region on size among non-target species.

Commented [JM7]: Check reference format.

Species composition varied between the three regions (Table 2, Figure 3.). The West region was characterized by the ocean leatherjacket and the sea sweep (*Scorpis aequipinnis).* The endemic herring cale (*Olisthops cyanomelas)*, southern Maori wrasse (*Ophthalmolepis lineolata)* and bluelined leatherjacket (*Meuschenia galii)* were typical of the Middle region with the rough leatherjacket (*Scobinichthys granulatus)* and a lack of sea sweeps characterizing the East region (Figure 3).

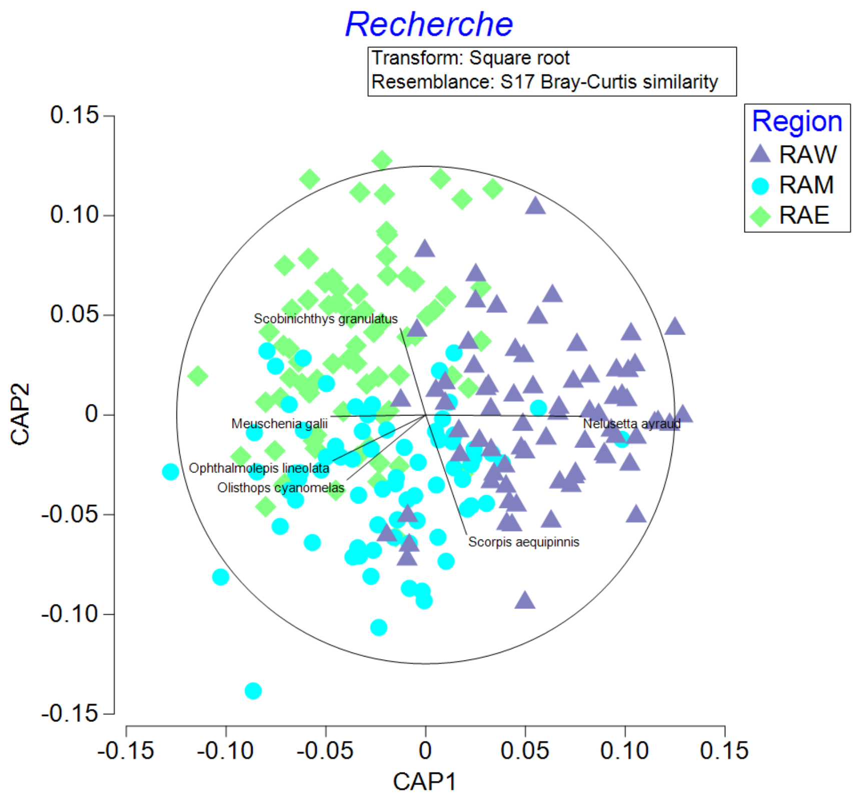


Figure 3. A canonical analysis of principle coordinates (CAP) looking at regional differences in species composition.

Discussion

Remote locations around the world are often considered to be "pristine". However studies show that even the most uninhabited parts of our oceans are adversely impacted by anthropogenic activities (Graham et al. 2010; Punzón et al. 2016; Xanthos & Walker 2017; Chiba et al. 2018; Vega-Cendejas & de Santillana 2019). This study found a similar pattern at the Recherche Archipelago. Fish size increased with distance from the population centre of Esperance. This is consistent with previous research that indicates that one of the first impacts of fishing is the removal of larger individual fish to smaller less desired fish (Friedlander et al. 2010), and is consistent with Edgar et al. (2018) showing that 30% of larger fish have been lost from Australian waters in the last decade. Larger fish have more persistent and greater declines in size and abundances due to size selective fishing (Genner et al. 2010) and more negative impacts on slow growing large fish with average maximum sizes shown to decrease (Jennings et al. 1999). This pattern may reflect both the greater vulnerability of larger species as well as the removal of the largest individuals within a species (Jennings et al. 1999).

Abundance showed the opposite pattern with greater abundance of fish near Esperance but of smaller fish. This was largely due to small schooling species, such as the hulafish (*Trachinops noarlungae*), bullseye fish (*Pempheris sp.*) and puller fish (*Chromis kluzingeri*) which made up 32% of fish in the West region, with average sizes of < 6 cm, and juvenile ocean leatherjacket (*Nelusetta ayraud*) which made up 27% of the assemblage and had a maximum fork length of 15 cm. Abundance may increase with increasing fishing pressure where the removal of predatory species such as sharks and large teleosts leads to the rise in abundance of smaller fish as they are released from predation (Hall 2015; Barley et al. 2017; Lynam et al. 2017). As these were primality schooling species, the high abundance may also reflect local oceanographic conditions (Genner et al. 2010) or localized habitat conditions (Kendrick et al. 2005).

There were no visible regional differences in species richness and total biomass as initially hypothesized. Species diversity is shown to be influenced by temperature and habitats of ecosystems (Cheal et al. 2008; Brown 2020) and is the least responsive variable to both extraction and protection in that species can still persist at low numbers. Reviews on the benefits of MPAs typically show species richness having the lowest percentage increase when compared to abundance and size (Cabral et al. 2019). Biomass is the product of abundance and weight (estimated from size) and thus the lack of a signal here may reflect that the biomass of Eastern Recherche is comprised of few larger fish whilst that of Western Recherche near Esperance is comprised of abundant small fish.

