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Putting marine sanctuaries into context: a comparison of estuary fish assemblages over multiple levels of protection and modification

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ABSTRACT

1. In recent decades there has been a significant effort to establish marine sanctuaries for the purpose of protecting marine biodiversity and ecological processes. While many studies have demonstrated that marine sanctuaries increase the abundance, diversity, and trophic level of marine fish communities, few have compared these parameters across multiple levels of protection and human modification.
2. This study utilized baited remote underwater video to compare fish assemblages between marine parks, between different levels of protection within parks (sanctuary and habitat protection zones), and between parks and highly modified systems with similar ecological communities.
3. It was demonstrated that sanctuary zones have higher abundance of targeted fish species compared with other areas within some marine parks.
4. The total abundance of targeted species and abundances of some key fisheries species (e.g. pink snapper) were found to be higher in sanctuary zones. This suggests that increased protection may be effective at improving these aspects of the fish assemblage.
5. However, when marine parks were compared with highly modified environments it was found that targeted species were much more abundant in the highly modified systems.
6. Community composition of entire fish assemblages also differed between these levels of modification and economically important fisheries species contributed most to this difference.
7. These findings suggest that while highly protected sanctuary zones may increase the abundance of targeted fish compared with less protected areas within the same estuary, highly industrialized or urbanized systems, not typically chosen as marine parks, may actually support more targeted species of fish.
8. It was demonstrated that forms of modification in addition to fishing pressure are having large effects on fish assemblages and productivity.

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KEY WORDS: estuary; marine protected area; marine park; marine reserve; fish; fishing; urban development; modification; baited remote underwater videos; marine sanctuary

INTRODUCTION

Human stressors including pollution (Costello and Read, 1994; Johnston and Roberts, 2009; McKinley and Johnston, 2010; McKinley *et al*., 2011), overharvesting (Pauly *et al*., 2002), habitat modification (Dafforn *et al*., 2009b; Kaiser *et al*., 2002) and introduced species (Mack *et al*., 2000) have precipitated large and significant changes to the distribution, abundance, and diversity of marine organisms. Marine sanctuaries aim to reduce human stressors by providing areas set aside for the protection and maintenance of biological diversity and ecological processes (Kelleher *et al*., 1995; Claudet *et al*., 2006; MPA, 2010). A substantial number of studies have established that marine sanctuaries are successful

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at achieving a variety of conservation goals (Halpern, 2003; Pérez-Ruzafa *et al*., 2006; Harmelin-Vivien *et al*., 2008; Edgar *et al*., 2009). Studies examining the success of sanctuaries have assessed impacts primarily over small spatial and temporal scales and rarely have results been compared with modified reference locations. Conversely, few studies have examined the impacts of human stressors on fish assemblages by systematically comparing heavily modified environments with relatively unmodified systems (Agardy *et al*., 2003). Because marine sanctuaries are often located in relatively pristine environments and are protected from many forms of modification by legislation, monitoring, and enforcement, they provide excellent reference locations against which the effects of modification can be compared (McKinley and Johnston, 2010). The comparison of marine sanctuaries with highly modified environments is of interest both to evaluate the success of sanctuary zones and the impacts of a variety of stressors in modified areas. The success of marine sanctuaries in increasing the density (Edgar and Stuart-Smith, 2009), biomass (Williamson *et al*., 2004), and diversity (Lester *et al*., 2009) of marine fish has been well documented (Rowley, 1994). These sanctuary areas have been shown to increase the average trophic level of the ecosystem and the abundance of harvested species (Evans and Russ, 2004). A comprehensive meta-analysis of marine parks worldwide found that 90% of parks increased biomass of target species by an average of 250%, while the average abundances of organisms doubled and the mean size of organisms increased by a third (Halpern, 2003).

The creation of sanctuary zones, their design, and biological as well as socio-economic effects has been the primary focus of much scientific debate. Most studies examining the effects of marine parks observed conservation benefits with effects attributed primarily to the creation of marine sanctuaries that limit or entirely eliminate fishing pressure as a source of modification (Halpern, 2003). Most of these studies evaluated the effects of sanctuaries by comparing nearby environments (where fishing is permitted) with sanctuary zones. In many cases these studies are conducted within the same coastal or estuarine system, such that the sanctuary is compared directly with a nearby commercial or recreational fishing zone within the same study area (Halpern, 2003; Lester *et al*., 2009) and presumably similar levels of modification. Many of these studies lack reference to external sites and conditions. As a result, the way that removal of fishing pressure compares with other forms of modification, and the effects on fish assemblages resulting from changes to human disturbance regimes have been less well studied.

Several studies have demonstrated that the continuation of recreational fishing within marine protected areas reduces the effectiveness of conservation initiatives and that recreational fishing has a major impact on fish assemblages (Jennings *et al*., 1996; Denny and Babcock, 2004; Samoilys *et al*., 2007). While fishing pressure is a conspicuous pathway for human impacts on fish assemblages, a variety of other forms of modification have been demonstrated to have impacts on marine fish assemblages (Kaiser *et al*., 2002; Bax *et al*., 2003; McKinley and Johnston, 2010; McKinley *et al*., 2011). In addition to reducing fishing pressure, the establishment of marine parks and sanctuaries can limit human modification via legislation and placement. Legislation governing these areas is generally designed to limit contamination loading, reduce habitat modification and catchment alteration, and reduce susceptibility to colonization by invasive organisms (Stachowicz *et al*., 1999; Marchetti *et al*., 2006) compared with unprotected areas. In effect, these conservation areas can generally be characterized as 'less anthropogenically modified' environments compared with other managed ecosystems. Some of these other modification factors may act synergistically with fishing pressure to alter fish assemblages (Micheli, 1999; Islam and Tanaka, 2004; Breitburg *et al*., 2009).

Currently, literature addressing the impacts of marine sanctuaries leaves a variety of unanswered questions. Do legislation and management practices limiting processes of human modification (other than fishing) affect the fish assemblage in marine parks? Do some forms of modification change fish assemblages? Should we expect marine sanctuaries to support higher abundances of targeted species simply because they are less harvested, or will other modification factors have a strong influence? Hypothetically, what would happen if we had sanctuary zones in areas typically not chosen for protection such as highly modified or urbanized environments?

