

Distribution, abundance, habitat association and extinction risk of marine fishes endemic to the Lord Howe Island region



Report to Lord Howe Island Marine Park November 2009

Hobbs J-P. A., Neilson J., Gilligan, J.J.

School of Marine and Tropical Biology, James Cook University, Townsville QLD 4811



EXECUTIVE SUMMARY

Endemic fishes with small populations and specialised habitat or dietary requirements are among the most vulnerable species to extinction. The extinction risk of marine fishes endemic to the Lord Howe Island (LHI) region was assessed by underwater visual surveys at 23 sites around LHI. Surveys were done in March and April 2009 between 1 and 15 m depth to determine the distribution, abundance and habitat associations of fishes endemic to the region. McCulloch's anemonefish (*Amphiprion mccullochi*) appears to have the greatest extinction risk of the endemic fishes due to its small geographic range, low abundance at Middleton and Elizabeth Reefs, and its reliance on anemones. This anemonefish was found to be locally abundant on reef edges in the lagoon at LHI where its host anemone (*Entacmaea quadricolor*) was abundant. The lagoon at LHI represents the last remaining stronghold in the world for this anemonefish, however, bleaching and subsequent mortality of anemones remains a serious threat to its persistence. The endemic three-striped butterflyfish (*Chaetodon trilineatus*) was also abundant in the lagoon, particularly in areas where complex hard corals were common. The three-striped butterflyfish is the most abundant butterflyfish at LHI, Middleton Reef and Elizabeth Reef although the future of this fish may potentially be affected by the loss of vulnerable coral species that it associates with. The endemic doubleheader wrasse (*Coris bulbifrons*) was common around LHI and reached its greatest abundance in the lagoon, which appears to be an important habitat for juveniles. This species seems less reliant on particular habitats and therefore may be less affected by habitat loss, however, fishing pressure needs to be monitored to prevent overfishing. Other endemics *Amphichaetodon howensis*, *Chaetodontoplus ballinae* and *Genicanthus semicinctus* were rare or absent from transects. These species inhabit deeper reefs and future surveys of this habitat are required before an accurate assessment of their extinction risk can be made. Two vulnerable species were also surveyed and both species, the black cod (*Epinephelus daemeli*) and the Galapagos shark (*Carcharhinus galapagosensis*), exhibited considerably lower abundance at LHI compared to Middleton and Elizabeth Reefs. Their low densities in the lagoon at LHI is concerning because the lagoons at Middleton and Elizabeth Reefs support the greatest densities of both these species and this habitat appears to be an important nursery area. Further research is required to determine the

location of nursery areas, and the abundance of these two species in deeper water around LHI. Although more research is needed to determine extinction risk in some endemic fishes, it's clear that the preservation of lagoonal habitat from extrinsic impacts, such as bleaching and terrestrial runoff, is important to the persistence of at least two endemic fishes, particularly McCulloch's anemonefish. Molecular studies are required to determine population connectivity of endemic fishes between LHI, Middleton Reef and Elizabeth Reef, and thereby ascertain whether populations could replenish each other if one population declines or goes locally extinct.

INTRODUCTION

Island communities are unique in that they contain a high proportion of endemic plants and animals, but they also have suffered the highest rates of extinctions (Whittaker, 1998). Endemic species are particularly susceptible to extinction because their small geographic range is usually associated with low abundance (Gaston, 1994; Brown, 1995; Gaston et al, 1997). Endemic species face a dual threat of extinction because they are vulnerable to impacts that affect their restricted geographic range, and are also threatened by processes that reduce their small populations (Gaston, 1998). Thus, endemic species are naturally vulnerable to extinction, and human impacts, such as, habitat destruction, introduced species and overharvesting have exacerbated the loss of endemic species (Whittaker, 1998; Blackburn et al, 2004).

While most research on extinction risk has focussed on terrestrial systems, marine systems have also been affected by human impacts such as overharvesting and habitat destruction (Jackson et al, 2001; Dulvy et al, 2003; Hughes et al, 2003; Hoegh-Guldberg et al, 2007). Fishes are one of the best-studied marine groups and they reveal a similar story to terrestrial communities: isolated islands contain a high number of endemic species (Jones et al, 2002; Hughes et al, 2002; Allen, 2008), and all 3 recent extinctions have been island endemics (Dulvy et al, 2003). The greatest diversity of fishes occur on coral reefs; a habitat that is under increasing threat from overfishing, disease, pollution, habitat loss and coral bleaching (Harvell et al, 1999; Hughes et al, 2003, Hoegh-Guldberg et al, 2007). Approximately 20% of the world's coral reefs have been destroyed and a further 50% are at risk of collapse (Wilkinson, 2004). Therefore, there is an urgent need to identify the reef fishes that are most at risk of extinction from impacts such as habitat loss.

Endemic reef fishes have an increased risk of extinction because of their small geographic range, but this risk may be greatly amplified if endemics have other vulnerable ecological traits (McKinney, 1997). Recent coral bleaching events resulting in sudden loss of habitat has caused declines in reef fish diversity and the species most affected have been those with specialist habitat (Jones et al, 2004; Munday, 2004;

Bellwood et al, 2006; Wilson et al, 2006; Wilson et al, 2008) or dietary requirements (Pratchett et al, 2006; Graham, 2007). If endemic species have low abundance, and are specialists, then this combination will render them among the most susceptible to extinction of any reef fishes (Munday, 2004). Although endemic species in the terrestrial environment usually have low abundance (Brown, 1995; Gaston, 1994, 1998; Gaston et al, 1997), and are often specialists (Brown, 1984; Gaston, 1994; Gaston et al. 1997), endemic reef fishes can reach high abundance (Randall, 1998; Jones et al, 2002; DeMartini, 2004; DeMartini and Freidlander, 2004) and this may compensate for the risk of extinction associated with having a small geographic range. Therefore, examination of other vulnerable ecological traits (e.g. small population size and specialisation) is required to make an accurate assessment of extinction risk in endemic reef fishes.

One area with a relatively high proportion of endemic reef fishes is the Lord Howe Island (LHI) region (Randall, 1976, 1998), located in the northern Tasman Sea, off Australia's east coast. The LHI region comprises the southernmost coral reefs in the world and is home to approximately 16 endemic reef fishes (Coleman, 2002). The LHI region includes the rock formations and reefs surrounding LHI as well as Middleton and Elizabeth Reefs which lie to the north of LHI. The distribution of some endemic species may extend to any of the following locations as small populations or vagrants: Australia's east coast, Norfolk Island, the Kermadec Islands and northern New Zealand (Figure 1). Therefore, species referred to as endemic in this study primarily occur at LHI, but may also be present at locations within the surrounding biogeographic region (see Randall, 1976).

Although LHI supports a concentration of endemic reef fishes, little is known about their ecology or risk of extinction. Therefore, the aim of this study was to assess the extinction risk of endemic reef fishes at LHI by examining their distribution, abundance and habitat associations around LHI. Particular attention is given to McCulloch's anemonefish (*Amphiprion mccullochi*) because this species appears to be the most vulnerable endemic species at LHI. This anemonefish is susceptible because it is a habitat specialist and its abundance and distribution is restricted by the occurrence of its host anemone. Furthermore, assessing its abundance at LHI is a priority given that its two other populations (Middleton and Elizabeth Reef) have very low abundance (Choat et al, 2006;

Hobbs and Feary, 2007). Where possible, the abundance of endemic fishes at LHI is compared to their corresponding populations at Middleton and Elizabeth Reefs (Choat et al, 2006; Hobbs and Feary, 2007).

METHODS

LHI (31° S, 159°E) is situated on the Lord Howe Rise of seamounts in the northern Tasman Sea, approximately 770km north-east of Sydney, Australia. The same chain of seamounts also includes Middleton and Elizabeth Reefs, which are remote oceanic platform reefs located approximately 160 km and 220 km (respectively) north of LHI. The seafloor around LHI slopes gradually to 100 m depth about 7-14 km from shoreline and then drops steeply to the abyssal plain. On the western side of LHI there is a lagoon protected by an outer reef. The shallow lagoon (0-3 m) contains a network of reefs, interspersed with sand, rock, algae, and seagrass beds. The lagoon also contains a small number of coral-fringed deeper holes, reaching depths of 5-7 m, the most notable being Sylph's Hole, Comet's Hole, and Erscott's Hole. Several passes connect the lagoon to the ocean. There are a series of rocky outcrops and islets surrounding Lord Howe Island, including Ball's Pyramid 23 km to the south-east.

LHI is listed as a World Heritage Area due to its internationally significant and globally unique terrestrial and marine life. The waters, habitat and marine life around LHI are protected by the Lord Howe Island Marine Park (LHIMP). The Marine Park was established in 1999 and includes New South Wales (NSW) waters out to 3 nautical miles from the shore and Commonwealth waters 3-12 nautical miles from shore. The NSW waters of the Marine Park cover approximately 48,000 hectares. Approximately, 27 % (12,500 hectares) of the NSW section of the Marine Park is designated as sanctuary zones. These sanctuary zones provide the highest level of protection, including prohibition of all forms of fishing and extractive activities. A considerable proportion of the lagoon is protected within three of these sanctuary zones. A further two sanctuary zones occur outside the lagoon and extend seawards from the north-eastern and south-eastern shores of LHI.

Endemics fishes surveyed included: *Amphiprion mccullochi* (Pomacentridae), *Amphichaetodon howensis* (Chaetodontidae), *Chaetodon tricinctus* (Chaetodontidae), *Chaetodontoplus ballinae* (Pomacanthidae), *Genicanthus semicinctus* (Pomacanthidae), and *Coris bulbrifrons* (Labridae)(Figure 2). To identify potential nursery areas, juvenile and adult *C. bulbrifrons* were counted separately and were distinguished based on their distinct colour differences (Figure 2C,D). Other endemics fishes were not surveyed because their cryptic or nocturnal lifestyles make it difficult to obtain accurate abundance estimates using visual surveys (e.g. *Apogon norfolcensis*, *Gymnothorax annasona*). We also recorded the abundance of black cod (*Epinephelus daemeli*) and Galapagos sharks (*Carcharhinus galapagosensis*). Both these species have been overfished throughout their range. The Galapagos shark is listed as “Near Threatened” by the IUCN, and the black cod is listed as “Vulnerable” by the NSW government. Recording the abundance of these two species will determine whether LHI provides a valuable refuge for these susceptible species, as is the case for Middleton and Elizabeth Reefs to the north (Hobbs et al, 2008).

To assess the distribution and abundance of endemic and vulnerable fishes we surveyed 23 sites surrounding LHI (Figure 3, Table 1). This included 9 sites in the lagoon, 12 on the outer reefs and rocky outcrops around LHI, and two at Ball’s Pyramid. Unsuitable weather prevented surveys of the south-eastern side of LHI. To determine the depth distribution of endemic fishes, surveys were done at two depths (5 and 15 m), except at North Passage where only 5m depth could be done. The shallowness of the lagoon limited the depth surveyed, and transects were done on reefs at 9 sites that varied between 1 and 3 m deep. To examine fine scale patterns of distribution and abundance of endemic fishes within the lagoon, the nine sites were divided equally between three different habitat types: patch reefs, the edge of large reefs, and the centre of large reefs. Patch reefs were areas in lagoon that contained networks of small reefs (or “bommies”: usually < 5m in diameter) and interspersed amongst areas of sand and seagrass. The “reef edge” habitat included the reef matrix on the perimeter of large reefs, and at some sites the reef edge bordered the deeper, sandy holes. The “reef centre” habitat was in the middle of large lagoonal reefs and transects did not come within 10 m of the reef edge. SCUBA diving and time constraints prevented surveys of deeper habitats (> 20 m) around LHI.