The presence of large fish in the Eastern region suggests it is afforded some protection due to its remoteness, relative to areas around Esperance. The region is accessible only by vessels with overnight capacity or by vehicles with four-wheel drive. However, it may well be that even this remote area reflects a human footprint. Web-based information indicates shore-based access to the region at Israelite Bay, located just north-east of the East region sampling area. Israelite Bay is a popular fishing destination with beach access (Department of Parks and Wildlife 2020; Schubert 2020), and while the route from Esperance is off road it is easily accessible and traversed by the locals of Esperance, domestic travelers and avid fishers. Commercial shark and reef fishing is also active in the area (Gaughan & Santoro 2019) as is commercial tourism and shipping with vessels transiting the National Park (IUCN II) no-take

Commented [JM8]: Tickler didn't write about Rechereche. Inappropriate reference area. The Recherche Archipelago also has a recreational shark fishery active within its waters with the most commonly fished sharks in 2017 and 2018 reported in the south coast of WA being gummy sharks (*Mustelus antarcticus)* whaler sharks (*Carcharhinus sp.)* and Port Jackson sharks *(Heterodontus portusjacksoni*) (Ryan et al. 2017). Similarly to other marine organisms sharks cannot survive outside of water, even with catch and release, sharks become impaired which can lead to mortality (Danylchuk et al. 2014; Kilfoil et al. 2017). Apex predators have been shown to be indicators of healthy ecosystems with higher abundances resulting in more resilient ecosystems (Friedlander et al. 2010; Letessier et al. 2019) and thus the low number of sharks observed in this area may be indicative of the impact of fishing.

Fishing is one of the most consistent human pressures in the marine environment (Britten et al. 2016), but it holds high value for the future of human kind as one of the most sustainable ways to feed humanity (Buttriss & Riley 2013; Searchinger et al. 2018). The Recherche Archipelago has a variety of fish species within its waters with approximately 28% of the fish being endemic to the Recherche Archipelago region (Kendrick *et al.*, 2005). The most common target species in the Esperance region according to Ryan *et al*. (2017) were bight redfish (*Centroberyx gerrardi*), Australian herring (*Arripis georgianus*) and the breaksea cod (*Epinephelides armatus*), all of which were observed in our samples. These species tended to be larger in the more remote East region with non-fished species showing no differences between regions. Data from Western Australia's Department of Primary Industries and Regional Development (DPIRD) indicates that recreational fishing is shifting from coastal (0-20 m) to the inshore demersal zone with depths greater than 20 m. In 2011/12, 23% of recreational boat based fishing occurred in waters greater than 20 m (Ryan et al. 2013), rising to 30% in 2017/18 (Ryan et al. 2019). Recreational fishing from Esperance may reflect this statewide pattern with individuals able to launch large private boats from the towns boating facilities. Fisheries management has generally been unsuccessful in halting declines in fish populations (Pauly & Zeller 2016; Edgar et al. 2018) with unsustainable practices and increased fishing effort widespread (Hilborn et al. 2015, 2019; Tickler et al. 2018).

The analysis of species composition showed significant differences between the regions. This is not consistent with Kendrick et al. (2005) who found no differences between Esperance Bay, Duke of Orleans and Cape Arid, with Esperance Bay corresponding to this study's Western region and the latter two corresponding to the Middle region. This may reflect that their spatial range was more restricted than the analysis here. The surveys were conducted between April and May 2002 in contrast to January and February 2019 adding seasonal variability between studies. Alternatively, given Esperance's population increased by 18% between 2002 and 2018 (Australian Bureau of Statistics 2020), it may well reflect population growth with consequent increased exploitation making regional variation more obvious. Kendrick et al. (2005) did however find significant variation in species composition as a function of habitat. Thus, our regional differences may reflect some variation in habitat although the sampling specifically targeted reef areas. Similarly, the 2019 data from Frederick Island (West region) were found to have high mean number of species and the abundance was found to be higher in the West than Middle Island (2005 East region). Exposure was found to be statistically significant key factor in influencing fish assemblage distribution.

Management implications

A study by O'Leary *et al.* (2016), based on a meta-analysis of MPAs, recommended that 30% should be the minimum level of protection to support recovery of marine ecosystems. Remote regions are considered to be less impacted than those close to human populations, and provide a window into what unexploited ecosystems could have looked like prior to human exploitation (Perry et al. 2015; Letessier et al. 2019). However, that a human footprint can be discerned even in this remote part of Australia suggests that increased protection is necessary. The variation in fish assemblages observed here and that are documented by Kendrick et al. (2005) also have implications for the design of MPAs with their study finding that fish assemblages had a significant interaction with distance, availability of shelter and depth. Our study can support MPA planning and design in this region, demonstrating the need to include representative habitats across the region. Ultimately, MPA management needs to be reviewed and adapted and thus effective monitoring is essential to track climatic events, topicalization and changes in species composition and habitats. It can also monitor how management strategies such as MPAs (if implemented) are influencing fish diversity, abundance, biomass and size in marine ecosystems or if further restrictions are required. Currently, the Western Australian Department of Biodiversity, Conservation and Attractions has proposed the Recherche Archipelago as a potential location for protection (Department of Biodiversity Conservation and Attractions 2019) and an increased regional understanding, as presented by this study, will assist in that matter.

The Recherche Archipelago is still considered to be a remote ocean paradise but is extensively used for its different services: fishing, recreational activities, charter vessels, commercial tourism and food resource. A no-take MPA (IUCN II) protecting a minimum of 30% of the Recherche Archipelago waters should be implemented protecting State and

Commonwealth waters surrounding coastline and islands where evidence shows higher risk of damage or decline. Such protection should be representative of important habitats and influential processes that affect the Recherche Archipelago fish assemblages. The Recherche Archipelago would still be available for recreational and commercial activities such as tourism (including fishing in certain regions) to support the local community while attempting to reduce their impact. Policies to manage the amount of anthropogenic pressure in the Recherche Archipelago are in the best interest of its coastal population as continued or increased anthropogenic pressures will cause fish assemblage diversity, abundance, biomass and size to continue being pressured and cause shifts. The archipelago is already experiencing significant differences in fish assemblages across its waters with no reliable baseline on fish assemblages from this region. Baseline data are essential in making inferences on future populations and assemblages and can see how they are changing over time resulting in time-series data. Without a baseline it is harder to monitor how the fish assemblages of the Recherche Archipelagos are changing or being affecting and limiting anthropogenic pressures. Future studies on the Recherche Archipelago fish assemblages should examine differences is fish assemblages through time, and changes in their habitats and environment. Continued research and effective monitoring of this region is vital in assessing how it is being influenced. This will provide important information to MPA authorities and the Department of Parks and Wildlife (Dpaw), who can implement stricter management of the Recherche Archipelagos waters where required, with justified placement of MPAs to limit anthropogenic influences.