This is one of the first studies to address some of these questions by simultaneously comparing fish assemblages across several levels of protection and modification. Within relatively unmodified marine parks, the impacts of sanctuary zones are examined by comparing these with habitat protection zones (where recreational and commercial fishing is permitted). This gives an idea of the response of fish assemblages to protection (from both fishing and other disturbances) over small spatial scales. Second, the effects of large scale human modification are assessed by comparing highly modified environments in heavily developed estuaries with relatively less disturbed environments of marine parks. We predict that sanctuary zones and marine parks will have higher abundances of fish than fished areas and modified estuaries. Further, we predict that there will be differences in fish community composition among these different places.

METHODS

Study location and modification categories

This study was conducted in four estuaries along the south-eastern coast of New South Wales, Australia; two modified estuaries (Port Jackson 33°44.258′S, 151°16.542′E and Port Hacking 34°04.680′S, 151°09.311′E) and two relatively unmodified estuaries within marine parks (Jervis Bay 35°04.762′S, 150°44.858′E and Batemans Bay 35°44.233′S, 150°14.272′E).

Both Batemans Bay and Jervis Bay are considered to be within relatively pristine ecosystems with less foreshore modification, artificial structures, boating traffic, pollution, urbanization of the catchment and lower nutrient loads compared with the modified estuaries (Scanes, 2010). In part, it is because these estuaries are relatively pristine that they were designated as marine parks. Sanctuary zones within these marine parks have been in place for 8 and 4 years for Jervis Bay and Batemans Bay, respectively (MPA, 2010). For these reasons, the marine parks are considered here as 'relatively unmodified estuaries'.

Port Jackson is the heavily urbanized port of the city of Sydney. It is classified as highly modified due to intense commercial and recreational boat traffic, historic and ongoing pollution, and widespread urbanization of its shoreline and catchment (Birch and Taylor, 1999; McKinley *et al.*, 2011) Port Hacking is located between the heavily urbanized suburbs of southern Sydney and the forested slopes of Royal National Park, which touches the southern border of the estuary. Port Hacking is also subject to heavy recreational boat traffic and frequent dredging. Monitoring programmes rank Port Jackson as heavily nutrient enriched while Port Hacking is less so, but both have higher nutrient loads, catchment modification, and urban run-off than the marine parks (Birch *et al.*, 2010; Scanes, 2010). These monitoring programmes use verified land-use and pollutant run-off data to model catchment pollution levels and to predict total nitrogen, phosphorous, and sediment loading (Scanes, 2010). For these reasons Port Jackson and Port Hacking are classified as 'modified estuaries'.

Zone definitions and fishing pressure categories

For the purposes of this paper, the term 'sanctuary zone' refers to areas where recreational and commercial fishing is completely prohibited. The term 'sanctuary' or 'sanctuary zone' has a similar meaning to the terms 'no-take area' or 'reserve' used in other studies. This contrasts with 'habitat protection' zones within marine parks where recreational and some forms of commercial fishing are allowed. In the marine parks examined in this paper, most commercial fishing is completely banned with the exception of some commercial bait fish collection using purse seine nets, and commercial beach seining within both parks. The commercial purse seine and beach seine activities are limited to the habitat protection zones and are prohibited within the sanctuary areas (NSW, 1999). Habitat protection zones within marine parks are therefore comparable with many other estuaries in terms of overall fishing pressure. 'Marine park' is used to describe designated conservation areas that are zoned to encompass a mixture of multiple sanctuary and habitat protection zones, as is the case with the marine parks examined in this study.

Both Port Jackson and Port Hacking are subject to intense recreational fishing pressure and are among the most recreationally fished estuaries in Australia (Henry and Lyle, 2003; DPI, 2010). While exact fishing effort data were not available at the time of this study, surveys indicated that approximately 10 times as many individuals practise recreational fishing in the Port Jackson/Port Hacking region compared with Batemans Bay and Jervis Bay (DPI, 2010). Most commercial fishing is banned from Port Jackson and Port Hacking, although some commercial bait fishing is permitted. Although some forms of recreational fishing (netting and trapping) are also banned in some parts of Port Hacking, the selected study sites fell outside of these areas.

'Fishing pressure' in this study is meant to refer to the level of harvesting that occurs in these environments. This includes both recreational and commercial fishing. In this study it is argued that sanctuary zones within the marine parks constitute an area of low fishing activity (because most forms of fishing are prohibited), habitat protection zones within marine parks constitute an area of moderate fishing activity (where recreational fishing and some forms of commercial fishing occur), and the modified estuaries represent an area of high fishing activity (where some forms of commercial fishing occur and where the greatest concentrations of recreational fishers are found).

Sampling design

In each of the four estuaries, four sites were sampled (Figure 1). In modified estuaries no sites were protected by any special conservation designation and all sites were located in the outer zone of the estuary in locations that were directly comparable with marine parks (Figure 1). In contrast, within each marine park two sites were placed within sanctuary areas and two within habitat protection zones. In Batemans Bay the sanctuary sites were within the North Head and Tollgate Islands sanctuary zones (Figure 1(d)) and in Jervis Bay they were located with the Hyams Beach and Huskisson sanctuary zones (Figure 1(c)). All sites were located at least 500 m away from the edge of adjacent zones to avoid edge effects. The sanctuary sites were compared with nearby sites within the habitat protection zones at Judges Beach and Lillipilli Point in Batemans Bay Marine Park and Plantation Point and Callala Beach in Jervis Bay Marine Park.

All fish sampling was conducted using baited remote underwater video stations (BRUVS), which were assembled in a standard configuration (Cappo *et al.*, 2004). Non-destructive methods such as BRUVS are preferable in marine sanctuaries where fish are protected. A single fixed camera was suspended on a quadrapod approximately 15 cm above the benthos. The camera was horizontally oriented in the direction of a baited bag containing 500 g of crushed pilchards *Sardinops sagax* and extended 1 m from the base of the camera quadrapod. In each estuary four sites were selected close to the mouth of the estuary. All sites were over bare sediment 5 m to 10 m from rocky reef, and in waters between 5 m and 12 m deep. This gave a clear field of view for the cameras and ensured consistency in the type of habitat sampled (e.g. bare sediment adjacent to rocky reef). Each site was randomly sampled twice, from November 2009 to March 2010, with four replicate BRUVS deployed at each time and site. As sampling was randomized, tidal phase was not taken into account. Temperature, salinity, and pH were sampled at all sites using a calibrated YSI 6820 V2 sonde. Visibility was also evaluated during image analysis. These parameters were similar among times of sampling across the four estuaries (ANOVA, $P > 0.05$). Moreover, preliminary analyses revealed that there were never any differences in fish abundances or diversity between these sampling times so 'time' was pooled for analyses, giving $n = 8$ BRUVS drops per site. All BRUVS deployments were spaced at least 200 m apart and each recording lasted for approximately 35 min.

