

Assessing the cumulative impacts of climatic disturbances on coral reefs in the Keppel Islands, Great Barrier Reef Marine Park

David Williamson, Daniela Ceccarelli, Gavin Rossetti, Garry Russ and Geoffrey Jones



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Project 2.1: Assessing the cumulative impacts of climate disturbances on inshore GBR coral reefs,
identifying key refuges and testing the viability of manipulative reef restoration

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ACRONYMS

GBR..... Great Barrier Reef

GBRMP Great Barrier Reef Marine Park

LHC Live Hard Coral

LME Linear mixed effects model

MAC Macroalgae

MDS..... Multi-dimensional Scaling

NTR No-take Marine Reserve

SCI..... Structural Complexity Index

UVC Underwater Visual Census

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EXECUTIVE SUMMARY

Inshore coral reefs in the Great Barrier Reef Marine Park (GBRMP) are subject to chronic stressors such as reduced water quality and sedimentation, as well as acute impacts from climatic disturbances. Severe climatic disturbance events often have major impacts on reef communities, generating cycles of decline and recovery, and in some extreme cases, community-level phase shifts from coral to algal-dominated states. Benthic habitat changes directly affect reef fish communities, with low coral cover usually associated with low fish diversity and abundance. Systematic long-term monitoring of the status and condition of GBRMP reefs is crucial for identifying key stressors, quantifying the effects of management actions, and assessing the viability of additional measures to enhance biodiversity conservation and resilience. Fringing coral reefs in the Keppel Islands, southern GBRMP, were impacted by successive climatic disturbance events in 2006 (coral bleaching), 2011 and 2013 (river flood plumes), and 2015 (Cyclone Marcia – Category 5).

Long-term monitoring of coral and fish communities at 20 sites revealed significant declines in live hard coral cover and fish abundances on both no-take reserve (green zone) and fished reefs between 2004 and 2015. Although the disturbance events have had a significant impact on live coral cover, community structure and productivity, the magnitude of the impacts were not spatially uniform. Approximately 21% of the total reef area in the Keppel Islands was identified as highly degraded in October 2015, with less than 5% cover of live hard coral, high cover of fleshy brown algae (often > 50%), low abundance of fishes, and low fish species diversity. Conversely, approximately 13% of the reef area had retained at least 45% cover of live hard coral cover in 2015. These remaining relatively healthy reefs were identified as key refuges for live hard coral (predominantly *Acropora* spp.). Refuge reefs generally also had low cover of macroalgae and relatively high abundances of a range of small to medium-sized reef fishes.

Throughout the monitoring period, green zone reefs consistently supported higher abundances of key fishery-targeted species such as coral trout (*Plectropomus* spp.) than reefs that are open to fishing. However, coral trout abundance declined markedly on reefs that were severely impacted by the disturbances, irrespective of whether those reefs were protected within green zones or not. Although coral trout have repeatedly been shown to be more abundant and larger on green zone reefs than on fished reefs in the GBRMP, our findings demonstrate that frequent and severe climatic disturbance events can progressively undermine many of the accrued benefits of green zones. It was evident that the abundance of coral trout was strongly influenced by live hard coral cover, habitat structural complexity and the abundance of prey fish species.

Protection of live coral and reef habitat structural complexity must remain a high priority in the Keppel Islands, and more broadly within the GBRMP. Keppel reefs that continue to support relatively high levels of live coral are evidently the most resilient reefs within the island group. These refuge reefs provide important local stores of coral reef biodiversity, and they should contribute to the replenishment and recovery of the degraded reefs through larval supply. We recommend that additional management resources (e.g. no anchoring reef protection markers) should be allocated to key remaining refuge reefs to improve current levels of habitat protection. Additionally, restoration of native riparian vegetation, and exclusion of cattle from key areas of river catchments, such as the Fitzroy, must be pursued

in order to minimise soil erosion and reduce the chronic effects of sedimentation and poor water quality in coastal waters of the GBRMP.