This study looked at how diversity, abundance, biomass and size of fish assemblages were being anthropogenically influenced in a remote region using proximity from the population of Esperance. These results are preliminary and require further investigation into how the regions differ from each other. To disentangle natural impacts from human impacts more information and research on habitat and environmental conditions across the Recherche Archipelago are required. Habitat is an important factor in fish assemblages as it has previously shown to influence species composition (Kendrick et al. 2005). In the future, a further analysis looking into habitat and environmental conditions, such as climate, will contribute to management and protection. It can also aid evidence-based marine spatial planning showing what areas of the Recherche Archipelago require the highest protection.

With global declines in fish populations, fishers venture to more remote regions (Tickler et al. 2018Letessier et al. 2019). This would infer that remote regions globally could also be seeing declines in fish assemblages due to anthropogenic pressures moving further offshore (Graham et al. 2010). This study found that the remote region of the Recherche Archipelago, over 700 km from the main population of Perth, Western Australia, had significant differences in abundance and size of fish between regions, consistent with the effects of fishing. In particular, the decline in fish size in the more remote East highlights the need for re-assessment of fish assemblage protection and conservation management strategies in the Recherche Archipelago. No-take MPAs covering 30% of the Recherche Archipelagos different habitats, waters and fish would be a suitable start to preserving the endemism and biodiversity of fish assemblages in the Recherche Archipelago. These significant differences suggest that even the remote Recherche Archipelago is being anthropogenically influenced by its proximity to Esperance and associated pressures such as fishing. This is globally significant as it provides additional evidence that remote regions are no longer "pristine" and require active protection from anthropogenic influences. This research provides a reliable baseline for the status of fish assemblages within the Recherche Archipelago and provides empirical evidence that even remote regions, such as Recherche, are being influenced by anthropogenic influences. This baseline data can provide a global case study for understanding and comparing other remote regions fish assemblages and environments. With the continued threat to fish populations, it is essential to have reliable baseline data, especially in a rapidly changing climate and where exploitation is accelerating.

References:

Barley SC, Meekan MG, Meeuwig JJ. 2017. Species diversity, abundance, biomass, size and trophic structure of fish on coral reefs in relation to shark abundance. Marine Ecology Progress Series **565**:163–179.

Bates AE, Barrett NS, Stuart-Smith RD, Holbrook NJ, Thompson PA, Edgar GJ. 2014. Resilience and signatures of tropicalization in protected reef fish communities. Nature Climate Change **4**:62–67. Nature Publishing Group.

Baum JK, Worm B. 2009. Cascading top-down effects of changing oceanic predator abundances. Journal of Animal Ecology **78**:699–714.

Bennett S, Wernberg T, Connell SD, Hobday AJ, Johnson CR, Poloczanska ES. 2016. The "Great Southern Reef": Social, ecological and economic value of Australia's neglected kelp forests. Marine and Freshwater Research **67**:47–56.

Brander K. 2013. Climate and current anthropogenic impacts on fisheries. Climatic Change **119**:9–21.

Brander KM. 2007. Global fish production and climate change. Proceedings of the National Academy of Sciences of the United States of America **104**:19709–19714.

Britten GL, Dowd M, Worm B. 2016. Changing recruitment capacity in global fish stocks. Proceedings of the National Academy of Sciences of the United States of America **113**:134–139.

Brown KF. S and JH. 2020. Patterns of Diversity , Depth Range and Body Size among Pelagic Fishes along a Gradient of Depth. Ecology, Source Global **11**:313–322.

Buttriss J, Riley H. 2013. Sustainable diets: Harnessing the nutrition agenda. Food Chemistry **140**:402–407. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.foodchem.2013.01.083.

Buxton CD, Hartmann K, Kearney R, Gardner C. 2014. When is spillover from marine reserves likely to benefit fisheries? PLoS ONE **9**:1–7.

C. Parmesan. 2006. Ecological and Evolutionary Responses to Recent Climate Change. Annual Review of Ecology, Evolution, and Systematics **37**:637–669. Available from http://www.aaai.org/Papers/Workshops/2006/WS-06-09/WS06-09-006.pdf.

Cabral RB, Halpern BS, Lester SE, White C, Gaines SD, Costello C. 2019. Designing MPAs for food security in open-access fisheries. Scientific Reports **9**:1–10.

Callum Roberts. 2007. The unnatural history of the sea. Island Press, Washington D.C.

Cheal AJ, Wilson SK, Emslie MJ, Dolman AM, Sweatman H. 2008. Responses of reef fish communities to coral declines on the Great Barrier Reef. Marine Ecology Progress Series **372**:211–223.

Chiba S, Saito H, Fletcher R, Yogi T, Kayo M, Miyagi S, Ogido M, Fujikura K. 2018. Human footprint in the abyss: 30 year records of deep-sea plastic debris. Marine Policy **96**:204–212. Elsevier Ltd. Available from https://doi.org/10.1016/j.marpol.2018.03.022.

Claudet J et al. 2008. Marine reserves: Size and age do matter. Ecology Letters **11**:481–489.

Costello MJ, Ballantine B. 2015. Biodiversity conservation should focus on no-take Marine Reserves: 94% of Marine Protected Areas allow fishing. Trends in Ecology and Evolution **30**:507–509.

Danylchuk AJ, Suski CD, Mandelman JW, Murchie KJ, Haak CR, Brooks AML, Cooke SJ. 2014. Hooking injury, physiological status and short-term mortality of juvenile lemon sharks (Negaprion bevirostris) following catch-and-release recreational angling. Conservation Physiology **2**:1–10.

Department of Biodiversity Conservation and Attractions. 2019. Plan for our parks. Available from dpaw.wa.gov.au/parks/plan-for-our-parks.