The number of endemic fishes was recorded within 50 x 5 m belt transects. Three replicate transects were done at each depth (where applicable) at each site. Immediately after the fish were surveyed, the entire area of each transect (250 m²) was searched intensively to determine the number and species of anemones present. To identify correlations between other habitat characteristics and the distribution and abundance of endemic fishes we used line intercept transects. Once the fishes and anemones had been counted, a diver swam along the 50 m transect tape and recorded the type of substrate located directly beneath the tape every 2 m (equalling 25 points per transect). The substrate was classified into the following categories: red algae (Rhodophyta), brown algae (Phaeophyta), green algae (Chlorophyta), soft coral, turfing algae, coralline algae, seagrass, other, and live hard coral (Scleractinia); Live hard coral was divided into six morphological groups: plating, branching, bushy, foliose, encrusting and massive. Dead hard coral, rock, rubble and sand were grouped together and classed as bare substrate. The category “other” included anemone and sponges and made up less than 1% of the substrate.

The densities of endemic species were each compared between three different habitats using a one-way ANOVA (Zar, 1999). The three habitats were lagoon, shallow outer reef sites (5 m depth), and deeper outer reef sites (15 m). The “outer reef sites” include all the sites distributed around LHI (including Ball’s Pyramid) that are not inside the lagoon. Where necessary, data was $\log_{10}(x + 1)$ transformed to ensure homogeneity of variances. Welch’s Test was used if the data remained heteroscedastic after transformation (Levene’s Test: $p < 0.05$) (Welch, 1947). Densities are presented in the results as the arithmetic mean \pm SE per 250m², unless otherwise specified. The densities of endemic species were compared to their corresponding populations at Middleton and Elizabeth Reef (Choat et al, 2006; Hobbs and Feary, 2007). Correlations were used to test associations between abundance of some endemics and particular habitats. Statistical analyses were performed using SPSS software (Chicago, U.S.A).

To construct distribution and abundance maps, recent (2008) orthorectified aerial imagery was obtained from the Lord Howe Island Board. This imagery was imported into ArcMap 9.1 (ESRI) and projected in WGS84 (Zone 57). Image quality was sufficient to

determine the extent of the lagoon and to further define the extent of coral reef habitat within the lagoon. Polygons defining entire lagoon area and lagoonal coral reef area were digitised by hand and the area calculated using XTools. Although no field validation of the reef boundaries were completed, the digitising process was done by people with field experience in the area and experience delineating habitats from aerial imagery. Notwithstanding this, the lagoon and lagoonal coral reef area estimates contained in this study are approximates only.

Table1. The co-ordinates (WGS84), site name, reef type and depth surveyed at 23 study sites around Lord Howe Island.

Site Number	Latitude	Longitude	Site Name	Reef type	Depth (m)
1	-31.53908	159.06543	Comet's Reef	Lagoon reef edge	3
2	-31.53961	159.06598	Comet's Reef	Lagoon reef centre	1
3	-31.542339	159.062397	Horseshoe Reef	Lagoon reef centre	1
4	-31.5426	159.062176	Horseshoe Reef	Lagoon reef edge	2
5	-31.529496	159.049551	Steven's Reef	Lagoon reef centre	1
6	-31.528884	159.052679	Steven's Reef	Lagoon patch reefs	1
7	-31.525946	159.049795	La Meurthe	Lagoon patch reefs	2
8	-31.5243	159.0484	North Passage	Lagoon pass	5
9	-31.522097	159.046456	North Bay	Lagoon patch reefs	1
10	-31.545598	159.060522	Erscott's Hole	Lagoon reef edge	3
11	-31.49935	159.06494	Rupert's Reef	Outer reef	5 and 15
12	-31.51059	159.0556	Malabar	Outer reef	5 and 15
13	-31.5134	159.06903	Ned's Beach	Outer reef	5 and 15
14	-31.5231	159.07723	Middle Beach	Outer reef	5 and 15
15	-31.51293	159.0428	Old Gulch	Outer reef	5 and 15
16	-31.50414	159.06679	Sugarloaf Rock	Outer reef	5 and 15
17	-31.54974	159.06295	Erscott's Blind Passage	Outer reef	5 and 15
18	-31.58355	159.06596	Little Slope	Outer reef	5 and 15
19	-31.57082	159.06824	Little Island	Outer reef	5 and 15
20	-31.53915	159.05341	Rabbit Island Offshore	Outer reef	5 and 15
21	-31.532047	159.047621	Yellow Rock	Outer reef	5 and 15
22	-31.75067	159.23682	Observatory Rock	Outer reef (Ball's Pyramid)	5 and 15
23	-31.75636	159.23627	Wheatsheaf Islet	Outer reef (Ball's Pyramid)	5 and 15

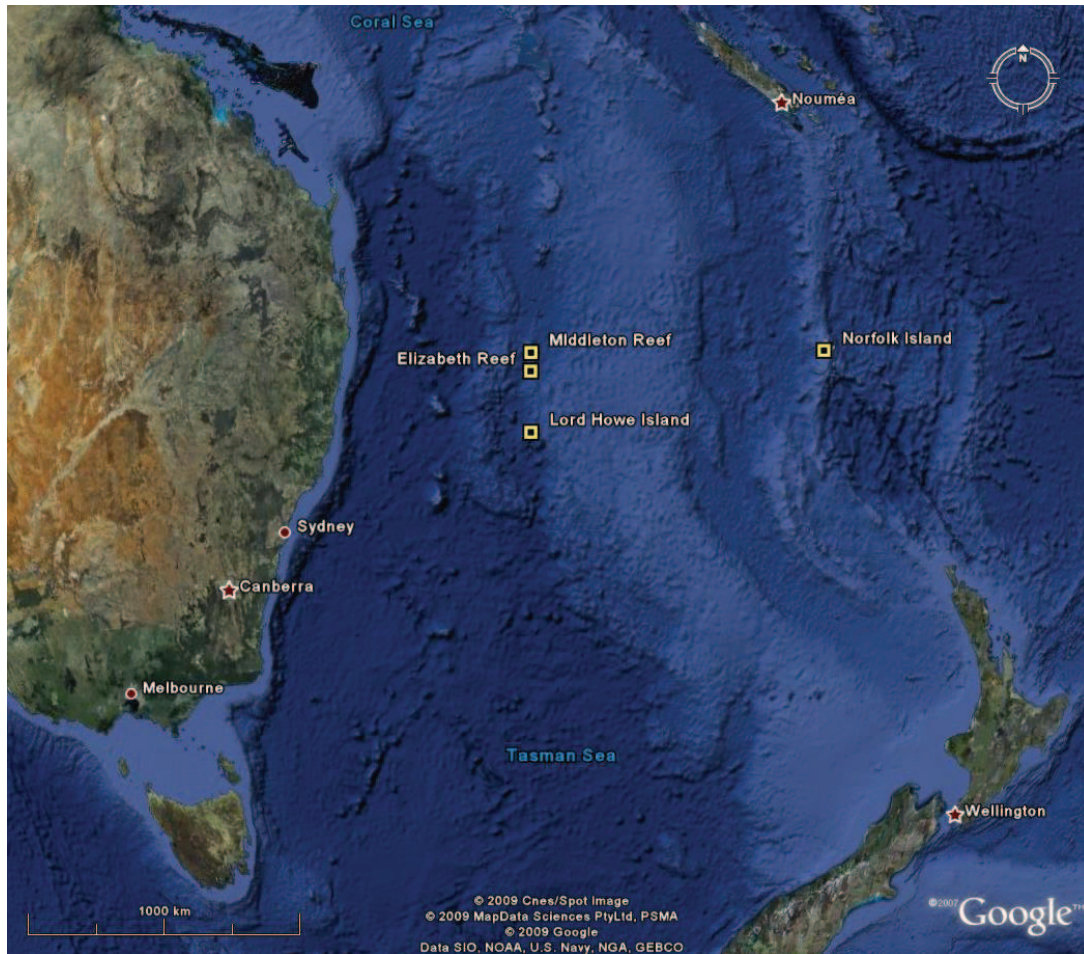


Figure 1: The regional setting of Lord Howe Island, including the approximate position of Elizabeth and Middleton Reefs. (Source = Google Earth)



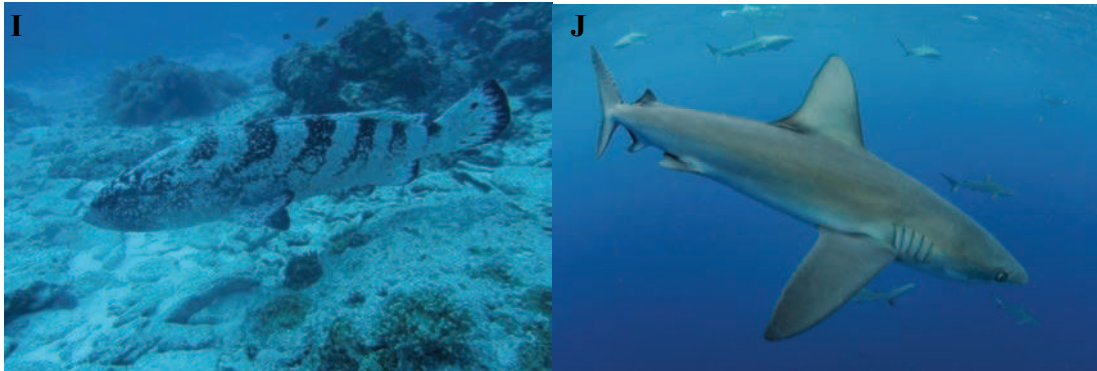


Figure 2. Underwater photographs of marine fishes endemic to the Lord Howe Island region that were examined in this study. A) *Amphiprion mccullochi* amongst a group of its host anemone *Entacmaea quadricolor*. The white anemone in the background is bleached. Photo J. Gilligan. B) *Chaetodon tricinctus*. Photo J. Gilligan. C) *Coris bulbrifrons* adult. Photo J. Gilligan. D) *Coris bulbrifrons* juvenile. Photo JP Hobbs. E) *Amphichaetodon howensis* Photo J. Gilligan. F) *Chaetodontoplus ballinae*. Photo J. Gilligan G) *Genicanthus semicinctus* female. Photo J. Gilligan. H) *Genicanthus semicinctus* male. Photo J. Gilligan. Vulnerable fishes surveyed at Lord Howe Island were I) *Epinephelus daemeli*. Photo T. Ayling. J) *Carcharhinus galapagosensis*. Photo J. Gilligan.