Our observations of decline and recovery dynamics on Keppel reefs suggest that there is considerable capacity for recovery from the recent series of disturbances. If conditions favourable to recovery prevail, live coral cover, fish abundances and biodiversity on Keppel reefs may potentially return to 2004 'healthy state' levels within 5 – 10 years. However, given the recent disturbance history and projections for increasing frequency of extreme climatic events as climate change progresses, it is expected that Keppel, and GBRMP reefs more generally, will be subject to escalating disturbance regimes in future years. Improved integration of targeted ecosystem monitoring with a proactive approach to management should lead to actions that effectively protect biodiversity and enhance resilience of the GBRMP ecosystem.

1. INTRODUCTION

Cycles of disturbance and recovery are a key feature of coral reef ecosystems and occasional acute disturbances are considered integral to maintaining high species diversity (Rogers 1993). However, if the intensity and frequency of disturbance exceeds certain thresholds, communities may not be able to fully recover between disturbance events and the health of the coral reef communities will gradually decline (Aronson *et al.* 2005; Thompson & Dolman 2010). In some cases this has led to reefs undergoing a 'phase shift' to stable algal-dominated states (Bellwood *et al.* 2004). Cycles of habitat change and long-term habitat degradation have major flow-on effects on the structure of reef fish communities (Jones & Syms 1998; Jones *et al.* 2004; Wilson *et al.* 2008).

The response of coral reef benthic communities to disturbance and the subsequent recovery trajectories depends not only on the type, frequency and severity of disturbances, but also on the pre-disturbance condition and composition of coral assemblages. For instance, branching and plating corals (*Acropora* spp.) are relatively vulnerable to damage, but they also tend to be fast-growing and quick to recover (Carpenter *et al.* 2008). Furthermore, local acclimation and/or adaptation within genera and species may be critically important in determining the degree to which coral reef communities are impacted by disturbances. Corals living on near-shore reefs may be more resistant to sedimentation and exposure to low-salinity water than those accustomed to the conditions on offshore reefs (Flores *et al.* 2012).

The response of reef fishes to habitat change also varies depending on the ecology and life history of the species. Coral-feeders and small habitat specialists are generally much more vulnerable to declining coral cover, or loss of certain types of corals, than generalist species (Munday 2004; Berumen & Pratchett 2008). Larger bodied reef fishes are more likely to fluctuate in response to changes in prey abundance or the structural complexity of the benthos, rather than simply the abundance of live coral (Wilson *et al.* 2009). However, in areas with low underlying habitat complexity of the coral reef matrix, corals provide structure at a scale that is relevant for most fish species (MacNeil *et al.* 2009). Overall reductions in fish species diversity in response to habitat loss may have little functional consequence in highly diverse systems such as coral reefs, where many species can perform the same ecological role (Bellwood & Hughes 2001). Therefore, assessing reef fish community responses to disturbance at the level of functional groups may provide greater insight into the magnitude and consequences of the impact than assessing species-specific changes.

Networks of no-take marine reserves (NTRs, green zones) are widely advocated and increasingly implemented for both conserving marine biodiversity and enhancing fishery sustainability (Russ 2002; Sale *et al.* 2014). Populations of targeted reef fish and invertebrate species can build rapidly within adequately protected NTRs (Russ *et al.* 2008; Babcock *et al.* 2010; Emslie *et al.* 2015), however in some systems population gains have been shown to accrue over decadal time scales (Russ & Alcala 2010). It has also been shown that effective NTR networks can enhance the persistence of populations of targeted reef fishes, such as coral trout (*Plectropomus* spp.) and tropical snappers (Lutjanidae), by protecting spawning stock biomass and providing important sources of juvenile recruitment to both NTR and fished reefs (Harrison *et al.* 2012; Almany *et al.* 2013).

It has been hypothesized that effective NTR networks can promote healthy and productive coral reef ecosystems that have a greater capacity for limiting declines and enhancing

recovery from disturbance events (Almany *et al.* 2009; Graham *et al.* 2011). However, the empirical evidence for such effects has been contradictory (Jones *et al.* 2004; Claudet *et al.* 2011; Williamson *et al.* 2014). Disturbance events often impact communities in both NTRs and fished areas, and the degree to which reserves may maintain high densities and biomass of exploited fishes following severe disturbance to the benthos is scarcely known. Reserves may play a critical role in population and community recovery following disturbances, but only if they can provide effective refuges in times of disturbance.