It should be noted that in NSW, modified estuaries are usually adjacent to major cities such as Sydney. The location of estuaries is therefore necessarily spatially pseudoreplicated along the coastline with modified estuaries around the urbanized shores of Sydney and marine parks in the less populated south (there are no marine parks in the Sydney area). Nevertheless, with proper replication of estuaries within these modification regimes (see sampling design above) and consideration of species with cosmopolitan distributions along this coastline, this issue can be largely overcome. It should also be noted that the marine parks and modified estuaries

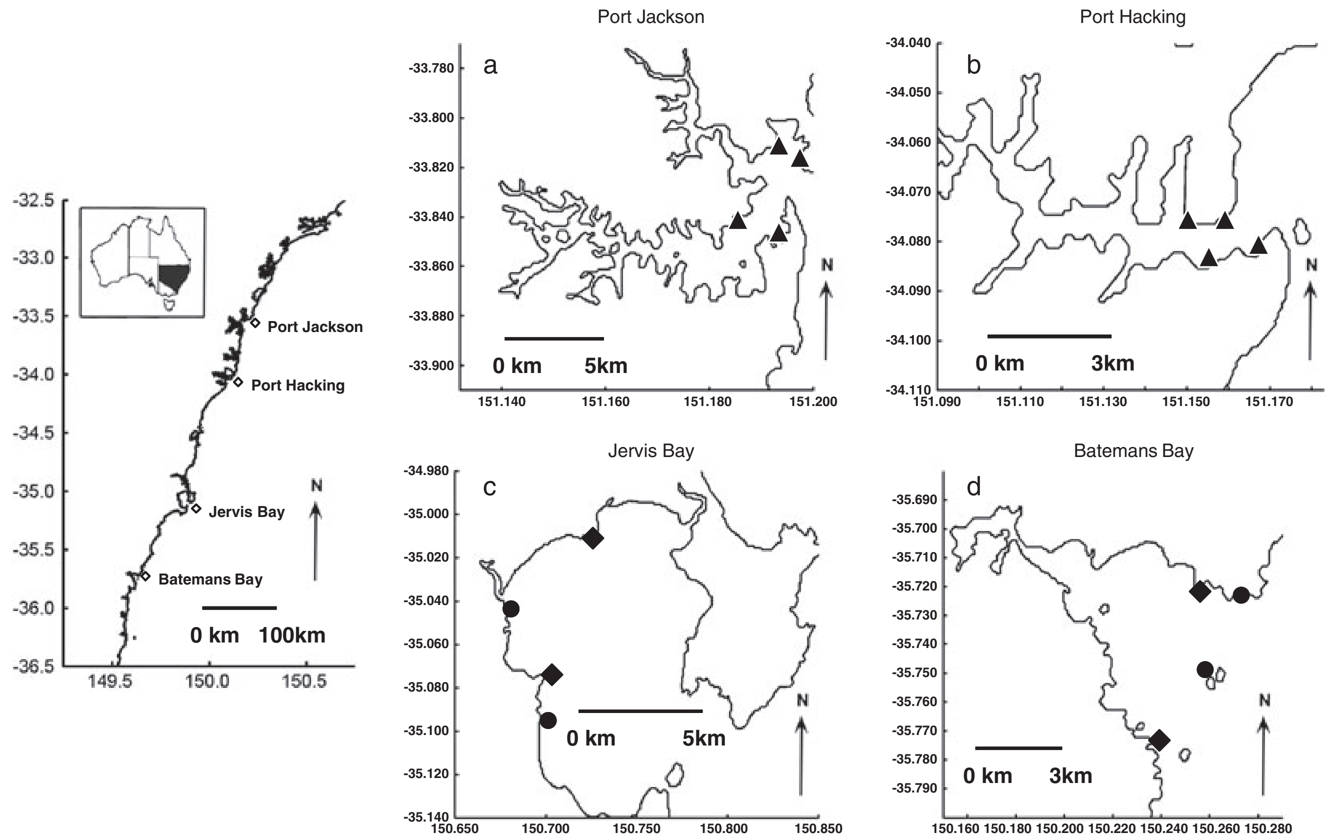

Figure 1. Locations of study sites in (a) Port Jackson, (b) Port Hacking, (c) Jervis Bay Marine Park, and (d) Batemans Bay Marine Park. Filled triangles (▲) indicate sampling sites within modified estuaries. For the relatively unmodified estuaries (marine parks), filled diamonds (♦) indicate sampling sites within habitat protection zones, filled circles (●) indicate sampling sites within sanctuary zones.

occur in different bioregions according to the Interim Biogeographic Regionalization of Australia (IBRA) system, though the maximum distance between estuaries is only 275 km (Batemans Bay to Port Jackson) (DSEWPC, 2011). While this indicates that some differences exist in the biological and environmental conditions between these areas, most of the fish species examined in this study are known to occur in all the estuaries examined in this study. Notably, the four estuaries examined in this study are at least several hundred kilometres within the known range of the major species which drive the trends in this analysis (e.g. pink snapper, silver trevally and yellowfin bream) (Edgar and Shaw, 1995; Gomon *et al*., 2008). In addition, no differences were found in physico-chemical variables between these estuaries at the time of sampling (see above) and the habitat sampled was judged to be reasonably similar in all estuaries (bare sediment near rocky reef). For these reasons, it is believed that comparisons between these estuaries are valid for this analysis, despite the existence of some differences in biological and environmental conditions. Other studies have utilized similar comparisons between these estuaries (Dafforn *et al*., 2009a; McKinley *et al*., 2011).