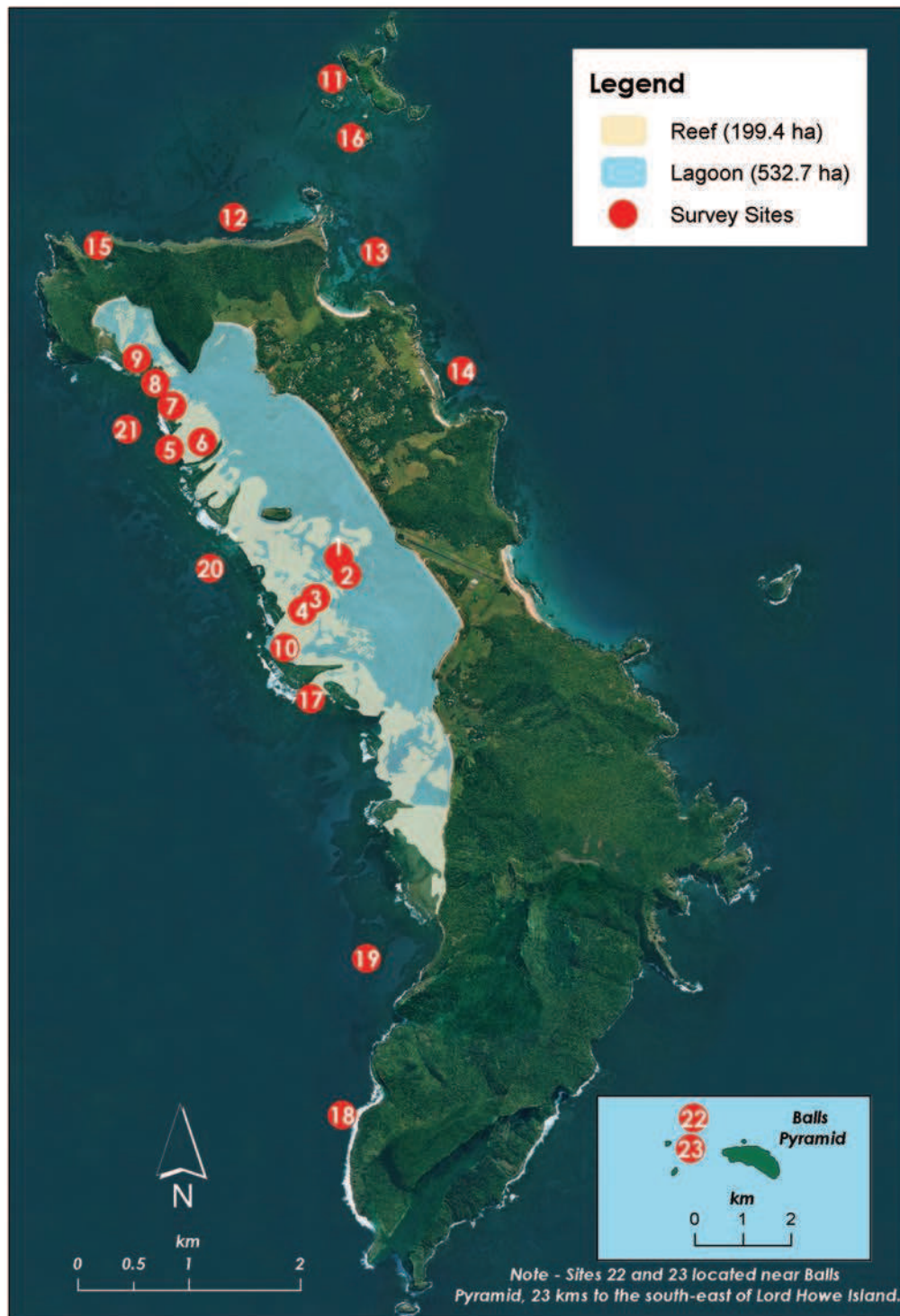


Figure 3. The location of 23 study sites around Lord Howe Island. GPS co-ordinates for each site are presented in Table 1.

RESULTS

Habitat:

The habitat at the 23 sites surveyed generally contained a mix of soft and hard corals (mean cover across all sites = 39% \pm 3.1 SE), macroalgae (28% \pm 4.6 SE) and bare substrate (16% \pm 1.6 SE)(Figure 4). Live hard coral cover tended to be greater at lagoon sites (mean = 42% \pm 3.4 SE) compared to sites on the outer reefs and rocky outcrops (mean = 23% \pm 2.8 SE). The hard coral community in the lagoon was dominated by structurally complex corals, such as branching and bushy growth forms, which accounted for approximately 80% of the scleractinian community (Figure 5).

Anemonefish and anemones

A total of 440 anemonefish (*Amphiprion mccullochi*) and 2777 anemones (*Entacmaea quadricolor*) were counted in transects across the 23 sites. No other species of anemonefish or anemones were encountered in transects. Approximately 92% of the total number of anemonefish occurred at sites within the lagoon (Figure 6). The mean density of *A. mccullochi* at lagoon sites was more than 18 times greater than at outer reef sites (Welch's Test: $F = 53.0$, d.f. = 2, $p < 0.001$, Figure 7). Three habitats were surveyed within the lagoon (reef edge, reef centre and patch reefs) and densities of *A. mccullochi* were greatest at reef edge sites (ANOVA: $F = 14.0$, d.f. = 2, $p < 0.001$, Figure 8). The overall mean density of *A. mccullochi* across all sites at LHI was more than 10 times the mean density recorded across sites at Middleton and Elizabeth Reefs (Figure 9).

The abundance of anemones was also greatest in the lagoon, representing 99% of the total number of anemones counted (Welch's Test: $F = 63.4$, d.f. = 2, $p < 0.001$, Figure 10). Within the lagoon, the mean density of anemones varied significantly between reef edges, patch reefs and reef centres (ANOVA: $F = 13.6$, d.f. = 2, $p < 0.001$). The greatest densities were found on the reef edge, which represented 76% of all anemones (and 73% of all anemonefish) that were counted in the lagoon. The site that had the greatest densities of anemones and anemonefish was the reef edge at Comet's Hole with a total 116 anemonefish and 970 anemones counted in 3 transects. Given their close symbiotic relationship, it is not surprisingly that the abundance of anemonefish was positively

correlated with the abundance of its host anemone at the site ($r_s = 0.96, p < 0.001, n = 23$) and replicate level ($r_s = 0.99, p < 0.001, n = 108$, Figure 11). Sixteen bleached anemones (see Figure 2A) were recorded in transects, representing only a very small fraction (0.6%) of the total number of anemones encountered. All the bleached anemones were in the lagoon, with 15 recorded at Comet's Hole and one at Erscott's Hole.

Chaetodon tricinctus

The endemic *Chaetodon tricinctus* was the most abundant butterflyfish recorded in transects at LHI (Figure 12). Its density was greatest in the lagoon followed by the shallow outer reef sites and then deeper outer reef sites (Welch's Test: $F = 52.5$, d.f. = 2, $p < 0.001$, Figure 13 and 14). Within the lagoon, there was no significant difference in the density of *C. tricinctus* between reef edges, reef centres and patch reefs (ANOVA: $F = 2.0$, d.f. = 2, $p < 0.151$). The density of *C. tricinctus* at each site was positively correlated with the amount of structurally complex (branching and bushy) live hard coral ($R^2 = 0.86, p < 0.001$, Figure 15). *C. tricinctus*, particularly juveniles, were regularly observed sheltering amongst the branches of these corals. *C. tricinctus* was also the most abundant butterflyfish at Middleton and Elizabeth Reefs, however, its density at these locations was much lower than that recorded at LHI (Choat et al, 2006; Hobbs and Feary, 2007, Figure 16).

Coris bulbifrons

The mean density of *Coris bulbifrons* was greater in the lagoon compared to outer 15 m and 5 m sites, however, this was largely due to greater densities of juveniles in the lagoon (Welch's Test: $F = 19.6$, d.f. = 2, $p < 0.001$, Figure 17). Within the lagoon, densities of *C. bulbifrons* were similar between the reef edge, patch reefs and reef centre (ANOVA: $F = 0.17$, d.f. = 2, $p < 0.84$). The density of *C. bulbifrons* across all sites at LHI was similar to that reported at Middleton and Elizabeth Reefs (Choat et al, 2006; Hobbs and Feary, 2007, Figure 18).

Other endemics

Only eight *Amphichaetodon howensis* and two *Genicanthus semicinctus* individuals were seen in transects. Most of these fishes were recorded in deep transects (15 m) at site 11 (Rupert's Reef). *Chaetodontoplus ballinae* was not recorded in any transects, however, two were seen outside transects at Ball's Pyramid. *Amphichaetodon howensis* and *Chaetodontoplus ballinae* have not been recorded at Middleton or Elizabeth Reefs, and *Genicanthus semicinctus* was not observed in transects at these locations but was occasionally seen outside transects, particularly in deeper water at Elizabeth Reef (Choat et al, 2006).

Black cod and Galapagos shark

Only four black cod individuals (*Epinephelus daemeli*) and four Galapagos sharks (*Carcharhinus galapagosensis*) were encountered in transects at LHI. All the black cod encountered were less than 70 cm in total length. The overall mean densities of black cod (0.037 per 250m²) and Galapagos shark (0.037 per 250m² per 250m²) at LHI were both considerably lower than densities recorded at Middleton and Elizabeth Reefs. The density of black cod at Middleton and Elizabeth Reefs were per 2.9 per hectare and 1 per 1000 m², respectively (Choat et al, 2006; Hobbs and Feary, 2007). For Galapagos sharks, mean densities at Middleton Reef ranged between sites from 0.4 to 12.1 per hectare (Choat et al, 2006) and at Elizabeth Reef the overall mean density was 1.77 per 1000 m² (Hobbs and Feary, 2007). The lagoons at Middleton and Elizabeth Reefs supported the greatest densities of black cod and Galapagos shark (Choat et al, 2006; Hobbs and Feary, 2007), however, both these species were rare in the lagoon at LHI. Only two Galapagos sharks and one black cod were recorded in transects at lagoon sites at LHI.

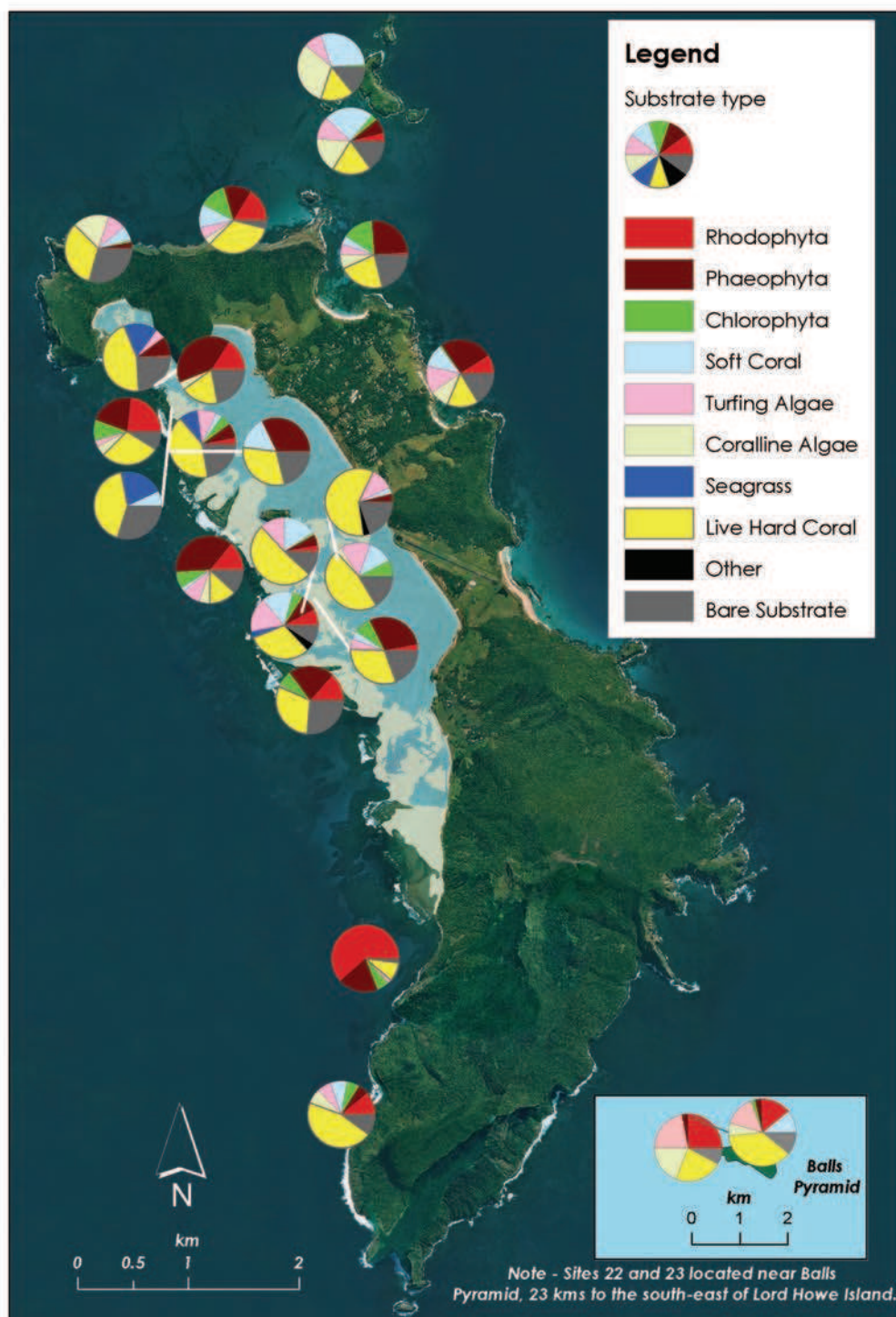


Figure 4. The mean percent substrate composition at 23 sites around Lord Howe Island. For sites where surveys were done at two depths (5 and 15 m) the mean was calculated across both depths. Substrate categories are defined in the methods.