Department of Parks and Wildlife. 2020. Israelite Bay | Explore Parks WA | Parks And Wildlife Service. Available from https://parks.dpaw.wa.gov.au/site/israelite-bay (accessed May 17, 2020).

Department of Primary Industries and Regional Development. 2019. Recfishers spend $2.4 billion a year on great fishing experiences. Available from https://www.fish.wa.gov.au/About-Us/Media-releases/Pages/Recfishers-spend-2point4-billion-a-year-on-great-fishing-experiences.aspx (accessed October 31, 2019).

Di M, Claudet J, Guidetti P. 2016. Spillover from marine protected areas to adjacent fisheries has an ecological and a fishery component. Journal for Nature Conservation **32**:62–66. Elsevier GmbH. Available from http://dx.doi.org/10.1016/j.jnc.2016.04.004.

Dorman SR, Harvey ES, Newman SJ. 2012. Bait effects in sampling coral reef fish assemblages with stereo-BRUVs. PLoS ONE **7**.

Edgar GJ, Ward TJ, Stuart-Smith RD. 2018. Rapid declines across Australian fishery stocks indicate global sustainability targets will not be achieved without an expanded network of 'no-fishing' reserves. Aquatic Conservation: Marine and Freshwater Ecosystems **28**:1337–1350.

FAO 2015. 2016. World aquaculture of food fish and aquatic plants , 1990-2016. Fao.Org:2018.

Friedlander AM, Sandin SA, DeMartini EE, Sala E. 2010. Spatial patterns of the structure of reef fish assemblages at a pristine atoll in the central Pacific. Marine Ecology Progress Series **410**:219–231.

Froese R. & Pauly D. 2019. FishBase. Available from http://www.fishbase.org.

Froese R, Thorson JT, Reyes RB. 2014. A Bayesian approach for estimating length-weight relationships in fishes. Journal of Applied Ichthyology **30**:78–85.

Gaughan, D.J. & Santoro K. 2019. Status Reports of the Fisheries and Aquatic Resources of Western Australia 2017/18: The State of the Fisheries. Page Department of Primary Industries and Regional Development, Western Australia.

Gaughan D et al. 2019. Comments on Edgar et al. (2018) paper for south-western Australia. Aquatic Conservation: Marine and Freshwater Ecosystems **29**:1380–1381.

Genner MJ, Sims DW, Southward AJ, Budd GC, Masterson P, Mchugh M, Rendle P, Southall EJ, Wearmouth VJ, Hawkins SJ. 2010. Body size-dependent responses of a marine fish assemblage to climate change and fishing over a century-long scale. Global Change Biology **16**:517–527.

Goñi R, Hilborn R, Díaz D, Mallol S, Adlerstein S. 2010. Net contribution of spillover from a marine reserve to fishery catches **400**:233–243.

Graham NAJ, Spalding MD, Sheppard CRC. 2010. Reef shark declines in remote atolls highlight the need for multi-faceted conservation action. Aquatic Conservation: Marine and Freshwater Ecosystems **20**:543–548.

Griffiths Gledhill D& L. 2014. Recreational Fisheries in Australia. CSIRO.

Hall AE. 2015. Top-down control, trophic interactions, and the importance of predatory fishes on coral reefs.

Harvey ES, Cappo M, Kendrick GA, McLean DL. 2013. Coastal fish assemblages reflect geological and oceanographic gradients within an Australian zootone. PLoS ONE **8**.

Harvey ES, Shortis MR. 2014. Counting and measuring fish with baited video techniques-an overview.

Hilborn R et al. 2004. When can marine reserves improve fisheries management? Ocean and Coastal Management **47**:197–205. Elsevier BV.

Hilborn R et al. 2019. Effective fisheries management instrumental in improving fish stock status. Available from www.pnas.org/cgi/doi/10.1073/pnas.1909726116.

Hilborn R, Banobi J, Hall SJ, Pucylowski T, Walsworth TE. 2018. The environmental cost of animal source foods. Frontiers in Ecology and the Environment **16**:329–335.

Hilborn R, Fulton EA, Green BS, Hartmann K, Tracey SR, Watson RA. 2015. When is a fishery sustainable? Canadian Journal of Fisheries and Aquatic Sciences **72**:1433–1441.

Hill NA, Barrett N, Ford JH, Peel D, Foster S, Lawrence E, Monk J, Althaus F, Hayes KR. 2018. Developing indicators and a baseline for monitoring demersal fish in data-poor, offshore Marine Parks using probabilistic sampling. Ecological Indicators **89**:610–621. Elsevier. Available from https://doi.org/10.1016/j.ecolind.2018.02.039.

Industries P, Development R. 2015. Catch the facts about what’s being caught in WA:4–7.

Jadhao G D. Khedkar B V. Chavan N V. and Khedkar C D. 2003. Demersal Species of Tropical Climates. Elsevier Science:2438.

Jennings S, Greenstreet SPR, Reynolds JD. 1999. Structural change in an exploited fish community: A consequence of differential fishing effects on species with contrasting life histories. Journal of Animal Ecology **68**:617–627.

Jeremy B. C. Jackson, Karen E. Alexander and ES. 2011. Shifting Baselines. The Past and the Future of Ocean Fisheries. Page (Jeremy B.C Jackson KEA and ES, editor). Island Press.

Juhel JB, Vigliola L, Mouillot D, Kulbicki M, Letessier TB, Meeuwig JJ, Wantiez L. 2018. Reef accessibility impairs the protection of sharks. Journal of Applied Ecology **55**:673–

683.

Kendrick G et al. 2005. Characterising the fish habitats of the Recherche Archipelago. Australian Government. Fisheries Research & Development Corporation. Fisheries Research and Development Corp. and University of Western Australia.

Kilfoil JP, Wetherbee BM, Carlson JK, Fox DA. 2017. Targeted Catch-and-Release of Prohibited Sharks: Sand Tigers in Coastal Delaware Waters. Fisheries **42**:281–287.