Video image analysis

For all BRUVS footage the first minute of tape was disregarded to allow time for the BRUVS to settle and disturbed sediment to clear. Following this the next 30 min of tape were analysed. To avoid repeatedly counting the same individuals, the maximum number of fish from each species present at any one time in the field of view were counted and summarized in a relative measure of abundance - Max N. All individuals which could be clearly seen and identified to species were counted. Individuals which were too far from the camera to be identified or were otherwise not clearly visible were ignored. All individuals were identified to species with the exception of the *Platycephalus* genus (Flatheads). These fish were grouped as '*Platycephalus* spp.' due to the difficult nature of species identification without close examination of a specimen. Each species was also identified according to whether it is 'targeted' by commercial or recreational fishing. Any species which was listed as a major game species by the Department of Primary Industries, NSW was classified as a targeted species (DPI, 2010). This source was used to classify the majority of species in this study. Species not listed by DPI were classified using the international fisheries database Fishbase, which classifies species as commercially or recreationally targeted 'game fish' based on international fisheries monitoring data and the scientific literature (Froese and Pauly, 2010). These classifications are summarized in Appendix 1.

Statistical analysis

All multivariate and univariate analyses were conducted using mixed model PERMANOVA in PRIMER v.6 (Anderson, 2001). Before analysis, data were fourth root transformed and Bray–Curtis similarity matrices were calculated for multivariate analyses. *SIMPER* analysis was used to determine the contribution of fish species to the average dissimilarity between significant factors in multivariate analyses (Clarke, 1993). The four highly abundant species yellowtail scad *(Trachurus novaezelandiae)*, mado *(Atypichthys strigatus)*, silver sweep *(Scorpis lineolata)* and ocean leatherjacket *(Nelusetta ayraud)* were excluded from the multivariate analysis of community composition. This was done because these predominately schooling species of fish occurred in extremely high abundances in each estuary and across almost all samples and so obscured differences in assemblage composition within the remainder of the fish assemblage. Univariate tests of these species indicated that only silver sweep differed significantly by modification, with increased abundance in the heavily modified estuaries ($P = 0.028$), though it was still present in large numbers in the relatively unmodified estuaries. Yellowtail scad, mado and ocean leatherjacket did not differ significantly by modification and were abundant in all estuaries ($P = 0.059$, 0.295, 0.907 respectively). None of these species differed significantly between sanctuary and habitat protection zones within marine parks ($P > 0.05$). These species were only excluded from the multivariate community composition analysis and are included elsewhere.

Univariate analyses were performed using the same PERMANOVA design as the assemblage data but with Euclidean distance as the measure of dissimilarity. These models were used to analyse total population data (average Max N and total number of species) as well as abundance of specific population sub-groups (targeted species). In cases where the site factor was insignificant ($P > 0.25$) it was pooled. Monte Carlo *P*-values were used where there were low numbers (< 50) of possible unique permutations in analyses. All analyses were subdivided into two separate parts. The first compared fish assemblages and variables between highly modified and marine park estuaries, and the second compared sanctuary and habitat protection zones within the marine park estuaries.

RESULTS

In total, 5508 fish from 59 species were recorded in this study. Fourteen species occurred in all estuaries and 26 species were found in at least one modified estuary and one marine park. Thirteen species of fish occurred only in the marine parks, while 20 species occurred only in the modified estuaries. Of these, five species occurred in both marine parks (but not the modified estuaries) and eight species occurred only in one park. One species occurred in both modified estuaries (but not in the marine parks) and 19 species occurred only in one modified estuary. The majority of these species were rare within the study and encountered in less than one or two samples.

Effects of protection

The abundance of targeted fish was greater in sanctuary zones relative to habitat protection zones but there were no differences in either the average Max N of all fish or the number of fish species (Table 1, Figure 2). When individual species were analysed separately, only pink snapper *(Pagrus auratus)* showed significant differences in abundance, with more in sanctuary zones than in habitat protection zones (Table 2, Figure 3). There was, however, a trend for more silver trevally (*Pseudocaranx georgianus)* in sanctuary relative to habitat protection zones (Figure 3) but variation at the site level probably obscured this pattern (Table 2). There was no difference in assemblage composition between zones (Table 3, Figure 4). However, there was variation in community composition between pairs of sanctuary zones within each estuary, but not between pairs of habitat protection zones. This indicates more variation in fish communities among sanctuary zones. Similarly, relative abundances of silver trevally varied between sanctuary zones within Batemans Bay but nowhere else.

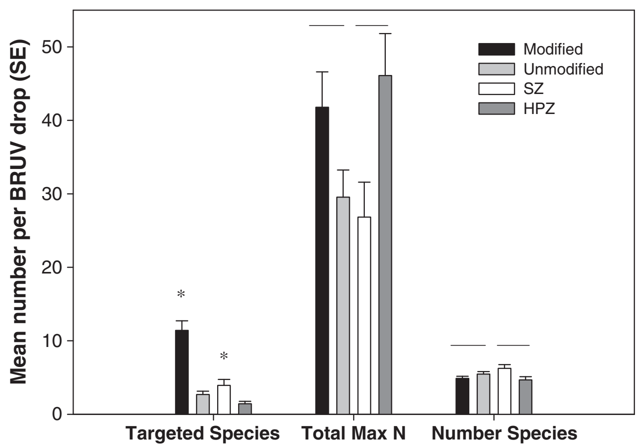

Figure 2. (a) Average Max N of targeted species and (b) species richness per BRUV drop in modified versus relatively unmodified estuaries (marine parks) ($n = 64$ drops per estuary) and in sanctuary and habitat protection zones within unmodified estuaries ($n = 32$ drops per zone). Error bars are ± Standard Error. Lines above bars indicate categories which do not significantly differ from one another. * Indicates categories which differ significantly from all other categories.

Table 1. Univariate analysis of the impacts of protection on overall fish abundance (Max N), number of species, and abundance of targeted fish. Factors: Zo = Zone (habitat protection and sanctuary), Es = Estuary, Si = Site. Significant values are indicated in bold

		Average Max N			Number of Species			Targeted Fish (Max N)		
Source	dF	MS	F	p-value	MS	F	p-value	MS	F	p-value
Zone	1	0.065	0.049	0.873	39.063	3.307	0.161	100	7.98	**0.028**
Estuary	1	0.048	0.036	0.902	14.063	1.191	0.339	45.563	3.636	0.144
Zo x Es	1	3.219	2.425	0.17	0.563	0.048	0.776	68.063	5.431	0.068
Site (EsxZo)	4	1.328	3.891	**0.008**	11.813	1.755	0.152	12.531	1.198	0.324
Residual	56	0.341			6.732			10.464		