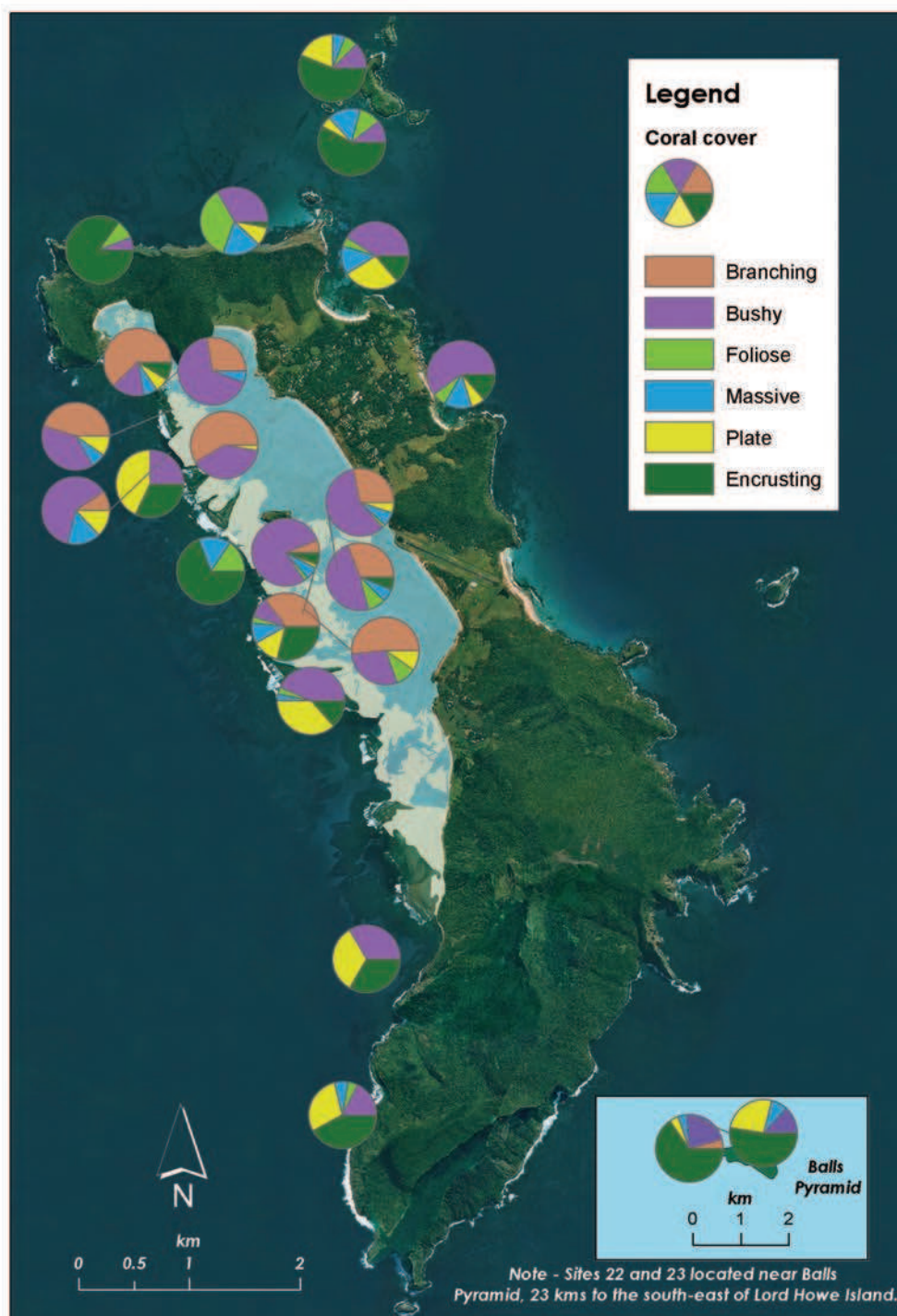


Figure 5. The proportional composition of six different morphologies of live hard coral at 23 sites around Lord Howe Island. For sites where surveys were done at two depths (5 and 15 m) the mean was calculated across both depths.

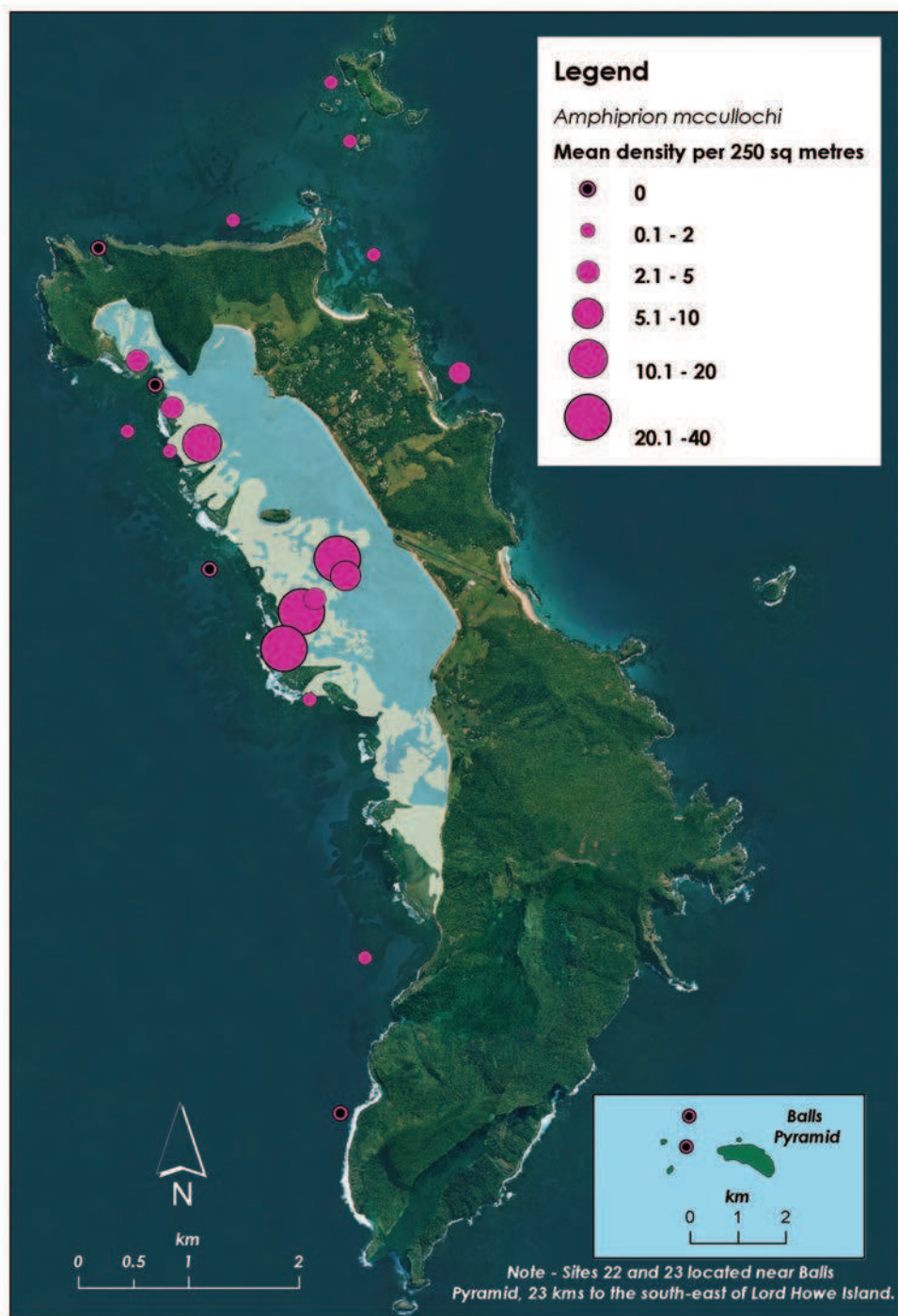


Figure 6. The mean density per 250m² of *Amphiprion mccullochi* at 23 sites around Lord Howe Island. For sites where surveys were done at two depths (5 and 15 m) the mean was calculated across both depths.

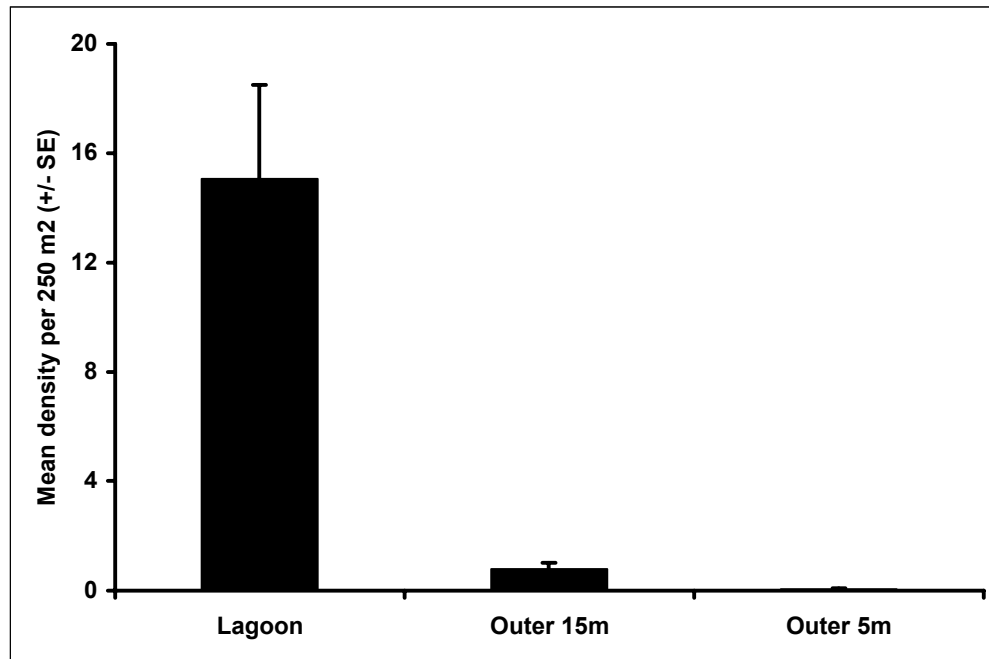


Figure 7. The mean density per 250m² (+/-SE) of *Amphiprion mccullochi* at lagoon sites (n=9), at 15 m depth on outer reef sites (n=13), and at 5 m depth on outer reef sites (n=14) around Lord Howe Island.