The Keppel Island group in the southern Great Barrier Reef Marine Park (GBRMP) is a high recreational use area with approximately 525 hectares of fringing coral reefs. Coral reefs in the Keppel Islands were subjected to four major climatic disturbance events between 2004 and 2015; a severe coral bleaching event in 2006, freshwater flood plumes from the Fitzroy River catchment in 2011 and 2013, and a direct hit from Cyclone Marcia (category 5) in March 2015. The overall aim of this study was to build upon our long-term reef monitoring program in the Keppel Islands to quantify the magnitude and spatial patchiness of the disturbance impacts on coral and fish communities.

The specific objectives of this project were to:

- Re-survey twenty core long-term monitoring sites to quantify the cumulative effects of recent disturbances on benthic and fish communities
- Survey additional sites in reef slope and reef slope habitats to generate broader and more detailed information on the current (October 2015) status and condition of reef communities
- Identify key post-disturbance refuge areas that continue to support moderate to high cover of live hard coral
- Identify key refuges for fishes, particularly fishery-targeted species (coral trout – *Plectropomus* spp.)
- Assess the role of GBRMP zoning in mitigating disturbance effects, enhancing recovery and building long-term ecosystem resilience

2. METHODS

2.1 Study area, marine park protection and the history of disturbance

This study was conducted in the Keppel Island group (23°100'S, 150°570'E) within the southern section of the Great Barrier Reef Marine Park (GBRMP), Australia (Figure 1). Multiple-use management zoning plans were first implemented within the GBRMP in 1987, and from that time until 2004 approximately 5% of the marine park area was protected within a network of NTRs. The GBRMP was rezoned in July 2004 and the area protected within NTRs was increased to cover approximately 33% of the total area (and 33% of the coral reefs). The principal objective of the new zoning plan was to increase biodiversity protection and ecosystem resilience by allocating a proportion of the area within each of seventy identified bio-regions into an interconnected network of NTRs (Fernandes *et al.* 2005). At the Keppel Islands, fringing coral reefs cover approximately 525 hectares, of which 147 hectares (~ 28%) is protected within a network of NTRs. Three reef areas have been protected within NTRs since 1987 (old NTRs), while four additional reef areas were designated as NTRs in July 2004 (new NTRs).

Four distinct climatic disturbance events impacted fringing reefs in the Keppel Islands during the monitoring period (2004 – 2015). In March 2006, a sustained period of elevated sea temperature triggered a severe coral bleaching event. Major floods in the Fitzroy River catchment in early 2011 and early 2013 generated flood plumes that engulfed the Keppel Islands for several weeks, inundating reefs with freshwater. In March 2015, Cyclone Marcia (Category 5) approached and crossed the Keppel Islands from the northeast, pounding exposed reefs with storm swells.

The 2006 bleaching event impacted all reef habitats (flat, crest, slope) in most monitoring sites. The 2011 and 2013 flood plume events tended to have the largest impact on reef flats, crests and shallower sections of reef slopes to a depth of approximately 2 m below low water datum. However, most fringing reefs in the Keppel Islands reach a maximum depth of less than 12 m and some only reach a depth of 4 to 5 m. The maximum tidal range in this region is approximately 5 m, thus, the flood plume inundated most of the reef slope habitat at the majority of the monitoring sites. Reefs that were oriented toward the North and East were most heavily impacted by Cyclone Marcia.

2.2 Underwater survey methods for reef fish and benthic communities

Reef fish and benthic communities were surveyed at twenty core monitoring sites in the Keppel Island group on seven occasions between 2004 and 2015 using underwater visual census (UVC). Six of the core monitoring sites were located within 'old' (1987) NTRs, four sites were within 'new' (2004) NTRs, and ten sites were located in areas that have remained open to fishing. In October 2015, fish and benthic communities were surveyed at an additional 10 reef slope sites, and benthic communities were surveyed at an additional 17

reef flat sites (Figure 1). Underwater visual census (UVC) was used to survey approximately 190 species of fish from 15 Families (Appendix 1.1).