Table 2. Univariate analysis of the mean Max N of (a) silver trevally, (b) yellowfin bream, (c) pink snapper by zone. Factors: Zo = Zone (habitat protection and sanctuary), Es = Estuary, Si = Site. Significant values are indicated in bold. * Indicates Monte Carlo *P*-value. Presented when less than 20 unique permutations

		Silvery trevally			Yellowfin bream			Pink snapper		
Source	dF	MS	F	p-value	MS	F	p-value	MS	F	p-value
Zone	1	2.954	3.127	*0.154	0.149	2.238	*0.215	1.241	14.087	***0.020**
Estuary	1	0.351	0.382	*0.565	0.24	3.598	*0.127	1.071	12.159	***0.031**
Zo x Es	1	0.351	0.382	*0.544	0.019	0.279	*0.648	1.241	14.087	***0.023**
Site (EsxZo)	4	0.918	6.85	**0.001**	0.067	0.631	0.668	0.088	0.466	0.796
Residual	56	0.134			0.106					

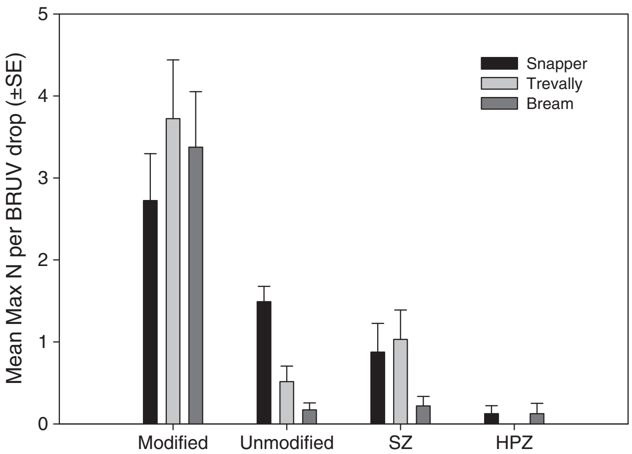

Figure 3. Average abundance per BRUV drop of three recreationally targeted fish in modified versus relatively unmodified estuaries (marine parks) ($n = 64$ drops per estuary) and in sanctuary and habitat protection zones within unmodified estuaries ($n = 32$ drops per zone). Error bars are ± Standard Error.

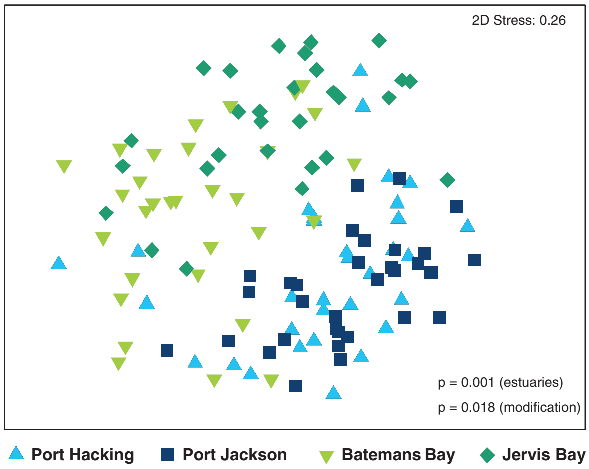

Figure 4. nMDS plots of multivariate assemblage composition by estuary. Symbols represent centroids of the assemblage composition. Batemans Bay and Jervis Bay are marine parks, Port Hacking and Port Jackson are modified estuaries.

Table 3. Multivariate analysis of the impacts of zone on assemblage composition. Factors: Zo = Zone (habitat protection and sanctuary), Es = Estuary, Si = Site. Significant values are indicated in bold

Source	dF	MS	F	p-value
Zone	1	3907.6	1.499	0.26
Estuary	1	12152	2.798	**0.049**
Zo x Es	1	2163	0.498	0.83
Site (EsxZo)	4	4342.4	2.521	**0.001**
Residual	56	1722.8		

Effects of modification

The relative abundance and number of fish species did not differ between modified estuaries and marine parks (Table 4, Figure 2). Modified estuaries, however, had more than four times higher abundance of targeted fish species (Table 4, Figure 2). Variation among sites within estuaries in both average Max N and Max N of targeted fish was largely confined to sites within Jervis Bay Marine Park. There were no differences in abundances of most individual species of fish between levels of modification, in many cases this was due to variability between sites within each estuary (Table 5). However, there was a clear trend towards more pink snapper, yellowfin bream and silver trevally in modified compared with relatively unmodified marine parks (Figure 3). The four estuaries examined in this study are at least several hundred kilometres within the known range of these species and so observed differences are not likely to be due to range effects (Edgar and Shaw, 1995; Gomon *et al*., 2008)

Overall assemblage composition was different between modified estuaries and the relatively unmodified marine parks (Table 6, Figure 4). Each estuary occupied a distinct cluster in multivariate space (Figure 4). SIMPER analysis revealed that the three species that contributed most to differences between the modified estuaries and marine parks were silver trevally, yellowfin bream, and pink snapper. These species collectively contributed approximately 35% of the difference (SIMPER) and there was a trend for them to be more abundant in the modified estuaries despite insignificant univariate analyses (Table 5, Figure 3).

DISCUSSION

This is one of the first studies to examine the impacts of sanctuary zones and modification in marine systems by simultaneously comparing fish assemblages across several levels of protection and modification. The findings support the idea that sanctuary zones increase the abundance of targeted species as a whole and abundances of some

Table 4. Univariate analyses of the impacts of modification on overall fish abundance (Max N), number of species, and abundance of targeted fish. Factors: Mo = Modification (Modified vs. Marine Parks Estuaries), Es = Estuary, Si = Site. Significant values are indicated in bold. * Indicates Monte Carlo *P*-value. Presented when less than 20 unique permutations

		Average Max N			Number of Species			Targeted Fish (Max N)		
Source	dF	MS	F	p-value	MS	F	p-value	MS	F	p-value
Mo	1	0.11	0.259	*0.665	11.281	1.249	*0.358	19.061	23.46	***0.039**
Es (Mo)	2	0.425	0.432	0.679	9.031	0.813	0.459	0.812	1.33	0.298
Si (Es(Mo))	12	0.983	2.9	**0.002**	11.115	1.75	0.07	0.608	3.12	**0.002**
Residual	112	0.339			6.353			0.195		