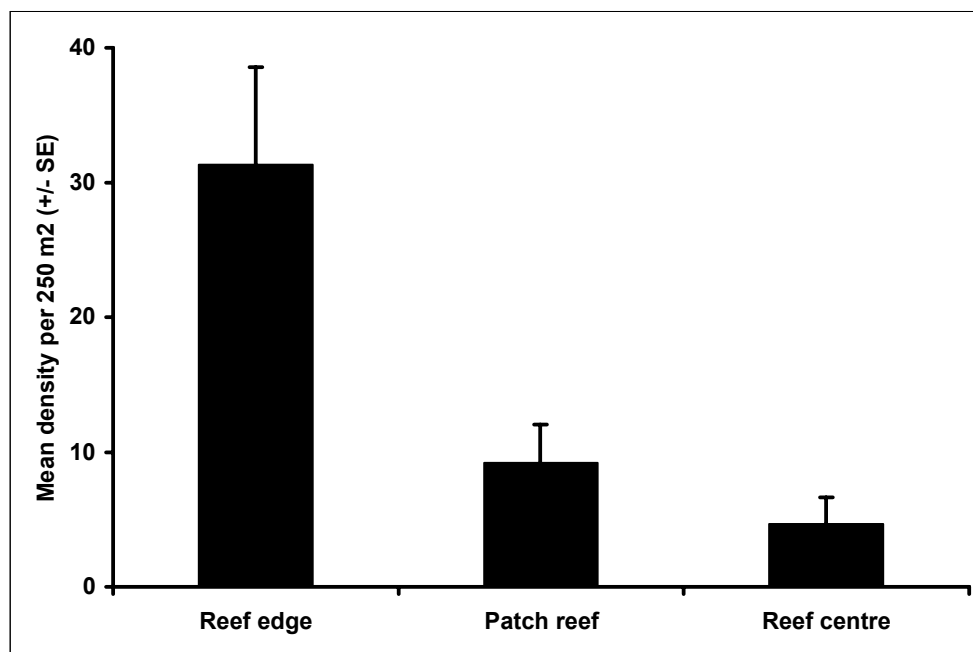


Figure 8. The mean density per 250m² (+/-SE) of *Amphiprion mccullochi* at reef edge sites (n=3), patch reef sites (n=3), and reef centre sites (n=3) in the lagoon at Lord Howe Island.

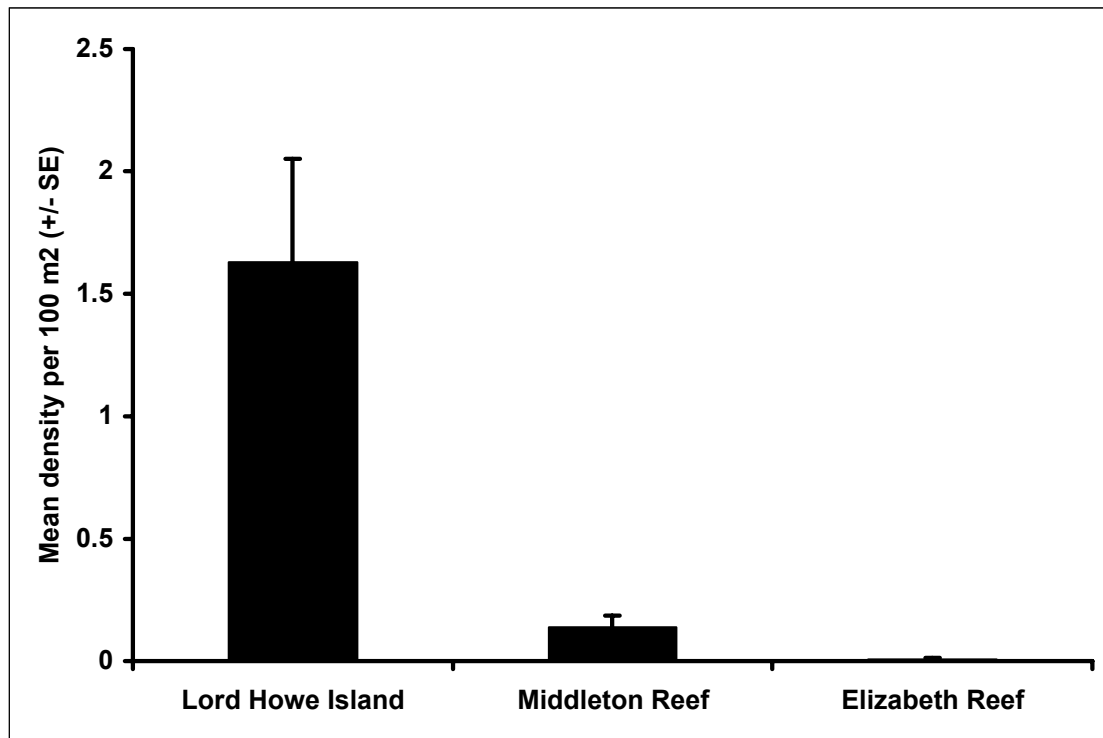


Figure 9. The mean density, standardised to 100m² (+/-SE), of *Amphiprion mccullochi* at Lord Howe Island (n=23), Middleton Reef (n=28), and Elizabeth Reef (n=11). Data from Middleton and Elizabeth Reef is from Choat et al, (2006), Hobbs and Feary (2007) and Hobbs unpublished data.

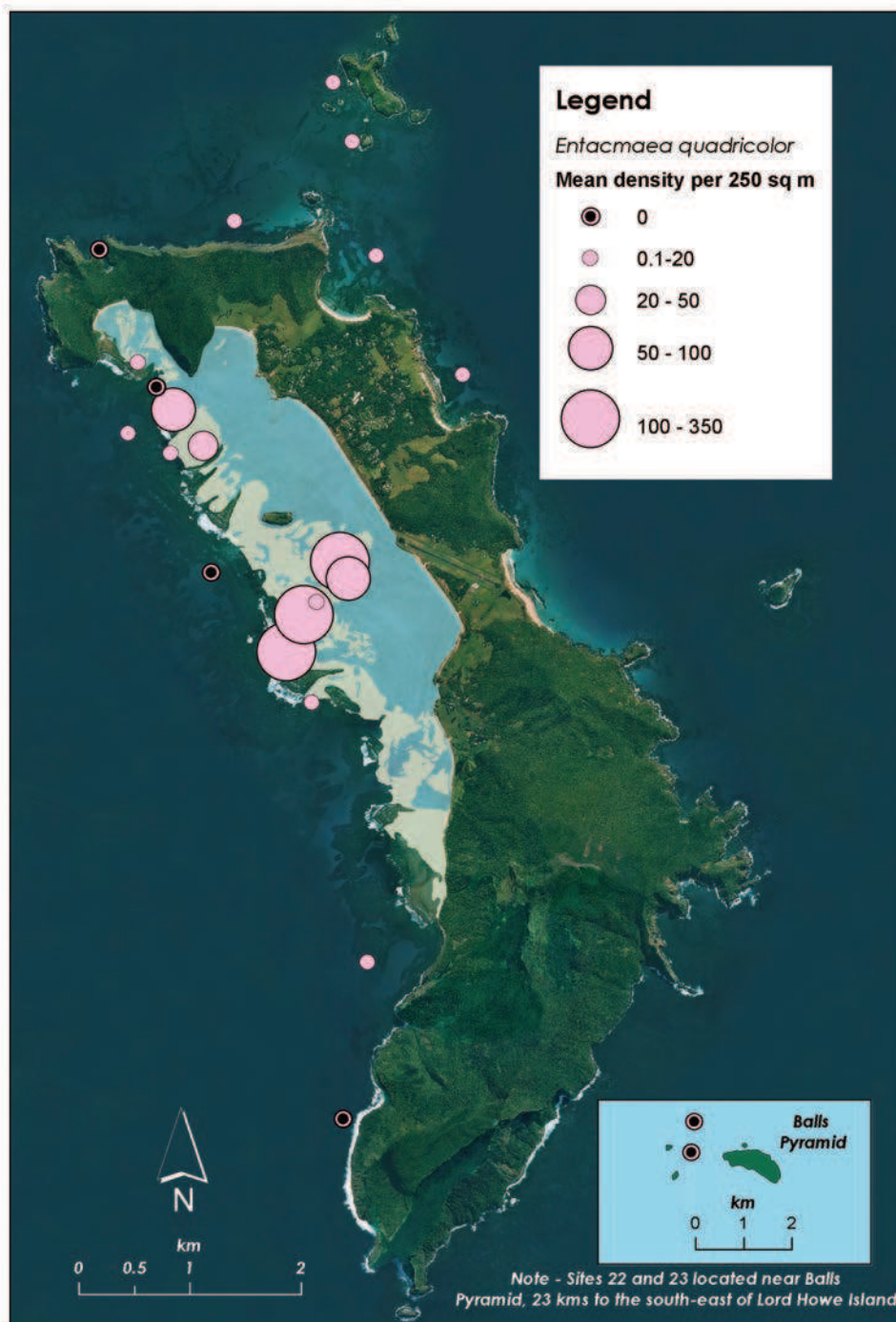


Figure 10. The mean density per 250m² of host anemone *Entacmaea quadricolor* at 23 sites around Lord Howe Island. For sites where surveys were done at two depths (5 and 15 m) the mean was calculated across both depths.

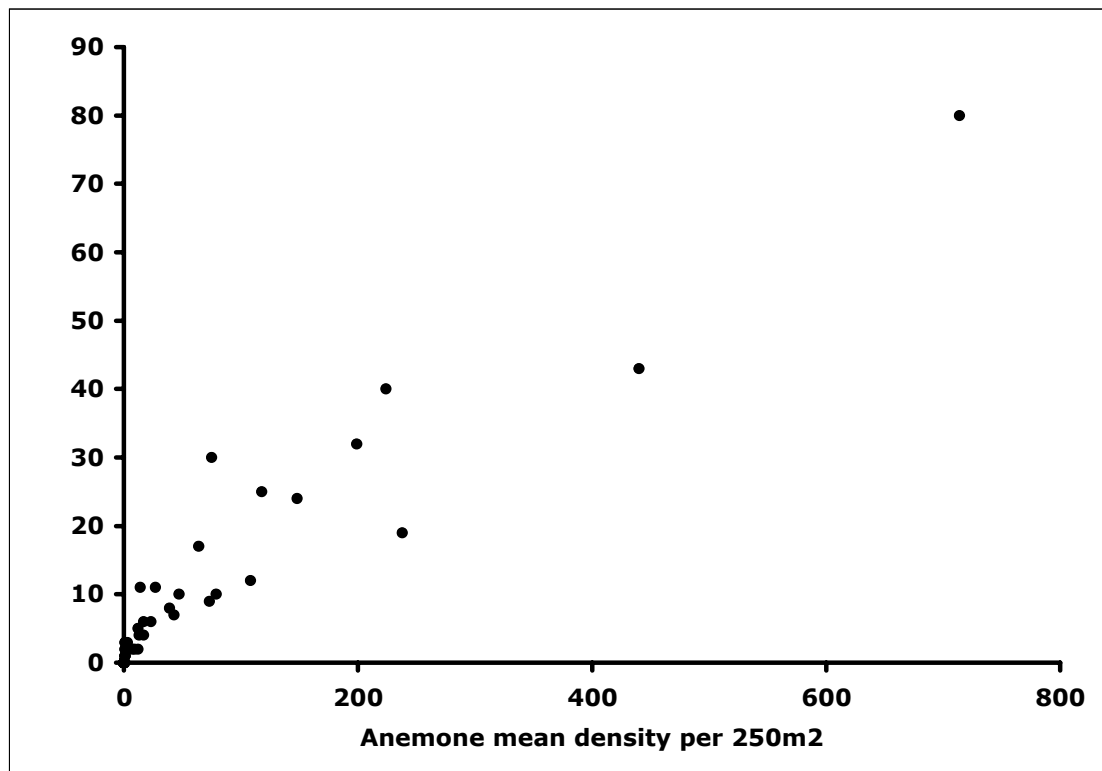


Figure 11. The relationship between the mean density per 250m² of *Amphiprion mccullochi* and its host anemone *Entacmaea quadricolor* at the replicate level (n=108) from 23 sites around Lord Howe Island.