Koldewey HJ, Curnick D, Harding S, Harrison LR, Gollock M. 2010. Potential benefits to fisheries and biodiversity of the Chagos Archipelago / British Indian Ocean Territory as a no-take marine reserve. Marine Pollution Bulletin **60**:1906–1915. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.marpolbul.2010.10.002.

Lajus DL, Lajus JA, Dmitrieva Z V., Kraikovski A V., Alexandrov DA. 2005. The use of historical catch data to trace the influence of climate on fish populations: Examples from the White and Barents Sea fisheries in the 17th and 18th centuries. ICES Journal of Marine Science **62**:1426–1435.

Langlois T et al. 2018. Marine Sampling Field Manual For Benthic Stereo Bruvs (Baited Remote Underwater Video). Page NESP Marine Biodiversity Hub. Available from https://www.csiro.au/en/Research/OandA/Areas/Marine-.

Lee D. 2013. Australian Fisheries Management. AusMarine:16.

Lester SE, Halpern BS, Grorud-Colvert K, Lubchenco J, Ruttenberg BI, Gaines SD, Airamé S, Warner RR. 2009. Biological effects within no-take marine reserves: A global synthesis. Marine Ecology Progress Series **384**:33–46.

Letessier TB et al. 2019. Remote reefs and seamounts are the last refuges for marine predators across the IndoPacific. PLoS Biology **17**:1–20.

Letessier TB, Juhel JB, Vigliola L, Meeuwig JJ. 2015. Low-cost small action cameras in stereo generates accurate underwater measurements of fish. Journal of Experimental Marine Biology and Ecology **466**:120–126. Elsevier.

Lynam CP, Llope M, Möllmann C, Helaouët P, Bayliss-Brown GA, Stenseth NC. 2017. Interaction between top-down and bottom-up control in marine food webs. Proceedings of the National Academy of Sciences of the United States of America **114**:1952–1957.

McIntyre PB, Jones LE, Flecker SA, Vanni MJ. 2007. Effects of Fish Extinction on Ecosystems. Science for Environment Policy **104**:1. Available from http://ec.europa.eu/environment/integration/research/newsalert/pdf/73na2_en.pdf.

Meekan MG, McCormick MI, Simpson SD, Chivers DP, Ferrari MCO. 2018. Never off the hook-how fishing subverts predator-prey relationships in marine teleosts. Frontiers in Ecology and Evolution **6**:1–10.

Mellin C, Aaron Macneil M, Cheal AJ, Emslie MJ, Julian Caley M. 2016. Marine protected areas increase resilience among coral reef communities. Ecology Letters **19**:629–637.

Novaglio C, Ferretti F, Smith ADM, Frusher S. 2016. Species–area relationships as indicators of human impacts on demersal fish communities. Diversity and Distributions **22**:1186–1198.

O'Leary BC, Winther-Janson M, Bainbridge JM, Aitken J, Hawkins JP, Roberts CM. 2016. Effective Coverage Targets for Ocean Protection. Conservation Letters **9**:398–404.

Pauly D. 1995. Anecdotes of the shifting baseline syndrome of fisheries. Elsevier Science **10**:430.

Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F. 1998. Fishing down marine food webs. Science **279**:860–863.

Pauly D, Christensen V, Guénette S, Pitcher TJ, Rashid Sumaila U, Walters CJ, Watson R, Zeller D. 2002. Towards sustainability in world fisheries. Nature **418**:689–695. Available from www.nature.com/nature.

Pauly D, Zeller D. 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nature Communications **7**. Nature Publishing Group.

Perry CT, Murphy GN, Graham NAJ, Wilson SK, Januchowski-Hartley FA, East HK. 2015. Remote coral reefs can sustain high growth potential and may match future sea-level trends. Scientific Reports **5**:4–11. Nature Publishing Group.

Poloczanska ES et al. 2016. Responses of marine organisms to climate change across oceans. Frontiers in Marine Science **3**:1–21.

Przeslawski R. 2018. Report to the National Environmental Science Programme, Marine Biodiversity Hub. 212 pp. V. 2018. Marine Sampling Field Manual for Autonomous

Underwater Vehicles (AUVs). In Field Manuals for Marine Sampling to Monitor Australian Waters. Available from http://dx.doi.org/10.11636/9781925297669.

Punzón A, Serrano A, Sánchez F, Velasco F, Preciado I, González-Irusta JM, López-López L. 2016. Response of a temperate demersal fish community to global warming. Journal of Marine Systems **161**:1–10. Elsevier B.V.

Rijnsdorp AD, Peck MA, Engelhard GH, Möllmann C, Pinnegar Rijnsdorp JK, Peck MA, Möllmann C, Engelhard GH, Pinnegar JK. 2009. Resolving the effect of climate change on fish populations. Page Journal of Marine Science. Available from https://academic.oup.com/icesjms/article-abstract/66/7/1570/657377.

Roberts CM et al. 2017. Marine reserves can mitigate and promote adaptation to climate change. Proceedings of the National Academy of Sciences of the United States of America **114**:6167–6175.

Ross Anderson, Berry O, Loo I. 2013. Historical sealskins from the Archipelago of the Recherche, Western Australia. Australian institute for Marinitime Archaeology **37**:114–123. Available from https://www.researchgate.net/publication/275652474.

Ryan K., Wise B., Hall N., Pollock K., Sulin E., Gaughan D. 2013. An intergrated system to survey boat-based recreational fishing in Western Australia 2011/12. Fisheries Research Report No. 249. Fisheries Research Report:168.

Ryan KL, Hall NG, Lai EK, Smallwood CB, Tate A, Taylor SM, Wise BS. 2019. Statewide survey of boat-based recreational fishing in Western Australia 2017/18. Fisheries Research Report No. 297.

Ryan KL, Hall NG, Lai EK, Smallwood CB, Taylor SM, Wise BS. 2017. Statewide survey of boat-based recreational fishing in Western Australia 2015/16. Fisheries Report No. 287. Page Fisheries Research Report No. 287.