Five replicate UVC transects were conducted within each site. All fish surveys were conducted on SCUBA by two observers (DHW and DMC), who swam side by side along a 50m transect line, recording fish within 3m either side of the line (total search area per transect = 300m²). A third diver (observer 3) swam directly behind observers one and two, deploying the transect. This UVC technique reduced diver avoidance or attractive behaviour of the surveyed fish species.

To increase accuracy of the fish counts, the species list was divided between the two fish observers. Observer one surveyed the fish families Haemulidae, Lethrinidae, Lutjanidae, Mullidae, Nemipteridae, Serranidae and the larger species of Labridae targeted by fishers. Observer one also recorded all derelict (discarded or lost) fishing tackle (predominantly monofilament fishing line) present on each transect. Observer two surveyed the families Acanthuridae, Balistidae, Chaetodontidae, Pomacanthidae, Pomacentridae, Scaridae, Siganidae, Zanclidae and small 'non-targeted' species of Labridae. Pomacentrids and small labrids were recorded by observer two during return transect swims within a 2m band (1m either side of the tape, 100m² survey area).

Broad-scale structural complexity of the reef habitat was estimated by observer one using a simple method that applied a rank (1 – 5) to both reef slope and rugosity for each 10m section of each transect (see Williamson *et al.* 2014 for further detail). Observer three used a point intercept method to record the benthos every 1 metre along each transect tape (50 samples per transect). Categories sampled were live and dead hard coral (branching, plate, solitary, tabular, massive, foliose, encrusting), live soft coral, sponges, clams (*Tridacna* spp.), other invertebrates (such as ascidians and anemones), macro-algae, coral reef pavement, rock, rubble and sand. All transects were carried out within a depth range of 4 – 9m with an average depth of 6m. Visibility was recorded on each transect and typically ranged from 6 to 12m. Surveys did not proceed if visibility was less than 5m.

2.3 Data handling and analysis

Benthic variables were multiplied by two to obtain % cover estimates, and total live hard coral (LHC) and macroalgae (MAC) were used to test zone effects and temporal dynamics. Rugosity and slope scores were multiplied to obtain a structural complexity index (SCI). For all fish species, raw counts were converted to density (individuals per 1000 m²). Fish species were assigned to functional groups for analysis (Appendix 1.1). Two species of coral trout (*Plectropomus* spp.) were recorded in the 2015 UVC surveys of the Keppel Island reefs, *P. maculatus* and *P. leopardus*. Raw UVC counts of coral trout were converted to density and biomass estimates of individuals or kilograms per 1000m². Biomass calculations were conducted using published length-weight relationships for *Plectropomus* spp.

Linear mixed effects models (LMEs) were used to assess the influence of time (i.e. year), reserve status and benthic habitat (i.e. LHC, MAC, Rugosity, SCI) on fish functional groups and on the *Plectropomus* spp. group. For LMEs on coral trout, the additional variable of "Prey" (Appendix 1.1) was included as an explanatory covariate. LMEs were also conducted on benthic habitat (i.e. LHC, MAC, Rugosity, SCI) to assess the influence of time and reserve

status. In all LMEs, replicate transect nested within site was treated as a random effect. All LMEs were conducted using the software package R (v.3.1.3; R Core Team 2015) with the nlme package and model fit was assessed using residual plots. To correct for heteroscedasticity and non-normality, we applied square-root transformations or a log transformation.

We used non-metric, multi-dimensional scaling (MDS) analysis (Clarke & Gorley 2006) on the Bray-Curtis resemblance matrix of transformed square root density of each benthic group, fish species and functional group to partition zones and sites within the Keppel Islands group. We then conducted a non-metric, 1-way, pairwise analysis of similarity (ANOSIM; Clarke & Warwick 2001) among the groups, and a SIMPER analysis (Clarke & Warwick 2001) to determine which species or groups contributed most to the similarities and differences among the years and zones.