Table 5. Univariate analysis of the mean Max N of (a) silver trevally, (b) yellowfin bream, (c) pink snapper by modification. Factors: Mo = Modification (Modified vs. Marine Parks Estuaries), Es = Estuary, Si = Site. Significant values are indicated in bold. * Indicates Monte Carlo *P*-value. Presented when less than 20 unique permutations

		Silver trevally			Yellowfin bream			Pink snapper		
Source	dF	MS	F	p-value	MS	F	p-value	MS	F	p-value
Mo	1	14.361	8.714	*0.103	19.607	3.757	*0.912	6.672	8.583	*0.101
Es (Mo)	2	1.628	2.199	0.148	5.219	12.611	**0.004**	0.777	0.998	0.396
Si (Es(Mo))	12	0.749	2.138	**0.024**	0.414	1.831	**0.046**	0.779	2.139	**0.02**
Residual	112	0.35			0.226			0.364		

Table 6. Multivariate analysis of the impacts of modification on assemblage composition. Factors: Mo = Modification (Modified vs. Marine Parks Estuaries), Es = Estuary, Si = Site. * Indicates Monte Carlo *P*-value. Presented when less than 20 unique permutations

Source	dF	MS	F	p-value
Mo	1	44581	3.622	***0.018**
Es (Mo)	2	12309	3.39	**0.001**
Si(Es(Mo))	12	3631.5	2.285	**0.001**
Residual	112	1589.1		

individual species. However, contrary to our predictions, we also found that modified areas had a substantially higher abundance of targeted species and supported different fish communities than relatively unmodified marine parks.

Differences in the abundance of targeted species are highly relevant for assessing the relative importance of recreational fishing pressure as an ecological stressor. It is well known that commercial and recreational fishing preferentially targets species that are predatory, larger bodied, and higher up the food chain (Pauly *et al*., 1998; Essington *et al*., 2006). A greater abundance of high trophic level species is often interpreted as an indication of increased productivity (Ryther, 1969; Pauly and Christensen, 1995) and ecosystem health (Munawar *et al*., 1989). In this study, large bodied predatory species which are most sensitive to over-fishing were more abundant in the highly modified systems, despite greater recreational fishing activity in these areas (Henry and Lyle, 2003; DPI, 2010). Yellowfin bream, pink snapper and silver trevally are the 3rd, 13th and 16th species most harvested by recreational fishing activity in the state (respectively) (Henry and Lyle, 2003) and there was a trend (significant for snapper) for each of these to be more abundant in modified estuaries. The types of commercial fishing undertaken in the study estuaries (beach seining and purse seine bait collection) do not typically target these species and so the majority of fishing pressure for these fish would probably come from recreational fishing (in these estuaries, elsewhere they are all commercially targeted). Given that the density of recreational anglers is highest in the estuaries where the greatest abundance of targeted fish was observed, these findings suggest that differences in recreational fishing pressure alone are insufficient to explain the trends observed in this study and that other conditions or stressors are having a substantial impact.

These findings do not imply that sanctuary zones or marine parks are ineffective at achieving conservation goals. Sanctuary zones contained a greater abundance of targeted species and more pink snapper than habitat protection zones. Moreover, there was a trend for more silver trevally in sanctuary zones but site specific differences in abundance probably obscured these patterns. The greater abundances of pink snapper found in sanctuary zones is encouraging and appears to be a general pattern for this species with the same result seen over a number of years of sampling in deeper offshore waters in Batemans Bay Marine Park (M. A. Coleman, unpbl. data). In past studies snapper have been shown to respond well to the establishment of marine protected areas and older marine parks in New Zealand have shown increases in snapper density of up to 14 times compared with fished areas (Willis *et al*., 2003). It should be noted that the current study was not temporally replicated over the long term and could reflect differences in fish abundances that were present before marine park establishment. Long-term monitoring data contrasting sanctuary zones within parks with comparable outside areas are required to ascertain definitively whether increased abundance of pink snapper is due to increased protection (Edgar *et al*., 2009). While the present study agrees with the general assertion in the literature that marine parks and specifically sanctuary zones are effective at achieving a variety of conservation targets (one of which is the protection of populations of targeted species), findings also suggest that protected areas need to be properly contextualized and compared with modified environments (Halpern, 2003; Lester *et al*., 2009). The role of modification factors other than fishing, and the impacts that conservation measures have on general modification regimes, are clearly important issues which may have a large effect on conservation outcomes (Greene and Shenker, 1993; McKinley and Johnston, 2010). It is likely that modification factors other than fishing will also have an effect on conservation outcomes in other kinds of marine environments. Coral reefs, offshore environments, and coastal systems are also affected by many of the same human stressors as estuaries. It is therefore likely that modification will also affect conservation outcomes for marine parks in these systems. The degree to which sanctuary zones will translate into increased abundance of targeted species in these other habitats cannot be addressed by this study, though a variety of other studies have examined sanctuary zones in these systems (Halpern, 2003).

Nutrient enrichment is a possible explanation for the increased abundance of targeted species in the modified estuaries (Nixon and Buckley, 2002; Breitburg *et al*., 2009). The modified estuaries are nutrient enriched relative to the estuaries sampled in marine parks (Birch *et al*., 2010; Scanes, 2010). It is likely that urbanization, land-use alteration and run-off are largely responsible for the elevated nutrient levels in these estuaries (Nixon, 1995; Scanes, 2010). Increased nutrient levels may be enhancing the productivity of the system and hence the abundance of fish. Several studies have demonstrated that nutrient enrichment (at pre-eutrophication levels) can enhance the abundance of fish and can substantially increase fisheries yields (Micheli, 1999; Oczkowski and Nixon, 2008; McKinley and Johnston, 2010).

However, it is also possible that the modified estuaries are naturally more productive than the marine parks systems. While historic data on productivity do not go back far enough to assess this quantitatively, it is likely that the placement of the major cities are not random and that they have been somewhat influenced by natural productivity. It is well documented that cities are preferentially built in areas which are naturally highly productive as the availability of natural resources (such as large fish populations) are a major incentive for early economic and urban growth (Folke *et al*., 1997; Haberl *et al*., 2004; Lotze *et al*., 2006). It is also possible that marine parks and sanctuary zones are selectively established in areas that are not heavily used by local recreational fishing (e.g. poor fishing locations) as creating sanctuary zones in such places is more politically feasible (Agardy *et al*., 2003; Ray, 2004; Edgar *et al*., 2008).