Sala E, Lubchenco J, Grorud-Colvert K, Novelli C, Roberts C, Sumaila UR. 2018. Assessing real progress towards effective ocean protection. Marine Policy **91**:11–13. Elsevier Ltd. Available from https://doi.org/10.1016/j.marpol.2018.02.004.

Schubert A. 2020. Israelite Bay; The Ultimate 4WD Adventure From Esperance. Available from https://www.4wdingaustralia.com/travel-western-australia/israelite-bay/ (accessed May 17, 2020).

SeaGIS Pty Ltd. 2014. EventMeasure™ Stereo.

Searchinger T, Waite R, Beringer T, Forslund A, Guyomard H, Le Mouël C, Manceron S, Marajo-Petitzon E. 2018. Creating a Sustainable Food Future. World Resources Institute:1–96.

Stamoulis KA, Friedlander AM. 2013. A seascape approach to investigating fish spillover across a marine protected area boundary in Hawai'i. Fisheries Research **144**:2–14.

Statistics AB of. 2020. Esperance (S) (LGA) (53290). Available from https://itt.abs.gov.au/itt/r.jsp?RegionSummary&region=53290&dataset=ABS_REGIONAL_LGA&geoconcept=REGION&datasetASGS=ABS_REGIONAL_ASGS&datasetLGA=ABS_NRP9_LGA&regionLGA=REGION&regionASGS=REGION.

Steve Lundeberg & William Ripple. 2019, January 30. Direct killing by humans pushing Earth's biggest fauna toward extinction. Oregon State University Newsroom. Oregon. Available from https://today.oregonstate.edu/news/direct-killing-humans-pushing-earth's-biggest-fauna-toward-extinction.

Sueiro MC, Awruch C, Gilardoni C, Demetrio M, Palacios MG. 2020. Immunity and health of two wild marine fishes naturally exposed to anthropogenic pollution. Science of the Total Environment **726**. Elsevier B.V.

Tickler D, Meeuwig JJ, Palomares ML, Pauly D, Zeller D. 2018. Far from home: Distance patterns of global fishing fleets. Science Advances **4**:4–10.

Valmonte-Santos R, Rosegrant MW, Dey MM. 2016. Fisheries sector under climate change in the coral triangle countries of Pacific Islands: Current status and policy issues. Marine Policy **67**:148–155. Elsevier. Available from http://dx.doi.org/10.1016/j.marpol.2015.12.022.

Van Sebille E. 2015. The oceans' accumulating plastic garbage. Physics Today **68**:60–61.

Vega-Cendejas ME, de Santillana MH. 2019. Demersal fish assemblages and their diversity on the Yucatan continental shelf: Gulf of Mexico. Regional Studies in Marine Science **29**. Elsevier B.V.

Xanthos D, Walker TR. 2017. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. Marine Pollution Bulletin **118**:17–26. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.marpolbul.2017.02.048.

Xilisoft Corporation. 2019. Xilisoft Ultimate converter. Xilisoft Corporation.

Zar JH. 2009. Biostatistical Analysis 5th Edition, 5th edition.

Supplementary Information

Supplemental Table 1. List of fish sampled by family, scientific name, common name, commonality, average size and abundance by region.

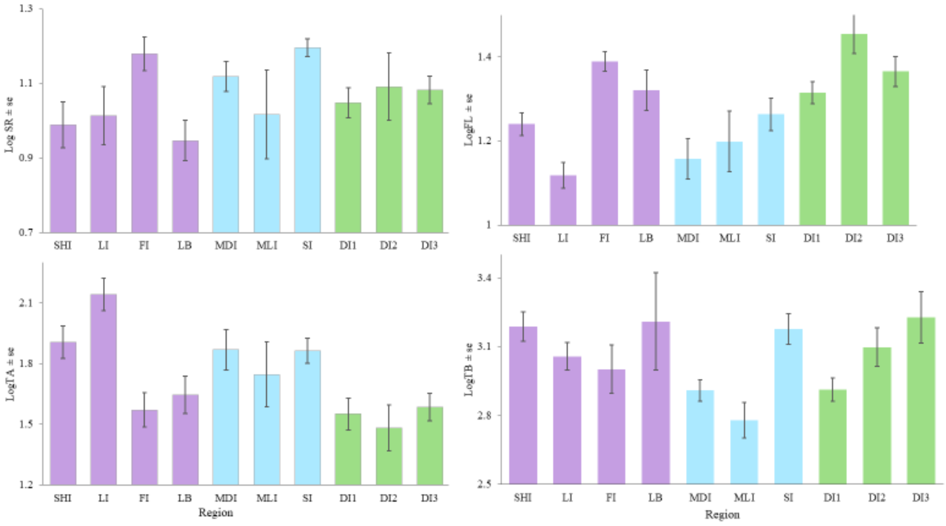
Family	Scientific Name	Common Name	Common (%)	Mean Size (cm)	West	Middle	East
Apolodactylidae	*Aplodactylus westralis*	Western Seacarp	9.0	41.3	2	14	4
Apogonidae	*Siphamia cephalotes*	Woods SiphonFish	0.5	2.2	0	0	34
Aracanidae	*Anoplocapros amygdaloides*	Western Boxfish	0.9	28.8	1	0	1
	Anoplocapros lenticularis	Whitebarred Boxfish	0.5	21.1	0	1	0
	Aracana aurita	Shaws Cowfish	0.5	16.7	0	0	1
Arripidae	*Arripis georgianus*	Australian Herring	10.8	20	233	147	90
	Arripis trutta	Australian Salmon	0.5	56.9	0	16	0
Aulopidae	*Latropiscis purpurissatus*	Sergeant Baker	2.7	37.1	4	2	1
Berycidae	*Centroberyx gerrardi*	Bight Redfish	7.2	32	8	8	2
	Centroberyx lineatus	Swallowtail	5.0	24.7	13	8	3
Carangidae	*Pseudocaranx georgianus*	Silver Trevally	37.8	25.2	293	321	238
	Pseudocaranx sp.	Juvenile Trevally	11.3	5.9	115	586	35
	Seriola hippos	Samsonfish	7.2	84.2	4	6	6
	Seriola lalandi	Yellowtail Kingfish	6.8	85.9	0	12	26
	Seriola sp	Trevallies	1.4	67.3	4	4	0
	Trachurus sp	Scad fish	2.7	16.5	21	0	0
Carcharhinidae	*Carcharhinus brachyurus*	Bronze Whaler	1.4	208	1	2	0
	Carcharhinus sp.	Whaler Shark	0.9	208	2	0	0
Chaetodontidae	*Chelmonops curiosus*	Western Talma	10.4	17.8	31	2	1
Cheilodactylidae	*Cheilodactylus nigripes*	Magpie Perch	35.1	31.3	14	41	37
	Dactylophora nigricans	Dusky Morwong	6.8	68.9	4	5	6