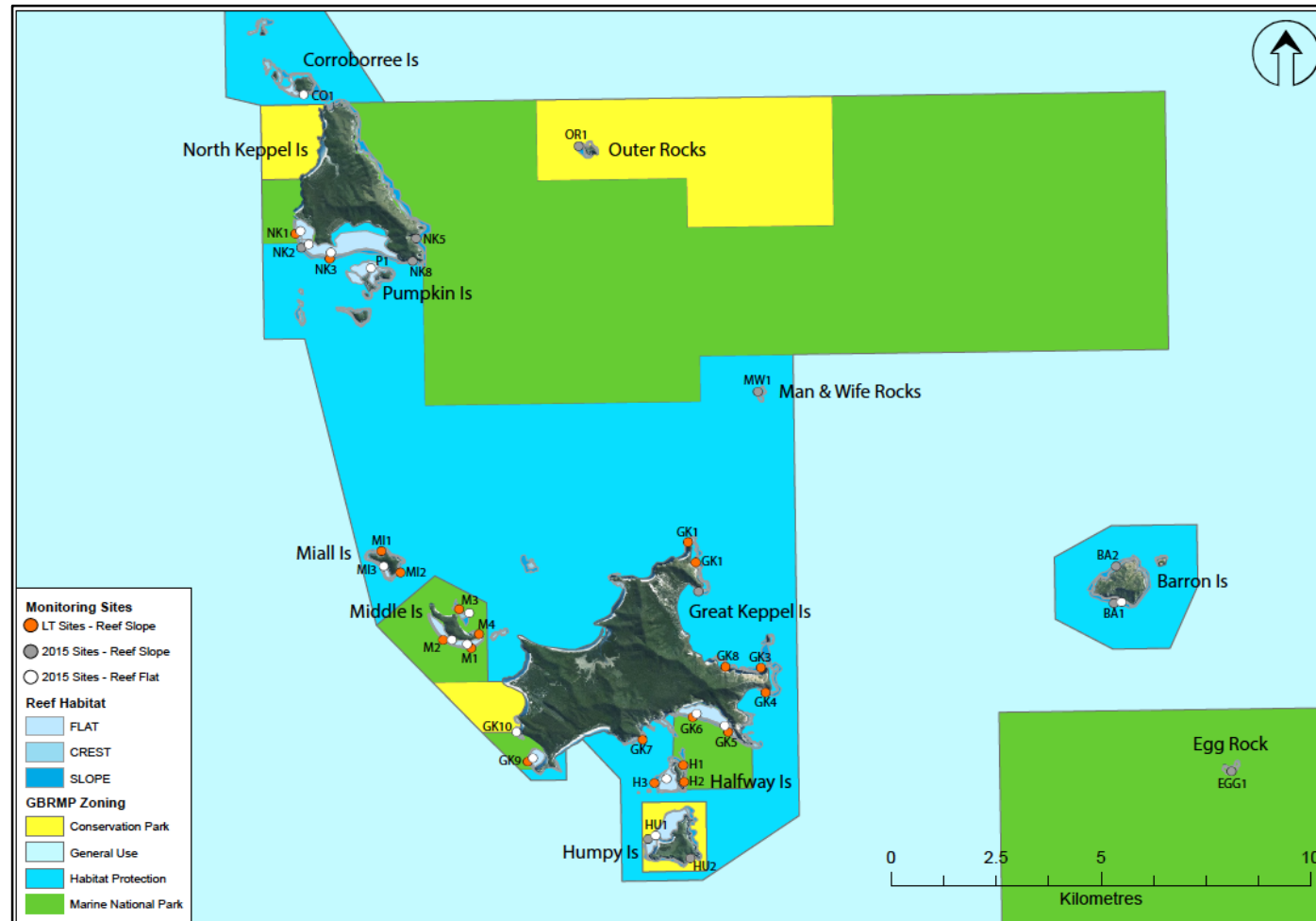


Figure 1: Map of the Keppel Islands showing GBRMP zoning and the position of reef monitoring sites. Core long-term (LT) reef slope monitoring sites are illustrated with orange markers. Additional sites surveyed in 2015 are also shown for reef slope (grey markers) and reef flat (white markers) habitats.