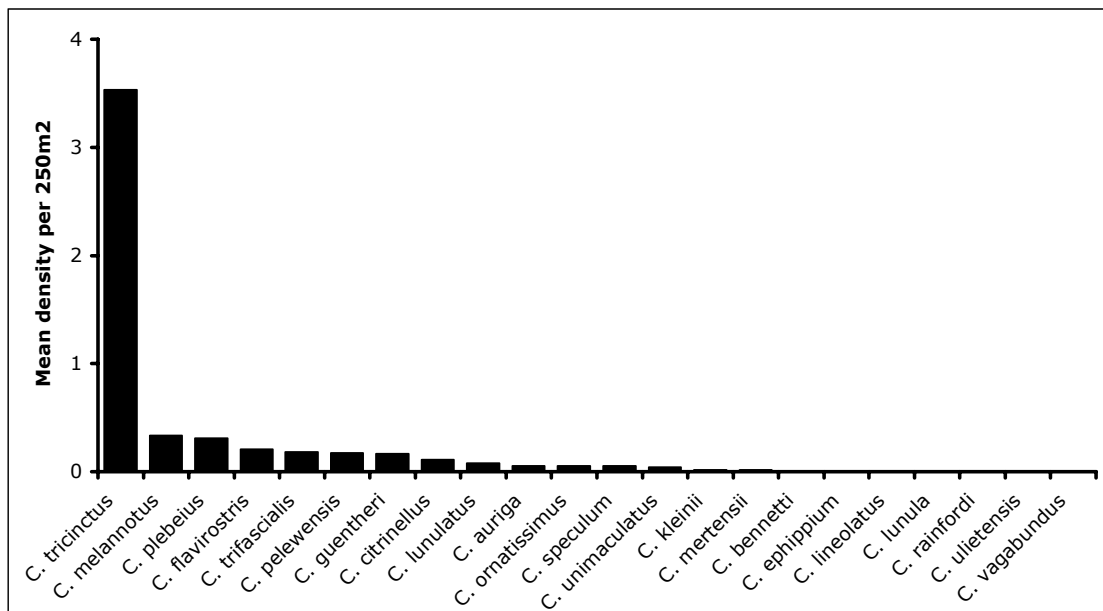


Figure 12. The mean density per 250m² (+/- SE) of butterflyfishes across all depths and sites (n=23) at Lord Howe Island. By far the most abundant species was the endemic *Chaetodon tricinctus*.

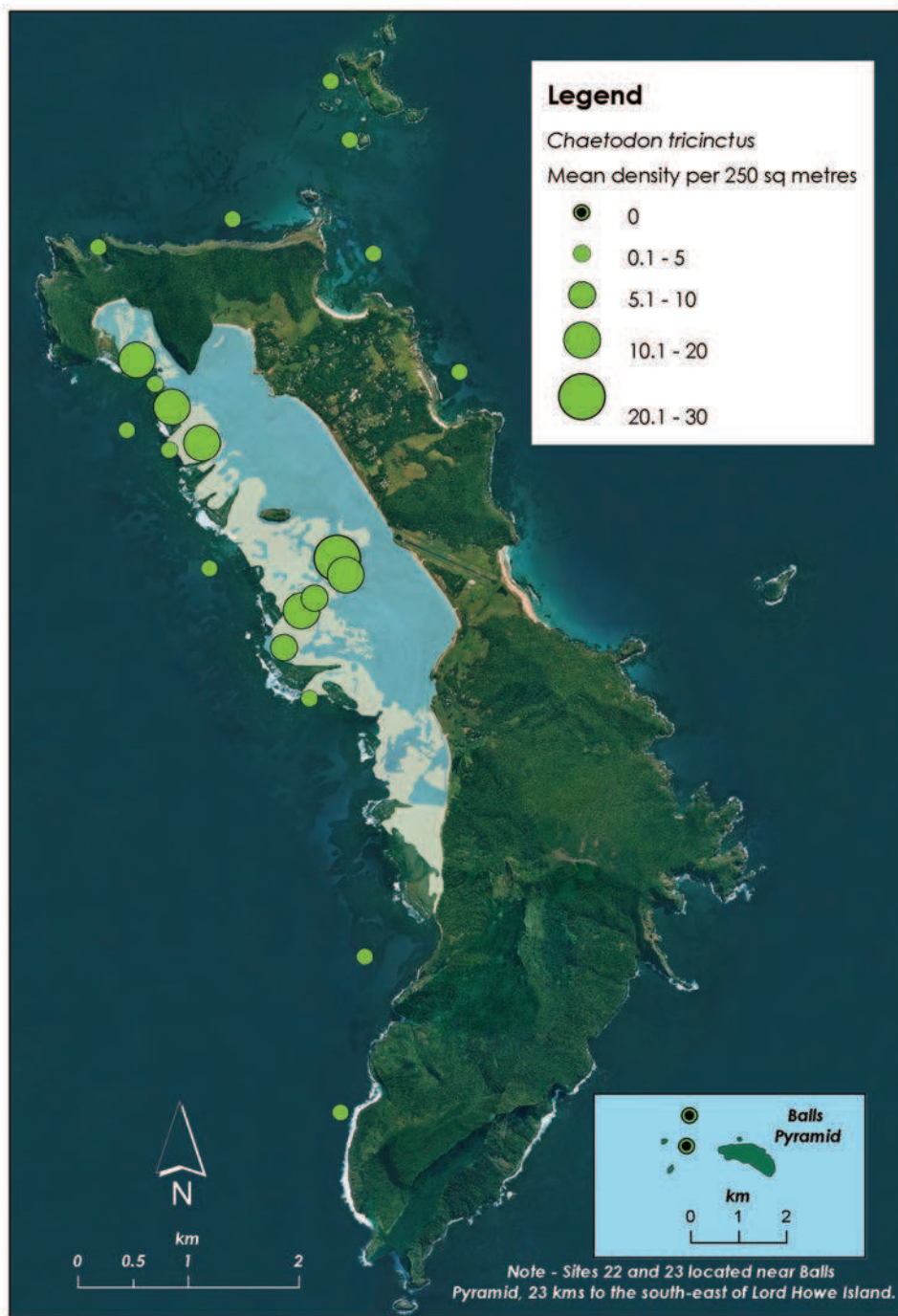


Figure 13. The mean density per 250m² of *Chaetodon tricinctus* at 23 sites around Lord Howe Island. For sites where surveys were done at two depths (5 and 15 m) the mean was calculated across both depths.

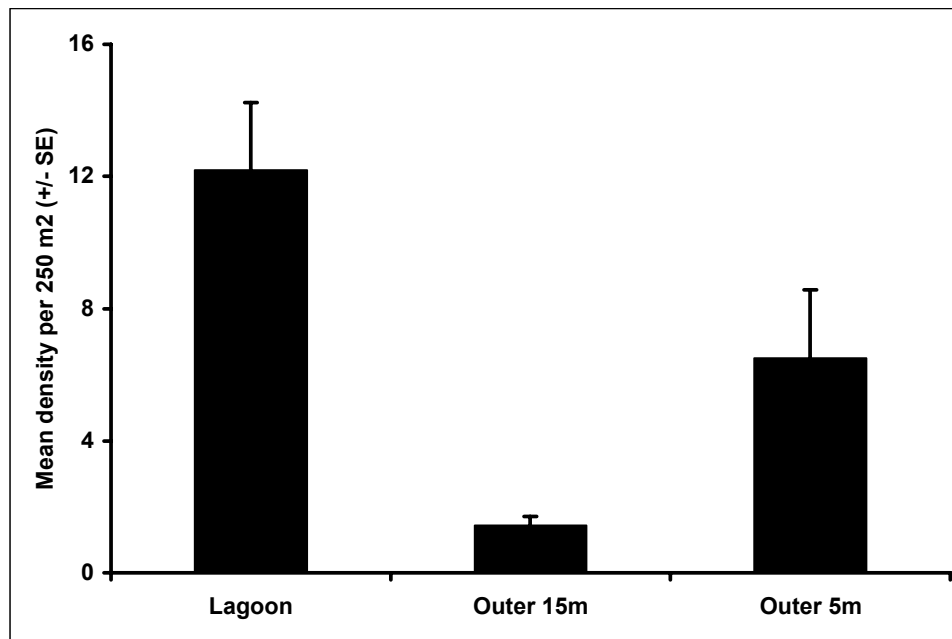


Figure 14. The mean density per 250m² (±SE) of *Chaetodon tricinctus* at lagoon sites (n=9), at 15 m depth on outer reef sites (n=13) and at 5 m depth on outer reef sites (n=14) around Lord Howe Island.

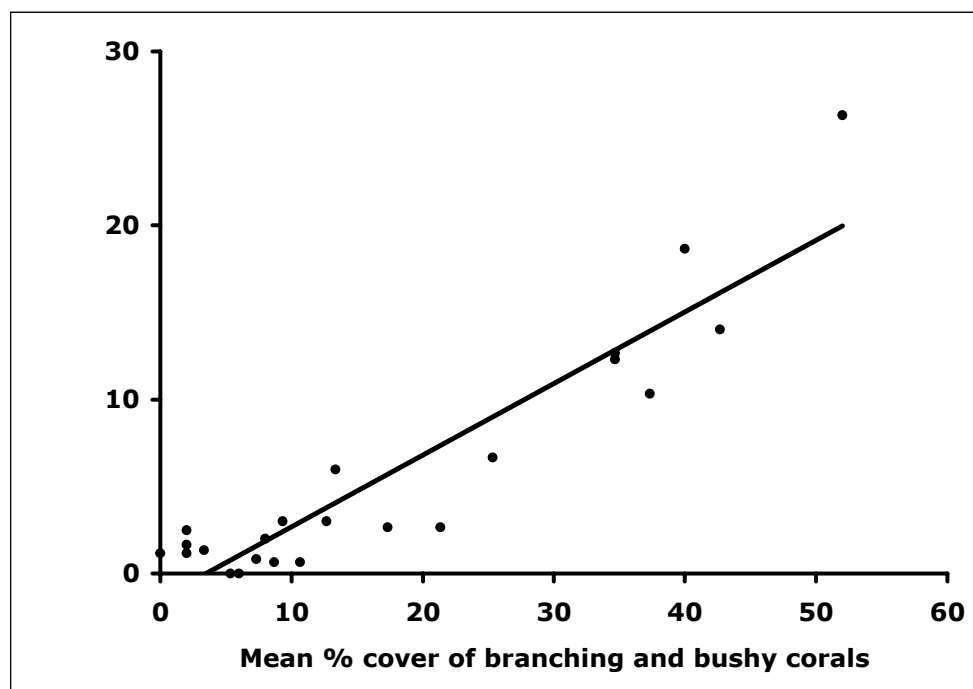


Figure 15. The relationship between the mean density of *Chaetodon tricinctus* per 250m² and the mean percent cover of structurally complex live hard coral at 23 sites around Lord Howe Island.



Figure 16. The mean density, standardised to 100m² (+/-SE), of *Chaetodon tricinctus* at Lord Howe Island (n=23), Middleton Reef (n=28), and Elizabeth Reef (n=11). Data from Middleton and Elizabeth Reef is from Choat et al, (2006), Hobbs and Feary (2007) and Hobbs unpublished data.