	Nemadactylus valenciennesi	Blue Morwong	46.8	47.1	42	50	47
Chironemidae	*Chironemus maculosus*	Silver Spot	5.4	22.5	0	2	10
	Chironemus sp	Kelpfishes	1.8	23.9	1	0	3
Clupeidae	*Clupeidae sp*	Herrings	1.4	10.1	786	0	0
Dasyatidae	*Bathytoshia brevicaudata*	Smooth Stingray	9.9	102.5	7	12	4
Dinolestidae	*Dinolestes lewini*	Longfin Pike	21.6	23.3	148	53	221
Enoplosidae	*Enoplosus armatus*	Old Wife	7.2	22.1	16	18	5
Gerreidae	*Parequula melbournensis*	Silverbelly	16.2	8.6	90	91	51
Heterodontidae	*Heterodontus portusjacksoni*	Port Jackson Shark	9.0	53.4	10	8	4
Juvenile	*Juvenile sp*	Juveniles	0.9	1	0	35	144
Kyphosidae	*Girella sp*	Blackfishes	0.5	29.1	0	2	0
	Girella tephraeops	Western Rock Blackfish	43.7	36.5	68	108	54
	Girella zebra	Zebra Fish	22.1	28.2	37	95	10
	Kyphosus sydneyanus	Silver Drummer	27.0	49.3	47	20	101
	Neatypus obliquus	Footballer Sweep	29.7	11.7	53	105	129
	Scorpis aequipinnis	Sea Sweep	41.9	31	93	101	22
	Scorpis georgiana	Banded Sweep	7.2	27.1	33	3	1
	Tilodon sexfasciatus	Moonlighter	10.8	29.3	9	14	5
Labridae	*Achoerodus gouldii*	Western Blue Groper	40.1	54.3	32	33	37
	Austrolabrus maculatus	Blackspotted Wrasse	15.3	10.0	9	9	20
	Bodianus frenchii	FoxFish	27.0	33.7	24	27	15
	Coris auricularis	Western King Wrasse	43.2	29.7	61	114	67
	Dotalabrus alleni	Little Rainbow Wrasse	0.5	5.4	0	1	0
	Eupetrichthys angustipes	Snakeskin Wrasse	2.7	12.5	0	4	4
	Halichoeres brownfieldi	Brownfields' Wrasse	0.5	9.6	10	0	0
	Labridae sp.	Wrasse	0.5	30	1	0	0

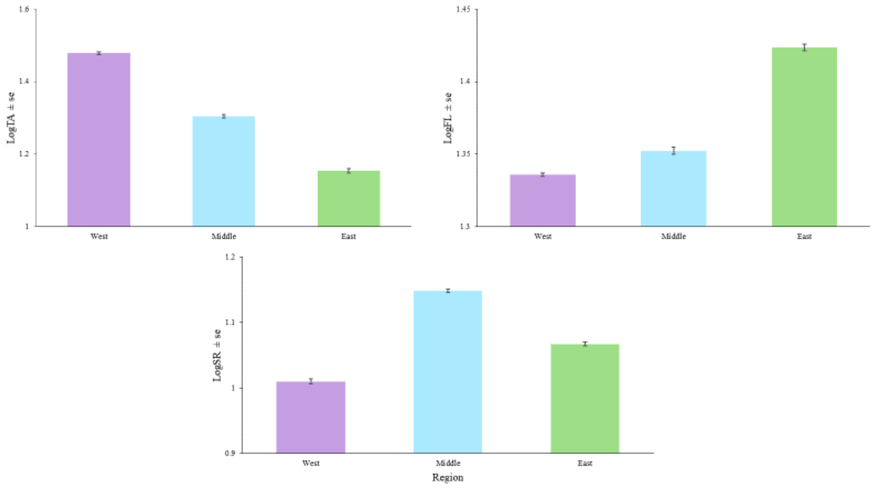
	Notolabrus parilus	Brown Spotted Wrasse	77.9	27.4	87	112	116
	Ophthalmolepis lineolata	Southern Maori Wrasse	80.6	19.3	332	508	398
	Pictilabrus laticlavius	Senator Wrasse	6.8	15.8	1	5	9
	Pictilabrus sp	Wrasse	1.8	17.7	1	2	3
	Pictilabrus viridis	False Senator Wrasse	4.5	13.5	1	7	3
	Pseudolabrus biserialis	Red-Band Wrasse	1.8	13.9	206	174	174
	Siphonognathus beddomei	Pencil Weed Whiting	0.5	11.4	0	0	20
Lamnidae	*Carcharodon carcharias*	Great White Shark	0.9	274.2	0	0	2
Loliginidae	*Sepioteuthis australis*	Australian Squid	9.0	24.1	0	14	11
Monacanthidae	*Eubalichthys cyanoura*	Bluetail Leatherjacket	0.5	22.7	0	0	1
	Eubalichthys mosaicus	Mosaic Leatherjacket	0.9	6.1	0	0	2
	Meuschenia flavolineata	YellowStriped Leatherjacket	27.5	25.9	25	44	34
	Meuschenia freycineti	SixSpine Leatherjacket	0.9	28.6	0	1	1
	Meuschenia galii	Bluelined Leatherjacket	61.3	27.4	38	75	84
	Meuschenia hippocrepis	Horseshoe Leatherjacket	29.3	36.3	17	44	19
	Meuschenia sp	Leatherjacket	3.2	30.8	2	7	2
	Nelusetta ayraud	Ocean Leatherjacket	15.3	12.9	2311	104	5
	Scobinichthys granulatus	Rough Leatherjacket	4.5	19.4	3	0	12
Mullidae	*Upeneichthys vlamingii*	BlueSpotted Goatfish	18.0	18.2	18	16	27
Muraenidae	*Gymnothorax prasinus*	Green Moray	15.3	35.4	8	15	16
	Gymnothorax sp.	Moray	2.3	35.4	4	2	0
	Muraenidae sp.	Moray	0.9	100	0	2	0
Myliobatidae	*Myliobatis australis*	Southern Eagle Ray	0.9	76.8	0	5	0