3. RESULTS & DISCUSSION

3.1 Benthic community dynamics

3.1.1 Live hard coral

Live hard coral (LHC) cover declined significantly throughout the Keppel Islands between 2004 and 2015 (**Figure 2a**). This overall decline during the monitoring period was recorded in both reserve zones (NTR 1987 & NTR 2004) and fished zones (**Table 1, Figure b**). Although the coral bleaching event in 2006 had a significant short-term impact on LHC, corals on reefs within old reserves (NTR 1987) and fished zones recovered rapidly, returning to pre-disturbance (2004) levels by 2009. Rapid recovery from the 2006 bleaching event was also documented in a study by Diaz-Pulido *et al.* (2009). The primary mechanism of the rapid recovery was regrowth of remnant surviving *Acropora* spp. coral tissue over dead coral branches (Diaz-Pulido *et al.* 2009). However, reefs within new reserves (NTR 2004), particularly at North Keppel Island, experienced negligible recovery from the bleaching event, and mean LHC cover remained below 40% in 2009 at these sites. It is probable that the failure of these reefs to recover is related to their geographic location, limited larval supply and infestation by several species of macroalgae (predominantly *Lobophora variegata*, *Sargassum* sp., *Padina* sp. and *Asparagopsis* sp.) at these monitoring sites. We do not consider that the zoning of these reefs within the new (2004) NTRs influenced the lack of post-bleaching recovery at these sites (Williamson *et al.* 2014)

The freshwater flood plumes from the Fitzroy River in 2011 and 2013 inflicted the greatest damage to Keppel reefs during the monitoring period, with the lowest ebb of LHC cover (13%) recorded in late 2013 (**Figure 2a**). Mean LHC cover declined in all zones following both flood events and there was no significant difference in mean LHC cover recorded between NTR and fished zones in either 2011 or 2013 (**Figure 2b**). Both the 2011 and 2013 flood events were among the largest recorded floods of the Fitzroy River (Wenger *et al.* 2016). Almost all reefs in the Keppel Islands were impacted to some degree by the 2011 and 2013 flood events, and the impact on some heavily exposed reefs was catastrophic (Jones & Berkelmans 2014; Williamson *et al.* 2014; Wenger *et al.* 2016). Although several reefs retained much live hard coral below a depth of approximately 8m, most shallow reef slopes and all reef flat habitats were severely impacted (Jones & Berkelmans 2014).

The additional impact of Cyclone Marcia in March 2015 was not as severe as expected. Reefs that are oriented toward the north and east were exposed to the full force of the storm swells and there were obvious signs of cyclone damage at several monitoring sites. One such site was GK1, which is located at Big Peninsula at the north-eastern extremity of Great Keppel Island (**Figure 1**). Despite the localised and spatially patchy impacts of the cyclone, LHC cover more than doubled from approximately 13% in 2013 to almost 30% in 2015 (**Figure 2a**). Generally, in 2015 LHC cover was highest in fished zones and lowest in new NTRs, but these differences were not significant (**Table 1, Figure 2b, c**). There was no indication that marine park zoning had influenced the degree of live coral retention or loss at individual reefs (**Figure 3a**). In 2015, reef flat sites generally supported lower levels of LHC than adjacent reef slope sites, and this was clearly due to the high exposure of the shallow reef flat habitats to the freshwater flood plumes (**Figure 2c**). The reefs at Barron Island, at the eastern extremity of the Keppel Island group, supported the highest LHC cover in October

2015 (46.2%). Conversely, sheltered (west oriented) and further inshore sites generally had lower LHC cover than the more exposed sites, again indicating that the reefs were most heavily impacted by the flood events, rather than new damage from Cyclone Marcia (Figures 1, 2c, 3b). The geographical position of the sites, and their relative exposure to the various disturbances (particularly the 2011 and 2013 flood plumes) was the primary determinant of post-disturbance reef condition in October 2015 (Figure 3b). Approximately 21% of the total reef area in the Keppels was identified as highly degraded in October 2015, with less than 5% LHC cover, while approximately 13% of the reef area had retained at least 45% LHC cover in 2015. These remaining relatively healthy reefs were identified as key refuges for live hard coral (predominantly *Acropora* spp.) (Figure 3b).