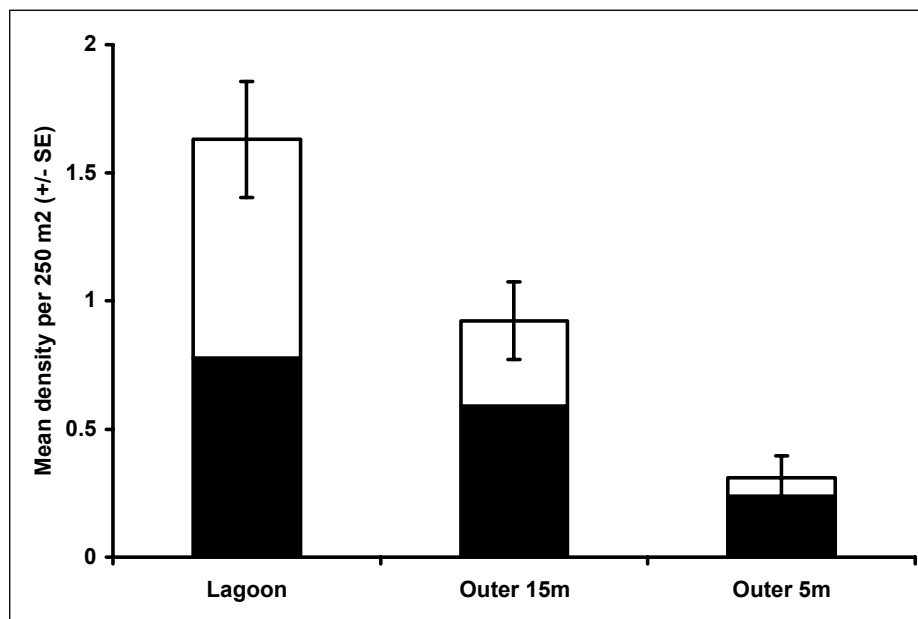


Figure 17. The mean density per 250m² (+/-SE) of *Coris bulbifrons* at lagoon sites (n=9), at 15 m depth on outer reef sites (n=13) and at 5 m depth on outer reef sites (n=14) around Lord Howe Island. The white fraction of the bar represents juveniles and the black fraction represents adults (see methods and Figure 2C and D for descriptions of juveniles and adults).

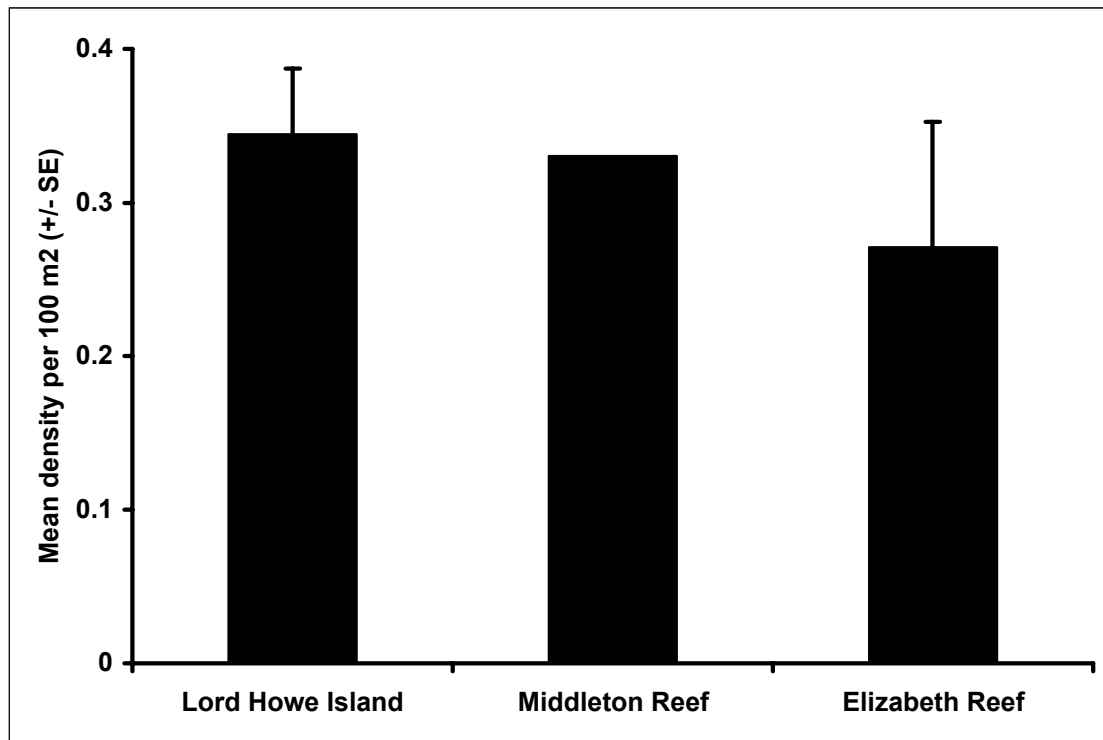


Figure 18. The mean density, standardised to 100m^2 (\pm SE), of *Coris bulbifrons* at Lord Howe Island ($n=23$), Middleton Reef ($n=28$, SE not provided in Choat et al, 2006), and Elizabeth Reef ($n=8$). Data from Middleton and Elizabeth Reef is from Choat et al, (2006), Hobbs and Feary (2007) and Hobbs unpublished data.

DISCUSSION

Underwater visual surveys of shallow reef areas (0-15 m) at 23 sites around LHI revealed that the endemic *Amphiprion mccullochi*, *Chaetodon tricinctus* and *Coris blubifrons* are relatively abundant and occur at greater densities at LHI than at Middleton and Elizabeth Reefs (Choat et al, 2006, Hobbs and Feary, 2007). These three species achieve their greatest densities in the lagoon at LHI. Other endemic species, *Amphichaetodon howensis*, *Genicanthus semicinctus* and *Chaetodontoplus ballinae* were rare or absent in the survey locations. The vulnerable black cod (*Epinephelus daemeli*) and Galapagos shark (*Carcharhinus galapagosensis*) were also rare at survey sites around LHI.

A. mccullochi is now very rare at Middleton and Elizabeth Reefs (Choat et al, 2006; Hobbs and Feary, 2007) and their abundance at LHI means that this location is the last remaining stronghold in the world for this species. The majority (92%) of the surveyed population occurred in the lagoon, particularly on reef edges and this was related to the abundance of its host anemone. Therefore, the lagoon represents critical habitat for *A. mccullochi*. It is important to highlight that an extremely small area of habitat (reef edges within the LHI lagoon) support a major portion of the world's *A. mccullochi* numbers. This is concerning because a relative small-scale impact can have a considerable effect on the global abundance of this species. Protecting this habitat, and the anemones that this fish relies on, will be critical to ensuring the long-term persistence of this species.

The major potential threat to *A. mccullochi* is the loss of its host anemone, which is most likely to occur from bleaching. Bleaching in anemones is probably caused by the same conditions that result in coral bleaching (e.g. changes in salinity, temperature, pH and infection). It is possible that other unknown factors may also cause the anemone to stress and bleach. The most serious cause of anemone bleaching is increased water temperatures. During mass bleaching events in 1998, some locations experienced 89% bleaching and mortality of anemones and this resulted in the local extinction of anemonefishes (Hattori, 2002, 2004). Water temperature and bleaching events are predicted to increase in the future (Hoegh-Guldberg et al, 2007). Water temperatures are likely to reach their highest levels in shallow lagoonal waters during summer. Periods of

hot calm weather and low tidal movements during summer may amplify temperature increases in the lagoon and exceed the thermal tolerances of marine organisms, resulting in mass mortalities (Hobbs and MacDonald, in press).

Chaetodon tricinctus is the most abundant butterflyfish at LHI, Middleton Reef and Elizabeth Reef and also occurs at Norfolk Island and occasionally, northern New South Wales (Allen et al, 1998; Choat et al, 2006; Hobbs and Feary, 2007). Its high abundance at LHI, Middleton Reef and Elizabeth Reef may compensate for the increased risk of extinction associated with its small geographic range. Specialisation also increases extinction risk, however, the dietary and habitat requirements of this species are poorly understood. *C. tricinctus* feeds on the polyps of hard corals (Kuiter, 2002), but it is unclear whether it feeds on a range of coral species, and if it can switch to feed on other non-coral items (e.g. algae and invertebrates). *C. tricinctus* was most abundant in the lagoon, particularly at sites where structurally complex coral (mainly bushy and branching *Acropora*) was common, which it was observed feeding on and sheltering in. The loss of these coral types would presumably cause a decrease in the abundance of *C. tricinctus*, as has been seen in other butterflyfishes that rely on coral for food or shelter (Pratchett et al, 2006; Graham et al, 2009). It is concerning that *C. tricinctus* associates with *Acropora* corals in the lagoon, given that *Acropora* corals are the most vulnerable corals to bleaching, crown-of-thorns starfish and disease (Marshall and Baird, 2000; Willis et al, 2004; Pratchett et al, 2008) and that the lagoon is likely to experience the warmest water temperatures at LHI. Mass bleaching events have caused devastating habitat loss in lagoons on other oceanic islands resulting in local extinction of fishes reliant on this habitat (Graham et al, 2006). The impact of future potential habitat loss on *C. tricinctus* populations will depend on the fish's reliance on *Acropora* corals within this lagoonal habitat.

Lagoonal environments also appear important to *Coris bulbifrons* which attains its greatest abundance in the lagoons of LHI, Middleton Reef and Elizabeth Reef (Choat et al, 2006; Hobbs and Feary, 2007). The lagoon at LHI supports a high proportion of juveniles and although this maybe the preferred habitat for this species, it did not seem to associate with any particular coral species. Juveniles appeared to search and prod the reef

matrix and rubble possibly looking for invertebrate prey. Adults are also common on the shallow and deep outer reefs of LHI, Middleton Reef and Elizabeth Reef (Choat et al, 2006; Hobbs and Feary, 2007) and are known to feed on a range of invertebrates including sea urchins. Therefore, *C. bulbifrons* does not appear to be a specialist, and is not reliant on vulnerable habitats such as live coral cover or anemones. Consequently, changes in habitat are likely to have less of an impact on this species. However, unlike the other endemic species, *C. bulbifrons* is caught by line-fishing and therefore overfishing may pose a threat to this species. Management should be aware that most of the stock occurs in the shallow waters (< 20 m) around the LHI shoreline and therefore should not rely on replenishment from deeper waters (Speare et al, 2004). Fortunately, a large proportion of the shallow water habitat is protected by sanctuary zones (no fishing), and a strict bag limit is in place for this species at LHI.

Other endemic species, *Amphichaetodon howensis*, *Genicanthus semicinctus* and *Chaetodontoplus ballinae* were rare or absent in surveys at LHI, Middleton and Elizabeth Reefs (Choat et al, 2006; Hobbs and Feary, 2007). These species are reported to occur in deeper waters (>20 m) (Allen et al, 1998; Speare et al, 2004) and therefore it is not surprising that they were lacking from shallow water surveys at LHI, Middleton or Elizabeth Reefs. Assessing extinction risk in these species requires surveys of deeper habitats around LHI and neighbouring locations. Determining their distribution, abundance and habitat associations will require the use of alternate survey methods, such as remote underwater video (Speare et al, 2004). Due to the limited amount of knowledge on these species, a precautionary management approach should be adopted until the necessary research has been done.

Black cod and Galapagos shark were rare at survey sites around LHI and densities were considerably lower than those reported at Middleton and Elizabeth Reefs (Choat et al, 2006; Hobbs and Feary, 2007). Of particular concern is their very low abundance in the lagoon at LHI. At Middleton and Elizabeth Reefs these two species attain their greatest densities in the lagoon, which appears to be an important nursery habitat (Choat et al, 2006; Hobbs and Feary, 2007). The Galapagos shark is highly abundant in the deeper waters surrounding LHI, and although the black cod also occurs in this habitat it does not

appear to be common (Speare et al, 2004). The Galapagos shark is reported to be particularly common around fishing boats and we observed 33 Galapagos sharks under one fishing boat that was anchored only a few hundred metres from the lagoon. An accurate assessment of the distribution and abundance of these two species will require surveys of these deeper waters using other techniques, such as mark-recapture studies and baited underwater video stations. Research is also required to determine what habitat is used by these species as nursery areas and why they do not utilise the lagoon at LHI.