Another possible explanation for these trends is increased habitat complexity in modified estuaries. Owing to the greater degree of development and boat traffic, a large amount of artificial habitat (maritime structures) exists in the modified estuaries (Connell and Glasby, 1999). It has been demonstrated that these structures can harbour diverse communities of invertebrates and plants (Connell and Glasby, 1999; Glasby and Connell, 1999; Glasby *et al*., 2007) and may aggregate or enhance fish abundances (Tuya *et al*., 2006). Several of the species that were more abundant in the modified estuaries are known to feed on both sessile and mobile invertebrates (Coleman and Mobley, 1984; Froese and Pauly, 2010). It is therefore possible that artificial structures support a higher abundance of these invertebrate food items and that this in turn has led to an increased abundance of the recreational fish species.

A fourth possible explanation for these findings could be differences in the abundance and activity of apex predators. In several cases increased abundance of predatory species in marine parks have been shown to have a 'top down' affect on aspects of the marine community (Shears and Babcock, 2002; Micheli *et al*., 2004). These methods did not produce a sufficient sample size to understand the distributions of these large predators, but it is likely that they are more abundant in the marine parks than in the modified estuaries. Both Jervis Bay and Batemans Bay have well documented resident populations of grey nurse sharks (*Carcharias taurus)* and common bottlenose dolphins (*Tursiops truncatus)*. Both of these species are significant predators of a variety of targeted fish species and both are believed to be largely absent from Port Jackson and Port Hacking (Gomon *et al*., 2008). However, Port Jackson also has a well documented breeding population of dusky whaler sharks *(Carcharhinus obscurus)* so it is difficult to speculate about differences in the overall abundance and activity of apex predators (McGrouther, 2010). Differences in apex predator activity could not explain the observed differences between sanctuary and non-sanctuary zones, as apex predators such as dolphins and sharks are likely to be active in both zones within a park (Shane *et al*., 1986; Last and Stevens, 2009).

Impacts of human modifications on the environment and associated ecological assemblages are complex, and so it is likely that a combination of these factors have influenced the results of this study. Regardless of which combination of factors is responsible for the differences observed in this analysis, it is clear that there is significant ecological value in the modified estuaries and that they are highly diverse and productive systems. Despite the abundance and diversity of the fish assemblages in Port Jackson and Port Hacking, there are no significant sanctuary zones in either of these estuaries, although many forms of commercial fishing have been limited. In fact, there are no major marine protected areas in any of the heavily modified estuaries in south-eastern Australia (MPA, 2010) other than small Aquatic Reserves, many of which allow line fishing. A similar trend can be observed worldwide, as very few heavily modified systems have been protected by international marine parks systems (Kelleher *et al*., 1995; IUCN, 2010). While modified areas are not highly valued in traditional conservation thinking, these systems may harbour significant biodiversity and may be heavily influenced by patterns of human activity. This study supports the idea that the ecological characteristics of these highly modified systems warrant further investigation and conservation efforts.

CONCLUSION

These findings support the idea that sanctuary zones increase the abundance of targeted species overall as well as the abundance of predatory species such as pink snapper *(P. auratus*) relative to fished areas. However, it was also found that modified areas had a substantially higher abundance of targeted species than the marine parks. Stressors other than fishing pressure may be causing increased abundance of targeted fish in the modified estuaries and it is suggested that nutrient enrichment, increased habitat complexity, and/or differences in the abundance of apex predators could be responsible. However, further investigation is needed to clarify the role of these variables. This study clearly supports the idea that modification factors other than fishing pressure are major determinants of fish assemblage structure. The minimization of these other stressors through the establishment of marine parks is possible via legislation, although it is unlikely that they can ever be totally removed. Reducing the impact of non-extractive marine stressors within marine parks may have a substantial yet poorly understood impact on fish assemblages.

There is substantial evidence that sanctuary zones are an efficient and successful conservation tool. The findings will help to contextualize the performance of marine sanctuaries and the metrics by which those parks are evaluated. The findings suggest that emphasizing the importance of marine parks as a method of bolstering populations of economically valuable species, an argument which is articulated in many studies and management plans, is perhaps not the best measure of a marine park's success (McClanahan and Kaunda-Arara, 1996). In the estuaries studied, the findings suggest that the pervasive belief that the most natural and pristine conditions will produce the most fish is not necessarily true, as some forms of modification may have large but poorly understood indirect effects on fish population productivity. A higher abundance of commercially and recreationally important species does not necessarily reflect natural conditions and reduced modification should not necessarily be expected to increase fisheries yields.

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APPENDIX 1. AVERAGE SPECIES ABUNDANCE DATA BY PROTECTION ZONE AND ESTUARY. SPECIES ARE DISPLAYED IN ORDER OF TOTAL ABUNDANCE ACROSS ALL ESTUARIES. VALUES REPRESENT THE AVERAGE OF BRUV TAPES FOR EACH CATEGORY. HABITAT PROTECTION AND SANCTUARY ZONES ARE SUBSETS OF THE MARINE PARKS. TARGETED SPECIES FROM DPI (2010) AND FROESE & PAULY (2010)

	Batemans HPZ	Batemans SZ	Jervis HPZ	Jervis SZ	Port Hacking	Port Jackson	Targeted Species
Yellowtail Scad *Trachurus novaezelandiae*	31.19	11.56	21.13	23.06	13.66	9.94	N
Mado *Atypichthys strigatus*	12.13	7.81	8.63	10.50	15.03	1.42	N
Ocean Leatherjacket *Nelusetta ayraud*	1.56	0.06	4.19	10.63	5.00	3.80	N
Silver Sweep *Scorpis lineolata*	4.38	1.31	1.19	1.69	3.69	2.95	N
Silver Trevally *Pseudocaranx georgianus*	0.00	1.63	0.00	0.44	4.00	3.45	Y
Pink Snapper *Pagrus auratus*	0.06	1.56	0.19	0.19	2.84	2.60	Y
Yellowfin Bream *Acanthopagrus australis*	0.25	0.38	0.00	0.06	1.94	4.81	Y
Weaping Toadfish *Torquigener pleurogramma*	0.00	0.00	0.19	3.06	0.84	0.99	N
Maori Wrasse *Ophthalmolepis lineolatus*	1.25	2.13	0.19	0.50	0.19	0.06	N
Flathead sp. *Platycephalus* sp.	0.25	0.06	1.00	0.69	0.72	0.04	Y
Fiddler Ray *Trygonorrhina fasciata*	0.31	0.38	0.81	0.75	0.03	0.06	N
Green Moray Eel *Gymnothorax funebris*	0.38	0.69	0.06	0.00	0.31	0.15	N
Common Eagle Ray *Myliobatus aquila*	0.00	0.31	0.31	0.44	0.16	0.00	N
Long Finned Pike *Dinolestes lewini*	0.19	0.13	0.00	0.00	0.50	0.21	Y
Luderick *Girella tricuspidata*	0.00	0.63	0.00	0.00	0.22	0.03	Y
Senator Wrasse *Pictilabrus laticlavius*	0.06	0.13	0.25	0.25	0.06	0.07	N
Tarwhine *Rhabdosargus sarba*	0.19	0.25	0.06	0.25	0.00	0.00	Y
Red Rock Cod *Scorpaena cardinalis*	0.19	0.44	0.06	0.00	0.00	0.00	Y
White Ear *Parma microlepis*	0.25	0.13	0.06	0.06	0.13	0.03	N
Common Stingaree *Trygonoptera imitata*	0.06	0.06	0.19	0.19	0.47	0.16	N
Wirrah *Acanthistius ocellatus*	0.13	0.25	0.00	0.13	0.09	0.00	Y