	Myliobatis tenuicaudatus	Southern Eagle Ray	50.0	82.7	57	44	55
Neosebastidae	*Neosebastes bougainvillii*	Gulf Gurnard Perch	0.5	25.6	0	1	0
Odacidae	*Heteroscarus acroptilus*	Rainbow Cale	9.5	15.1	1	5	16
	Olisthops cyanomelas	Herring Cale	51.4	28.3	33	82	51
	Siphonognathus beddomei	Pencil Weed Whiting	1.8	11.2	0	1	5
	Siphonognathus caninis	Sharpnose Weed Whiting	0.5	6.4	0	0	1
	Siphonognathus sp		0.9	6.5	6	0	0
Odontaspididae	*Carcharias taurus*	Grey Nurse Shark	0.9	185.7	0	3	0
Order:Teuthida	*Mollusca - Cephalopoda*	Mollusc	0.5	20.0	0	1	0
Orectolobidae	*Orectolobus sp*	Wobbegong	0.5	1500	1	0	0
	Sutorectus tentaculatus	Cobbler Wobbegong	0.5	58.9	0	1	0
Otariidae	*Neophoca cinerea*	Sea Lion	0.9	124.4	0	1	1
Paguridae	*Paguridae (Arthropoda - Malacostraca)*		0.5	5.0	0	1	1
Parascylliidae	*Parascyllium ferrugineum*	Rusty Carpetshark	0.5	51.2	0	1	0
	Parascyllium variolatum	Varied Carpetshark	5.0	58.5	0	6	5
Pempheridae	*Pempheris klunzingeri*	Rough Bullseye	9.0	12.9	128	102	273
	Pempheris sp	Bullseye	3.2	5.6	1	333	8
Pentacerotidae	*Pentaceropsis recurvirostris*	LongSnout Boarfish	1.4	33.3	2	1	0
Pinguipedidae	*Parapercis haackei*	Wavy Grubfish	0.5	6.8	1	0	0
Platycephalidae	*Platycephalus speculator*	Southern Bluespotted Flathead	8.1	22.4	28	24	2
Plesiopidae	*Paraplesiops meleagris*	Blue Devil	3.6	30.2	3	2	3
	Trachinops noarlungae	Yellowhead Hulafish	27.9	5.5	243 4	4658	1267
	Trachinops sp	Hulafish	0.5	3.4	20	0	0
Plotosidae	*Cnidoglanis macrocephalus*	Estuary Cobbler	0.5	58.2	1	0	0

Pomacentridae	*Chromis klunzingeri*	Blackhead Puller	19.8	5.9	284	981	216
	Parma bicolor	Bicolor Scalyfin	0.5	13.2	0	1	0
	Parma mccullochi	McCullochi Scalyfin	0.9	12.8	1	2	0
	Parma victoriae	Scalyfin	25.7	18.4	30	24	16
Scombridae	*Scomber australasicus*	Blue Mackerel	0.5	28.6	6	0	0
	Thunnus maccoyii	Southern Bluefin Tuna	0.5	62.8	0	0	1
Scorpaenidae	*Scorpaena sumptuosa*	Western Red Scorpionfish	0.9	25.6	1	1	0
Scyliorhinidae	*Aulohalaelurus labiosus*	BlueSpotted Catshark	3.6	42.9	1	4	3
Scyllaridae	*Ibacus peronii*	Butterfly Fan Lobster	0.9	14.7	0	2	0
Sepiidae	*Sepia apama*	Australian Cuttlefish	0.9	11.9	2	0	2
Serranidae	*Acanthistius serratus*	Western Wirrah	6.3	31.2	11	3	3
	Caesioperca rasor	Barber Perch	13.5	18.3	39	206	29
	Epinephelides armatus	Breaksea Cod	23.9	31.4	33	26	8
	Othos dentex	Harlequin Fish	19.8	43	22	12	12
Sillaginidae	*Sillago schomburgkii*	Yellowfin Whiting	0.5	22	0	0	4
Sphyraenidae	*Sphyraena novaehollandiae*	Snook	7.2	59.8	8	5	4
Tetraodontidae	*Omegophora cyanopunctata*	BlueSpotted Toadfish	21.2	11.5	9	50	16
	Polyspina piosae	Orangebarred Puffer	0.9	5.5	0	0	2
	Torquigener sp	Toadfishes	0.9	3.7	0	15	0
Triakidae	*Mustelus antarcticus*	Gummy Shark	6.8	107.5	3	7	5
Trygonorrhinidae	*Trygonorrhina dumerilii*	Southern Fiddler Ray	1.4	64.1	3	0	1
Urolophidae	*Trygonoptera ovalis*	Striped Stingaree	8.6	26.3	2	8	9



Supplemental information Figure 1. Bar chart of log transformed species richness (SR), taxonomic abundance (TA), fork length (FL) and total biomass (TB) by sites.



Supplementary information Figure 2. Bar chart of extracted fish log abundance (TA), log fork length (FL) and species richness by regions West, Middle and East.