While more research is required to determine extinction risk in endemic and vulnerable species inhabiting deeper waters (> 20 m) around LHI, it is clear that the lagoon is a critical habitat for *A. mccullochi*, *C. trincintus* and, to a lesser extent, *C. bulbifrons*. A large proportion of the lagoon is designated “sanctuary zone” which is closed to fishing and anchoring. More than 75% of *A. mccullochi*, 50% of *C. trincintus* and 33% of *C. bulbifrons* surveyed in this study occurred at 6 sites within the sanctuary zone. This protection may appear comforting, however, Jones et al 2004 provide a clear example of how habitat loss due to extrinsic impacts (coral bleaching and terrestrial runoff) caused devastating declines in fish diversity inside marine reserves. Considering *A. mccullochi* and *C. trincintus* use vulnerable habitats, the preservation of their habitat will be critical to their persistence. This is particularly important for *A. mccullochi* because it is entirely reliant on its host anemone, and the high abundance of anemones in the lagoon (especially within the sanctuary zone which accounted for 88% of all anemones counted) is currently supporting the last remaining stronghold in the world for this anemonefish.

The success of marine reserves and sanctuary zones is also reliant on the level of connectivity between different populations. Determining the scale of management that will be most effective in preventing the extinction of species endemic to the LHI region requires an understanding of the genetic connectivity between populations at LHI, Middleton and Elizabeth Reefs. Molecular studies have revealed high connectivity between Middleton and Elizabeth Reefs for the Galapagos shark, however, the LHI population is distinct and therefore these populations are unlikely to replenish each other naturally (van Herwerden et al 2008). Recent research in Papua New Guinea has found that both anemonefish and butterflyfish exhibit localised recruitment and limited

connectivity between populations (Jones et al, 2005; Almany et al, 2007; Planes et al, 2009). Therefore, determining genetic connectivity of *A. mccullochi* and *C. trincintus* between LHI, Middleton Reef and Elizabeth Reef should be a management priority as this will reveal if these populations are likely to replenish each other following declines or local extinctions.

Acknowledgements

We are very grateful for the valuable support and assistance provided by Sallyann Gudge and Ian Kerr from the Lord Howe Island Marine Park. We thank the Lord Howe Island Board, Envirofund Australia (Natural Heritage Trust) and the Lord Howe Island Marine Park for financial and logistical support. Brian Busteed of Howea Divers provided valuable local knowledge on the whereabouts of endemic fishes, access to Ball's Pyramid and diving supplies. We also thank Tas Douglass from Pro Dive for access to dive sites and tanks. Thanks also to the Lord Howe Island community for their support of this study and numerous volunteers involved in the anemonefish monitoring program. Heather Patterson provided valuable advice throughout the development of this study.

REFERENCES

Allen, G.R. (2008). Conservation hotspots of biodiversity and endemism for Indo-Pacific coral reef fishes. *Aquatic Conserv: Mar. Freshw. Ecosyst.* 18: 541–556.

Allen, G.R., Steene, R., and Allen, M.A.(1998). *Guide to Angelfishes and Butterflyfishes*. Odyssey Publishing/Tropical Reef Research, Australia.

Almany, G. R., Beruman, M. L., Thorrold, S. R., Planes, S. and Jones, G. P. (2007). Local replenishment of coral reef fish populations in a Marine Reserve. *Science* 316, 742–744.

Bellwood, D.R., Hoey, A.S., Ackerman, J.L. and Depczynski, M. 2006. Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. *Global Change Biol.* 12:1-8.

Blackburn, T. M., P. Cassey, R. P. Duncan, K. L. Evans, and Gaston, K. J. (2004). Avian extinction and mammalian introductions on oceanic islands. *Science* 305:1955–1958.

Brown, J.H. (1984). On the relationship between abundance and distributions of species. *Am. Nat.* 124:255-279

Brown, J.H. (1995) Macroecology. University of Chicago Press, Chicago, IL.

Coleman, N. (2002) Lord Howe Island Marine Park. Neville Coleman's Underwater Geographic. 96 pp. Brisbane, Australia.

Choat, J.H., van Herwerden, L., Robbins, W.D., Hobbs, J.P. and Ayling, A.M. (2006). A report on the ecological surveys conducted at Middleton and Elizabeth Reefs, February 2006. Report to the Australian Government Department of Environment and Heritage, Canberra. 65 pp.

DeMartini, E.E. (2004). Habitat and endemism of recruits to shallow reef fish populations: selection criteria for no-take MPAs in the NWHI Coral Reef Ecosystem Reserve. *Bull. Mar. Sci.* 14:185–205

DeMartini, E.E. and Friedlander, A.M. (2004). Spatial patterns of endemism in shallow-water reef fish populations of the Northwestern Hawaiian Islands. *Mar. Ecol. Prog. Ser.* 271:281–296

Dulvy, N.K., Sadovy, Y., and Reynolds, J.D. (2003) Extinction vulnerability in marine populations. *Fish. Fish.* 4:25–64

Gaston, K.J. (1994). *Rarity*. Chapman & Hall, London.

Gaston, K.J. (1998) Rarity as double jeopardy. *Nature* 394:229–230

Gaston, K.J., Blackburn, T.M., and Lawton, J.H. (1997). Interspecific abundance-range size relationships: an appraisal of mechanisms. *J. Anim. Ecol.* 66:579–601

Graham, N.A.J. (2007). Ecological versatility and the decline of coral feeding fishes following climate driven coral mortality. *Mar. Biol.* 153:119–127

Graham, N.A.J., Wilson, S.K., Jennings, S., Polunin, N.V.C., Bijoux, J.P., and Robinson, J. (2006). Dynamic fragility of oceanic coral reef ecosystems. *Proc. Natl. Acad. Sci. USA* 103:8425–8429

Graham, N. A. J., Wilson S. K. , Pratchett M. S., Polunin N. V. C., and Spalding M. D. (2009). Coral mortality versus structural collapse as drivers of corallivorous butterflyfish decline. *Biodivers. Conserv* 18:12, 3325-3336.

Harvell, C.D., Kim, K., Burkholder, J., Colwell, R.R., Epstein, P.R., Grimes, J., Hofmann, E.E., Lipp, E.K., Osterhaus, A.D.M.E., Overstreet, R., Porter, J.W., Smith, G.W., and Vasta, G.R. (1999). Emerging marine diseases – climate links and anthropogenic factors. *Science* 285:1505–1510

Hattori, A. (2002). Small and large anemonefishes can coexist using the same patchy resources on a coral reef, before habitat destruction. *J. Anim. Ecol.* 71:824–831

Hattori, A. (2004). High mobility of the protandrous anemonefish *Amphiprion frenatus*: nonrandom pair formation in limited shelter space. *Ichthyol. Res.* 52:57–63

Hobbs J-P.A, and Feary, D.A. (2007) Monitoring the ecological status of Elizabeth and Middleton Reefs, February 2007. Report to the Australian Government Department of the Environment and Water Resource, Canberra. 37 pp.

Hobbs, J.-P.A and McDonald C.A. (in press) Increased temperature triggers fish kill at the Cocos (Keeling) Islands, Indian Ocean. *Journal of Fish Biology* (in press)

Hobbs, J.-P. A., Choat, J.H., Robbins, W.D., van Herwerden, L., Feary, D.A., and Ayling A.M. (2008) Unique fish assemblages at world's southernmost oceanic coral reefs, Elizabeth and Middleton Reefs, Tasman Sea, Australia. *Coral Reefs* 27:15-15

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., & Hatziolos, M.E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science* 318: 1737–1742

Hughes, T.P., Bellwood, D.R. and Connolly, S.R. (2002). Biodiversity hotspots, centres of endemism, and the conservation of coral reefs. *Ecol. Lett.* 5:775-784

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nyström, M., Palumbi, S.R., Pandolfi, J.M., Rosen, B., Roughgarden, J., 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* 301: 929–933

Jones, G.P., Caley, M.J., Munday, P.L., 2002. Rarity in coral reef fish communities, in Sale, P.F. (Ed), *Coral Reef Fishes: dynamics and diversity in a complex ecosystem*. Academic Press, San Diego, pp. 81–101

Jones, G.P., McCormick, M.I., Srinivasan, M. and Eagle, J.V. (2004). Coral decline threatens fish biodiversity in marine reserves. *Proc. Natl. Acad. Sci. USA* 101: 8251-8253

Jones, G.P., Planes, S., and Thorrold, S. (2005). Coral reef fish larvae settle close to home. *Curr. Biol.* 15: 1314–1318

Kuiter R.H. (2002) Butterflyfishes, Bannerfishes and their relatives: a comprehensive guide to Chaetodontidae and Microcanthidae. TMC Publishing, Chorleywood, UK. 208 pp.

Marshall, P. A., and Baird A. H. (2000). Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. *Coral Reefs* 19, 155–163

McKinney, M.L. (1997). Extinction vulnerability and selectivity: combining ecological and paleontological views. *Annu. Rev. Ecol. Syst.* 28:495–516

Munday, P.L. (2004). Habitat loss, resource specialization, and extinction on coral reefs. *Global Change Biol* 10:1642–1647.

Planes, S., Jones, G.P. and Thorrold, S.R. (2009). Larval dispersal connects fish populations in a network of marine protected areas. *Proc. Nat. Acad. Sci. USA* 106: 5693–5697.

Pratchett, M.S., Wilson, S.K., and Baird, A.H. (2006). Declines in the abundance of *Chaetodon* butterflyfishes (Chaetodontidae) following extensive coral depletion. *J. Fish. Biol.* 69:1269–1280

Pratchett, M.S., Munday, P.L., Wilson, S.K., Graham, N.A.J., Cinner, J.E., Bellwood, D.R., Jones, G.P., Polunin, N.V.C., and McClanahan T.R. (2008). Effects of climate-induced coral bleaching on coral-reef fishes: ecological and economic consequences. *Oceanogr. Mar. Biol. Annu. Rev.* 46:251–296

Randall, J.E. (1976). The endemic shore fishes of the Hawaiian Islands, Lord Howe Island and Easter Island. Trav. Doc. O.R.S.T.O.M., no. 47:49-73.

Randall, J.E. (1998). Zoogeography of shorefishes of the Indo-Pacific region. *Zool. Stud.* 37:227–268

Speare P, Cappo M, Rees M, Brownlie J and Oxley W (2004) *Deep Water Fish and Benthic Surveys in the Lord Howe Island Marine Park (Commonwealth Water) February 2004*. Report for Department of the Environment and Heritage. Australian Institute of Marine Science, Townsville. 30 pp.

van Herwerden, L., Almojil, D. and Choat, J.H. (2009). Population genetic structure of Australian Galapagos reef sharks *Carcharhinus galapagensis* at Elizabeth and Middleton Reefs Marine National Nature Reserve and Lord Howe Island Marine Park. Report to the Australian Government Department of Environment and Heritage, Canberra. 45 pp.

Welch, B. L. (1947). The generalization of "student's" problem when several different population variances are involved. *Biometrika* 34: 28–35

Whittaker, R.J. (1998). *Island Biogeography: Ecology, Evolution, and Conservation*. Oxford University Press, Oxford.

Wilkinson, C. (2004). *Status of Coral Reefs of the World: 2004*. Australian Institute of Marine Science, Townsville, Queensland.

Willis, B.L., Page, C.A., and Dinsdale, E.A. (2004) Coral disease on the Great Barrier Reef. In: Rosenberg E, Loya Y (eds) *Coral disease and health*. Springer, Berlin, p 69–104

Wilson, S.K., Graham, N.A.J., Pratchett, M.S., Jones, G.P., Polunin, N.V.C. (2006). Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient? *Global Change Biol.* 12:2220–2234

Wilson, S.K., Burgess, S.C., Cheal, A.J., Emslie, M., Fisher, R., Miller, I., Polunin, N.V.C., and Sweatman, H.P.A. (2008). Habitat utilization by coral reef fish: implications for specialists vs. generalists in a changing environment. *J. Anim. Ecol.* 77:220–228

Zar, J.H. (1999) *Biostatistical Analysis*. Prentice-Hall, London.