(*Continues*)

Table 1. (Continued)

	Batemans HPZ	Batemans SZ	Jervis HPZ	Jervis SZ	Port Hacking	Port Jackson	Targeted Species
Eastern Shovelnose Stingray *Aptychotrema rostrata*	0.00	0.00	0.25	0.31	0.00	0.00	Y
Yellowtail Kingfish *Seriola lalandi*	0.00	0.00	0.00	0.00	0.00	0.54	Y
Striped Trumpeter *Pelates sexlineatus*	0.00	0.00	0.00	0.00	0.47	0.00	N
Eastern Kelpfish *Chironemus marmoratus*	0.13	0.25	0.00	0.06	0.00	0.00	N
Tailor *Pomatomus saltatrix*	0.00	0.00	0.00	0.00	0.03	0.38	Y
Blue Spotted Goatfish *Upeneichthys vlamingii*	0.00	0.00	0.00	0.00	0.38	0.00	N
Blue Stripped Goatfish *Upeneichthys lineatus*	0.00	0.13	0.00	0.06	0.19	0.00	N
Old Wife *Enoplosus armatus*	0.00	0.00	0.06	0.25	0.00	0.00	N
Crimson Banded Wrasse *Notolabrus gymnogenis*	0.13	0.13	0.00	0.00	0.03	0.03	N
Yellowfin Leatherjacket *Meuschenia trachylepis*	0.00	0.13	0.00	0.00	0.03	0.11	Y
Port Jackson Shark *Heterodontus portusjacksoni*	0.00	0.13	0.06	0.00	0.00	0.00	N
Red Morwong *Cheilodactlus fuscus*	0.06	0.00	0.06	0.06	0.00	0.00	Y
Blind Shark *Brachaelurus waddi*	0.00	0.19	0.00	0.00	0.00	0.00	Y
Eastern Blue Groper *Achoerodus viridis*	0.00	0.06	0.06	0.00	0.03	0.00	N
Eastern Smooth Boxfish *Anoplocapros inermis*	0.00	0.00	0.00	0.00	0.13	0.00	N
Amber Jack *Seriola dumerili*	0.00	0.13	0.00	0.00	0.00	0.00	Y
Comb Wrasse *Coris picta*	0.00	0.06	0.00	0.00	0.03	0.00	N
Girdled Parma *Parma unifasciata*	0.06	0.00	0.00	0.00	0.00	0.00	N
Sergeant Baker *Aulopus purpurissatus*	0.00	0.06	0.00	0.00	0.00	0.00	N
Eastern Garfish *Hyporhamphus australis*	0.00	0.06	0.00	0.00	0.00	0.00	Y
Bronze Whaler Shark *Carcharhinus brachyurus*	0.00	0.06	0.00	0.00	0.00	0.00	Y
Banded Wobbegong Shark *Orectolobus ornatus*	0.00	0.00	0.00	0.00	0.00	0.06	Y
Blue Morwong *Nemadactylus douglasii*	0.00	0.06	0.00	0.00	0.00	0.00	Y
Sergeant Major *Abudefduf vaigiensis*	0.00	0.00	0.00	0.00	0.00	0.04	N
Scaly Tail Toadfish *Torquigener squamicauda*	0.00	0.00	0.00	0.00	0.00	0.04	N
Fan Belly Leatherjacket *Monacanthus chinensis*	0.00	0.00	0.00	0.00	0.00	0.04	Y
Sand Whiting *Sillago ciliate*	0.00	0.00	0.00	0.00	0.00	0.04	Y
Herring Cale *Odax cyanomelas*	0.00	0.00	0.00	0.00	0.03	0.00	N
Common Beardie *Lotella rhacina*	0.00	0.00	0.00	0.00	0.03	0.00	N
Eastern Hulafish *Trachinops taeniatus*	0.00	0.00	0.00	0.00	0.00	0.03	N
Smooth Flutemouth *Fistularia commersonii*	0.00	0.00	0.00	0.00	0.03	0.00	N
Smooth Ray *Dasyatis brevicaudata*	0.00	0.00	0.00	0.00	0.03	0.00	N
Half Banded Seaperch *Hypoplectrodes maccullochi*	0.00	0.00	0.00	0.00	0.03	0.00	N
Globe Fish *Diodon nicthemerus*	0.00	0.00	0.00	0.00	0.03	0.00	N
Roach *Gerres subfasciatus*	0.00	0.00	0.00	0.00	0.00	0.03	Y

(*Continues*)

Table 1. (Continued)

	Batemans HPZ	Batemans SZ	Jervis HPZ	Jervis SZ	Port Hacking	Port Jackson	Targeted Species
Small Toothed Flounder *Pseudorhombus jenynsii*	0.00	0.00	0.00	0.00	0.00	0.03	Y
Silver Drummer *Kyphosus sydneyanus*	0.00	0.00	0.00	0.00	0.03	0.00	Y
Average Max N – Targeted Species	1.25	5.81	1.63	2.06	10.44	12.39	
Average Max N - All	53.19	31.31	39.00	53.63	51.41	32.16	
Species Richness	5.06	6.81	4.38	5.75	5.13	4.63	