3.1.2 Macroalgae

As expected, macroalgae proliferated in response to declines in LHC. However, during the period of strong coral recovery following the 2006 bleaching event, it was evident that the coral was able to outcompete the macroalgae (Figures 2a & 4a). Most of the *Acropora*-dominated reefs in the Keppel Islands have an underlying cover of macroalgae (predominantly *Lobophora variegata*) growing among the bases of the coral branches. Following the 2006 bleaching event, *L. variegata* proliferated in the short-term, however as the coral recovered over the following few years, the algae was suppressed (Diaz-Pulido *et al.* 2009). The extreme flood plume event of 2011 not only killed a high proportion of the live coral in the Keppel Islands, but it also led to mass mortality of macroalgae (Figure 4a). Following this decline, macroalgae cover increased rapidly and significantly in both NTR and fished zones between 2011 and 2015 (Table 1, Figure 4a, 4b). In October 2015, mean macroalgal cover across the 20 core monitoring sites was approximately 52%, higher than at any other time during the 2004 – 2015 monitoring period (Figure 4a).

3.1.3 Habitat structural complexity

The Structural Complexity Index (SCI) of reef habitats steadily declined between 2004 and 2015, with the majority of the decline occurring from 2009 to 2013 (Figure 5a). Structural complexity continued to decline on reefs within new NTRs between 2013 and 2015, however it stabilised and began increasing on old NTR reefs and fished reefs between 2013 and 2015 (Table 1, Figure 5b). Most of the reefs within the Keppel Islands are dominated by mono-specific stands of branching *Acropora* coral. Once the coral has died at these sites, habitat complexity tends to erode rapidly (Williamson *et al.* 2014). Typical examples of these low complexity reefs include the reef slopes at Middle Island (M1, M2), Clam Bay (Great Keppel Island, GK5 & GK6), the sheltered (western) side of Halfway Island (H3) and the sheltered side of Humpy Island (HU1). Conversely, reef slopes at Egg Rock (Egg1), the southern side of Barron Island (BA1), the exposed (eastern) side of North Keppel Island (NK5, NK8) and Big Peninsula (Great Keppel Island, GK2) retained above average habitat structural complexity through to 2015 (Figure 5c). The underlying reef matrix at these higher-complexity sites is predominantly rock, and the coral grows as a veneer on this robust substrate. Even if the live coral is removed from these sites, much of the habitat complexity will be retained. This has flow-on effects for reef fish communities as high complexity reefs tend to support more diverse fish communities and higher abundances of a range of species, including large-bodied, predatory species (Williamson *et al.* 2014).

3.1.4 Benthic community structure

Community-level analysis of benthic categories revealed that sites with high macroalgal cover were distinct from those with greater coral cover, even if the coral was dead (**Figure a**; ANOSIM Global $R = 0.719$, $p > 0.001$). Furthermore, sites were split between a predominance of branching and foliose corals, and a higher cover of massive coral and bare substratum (sand and pavement). Over time, the community shifted from a dominance of live branching coral in 2004, towards macroalgae dominance in 2006, coral recovery through to 2009, and a dramatic shift towards dead corals in 2011 and 2013 (ANOSIM Global $R = 0.289$, $p > 0.001$). The trajectory of change in benthic community structure on reefs within old NTRs and fished zones was almost identical (Figure 6b). However the shift toward macroalgae dominance was most pronounced on reefs within new NTRs, where hard coral recovery was limited (Figure 6b; ANOSIM Global $R = 0.123$, $p > 0.001$). Macroalgal cover contributed the largest proportion of the variability between years until 2009, dead branching corals drove the differences between 2011 and 2013 and the preceding years and a combination of macroalgae and dead and live branching corals distinguished 2015 from previous years (**Table 2**). The dissimilarity between new NTRs and both Fished zones and old NTRs was governed by differences in the cover of live branching corals, whilst dead branching corals accounted for the majority of the difference between Fished zones and old NTRs (**Table 2**).

It is apparent, that several reefs in the Keppel Islands have undergone a persistent phase shift from coral to macroalgae dominance (Williamson *et al.* 2014; Wenger *et al.* 2016). These degraded reefs currently support very low biodiversity and the prospects for recovery are limited. Active restoration through the removal of macroalgae and transplantation of live coral may assist in 'kick starting' recovery at these degraded reefs. However, any attempts to restore such reefs should establish a robust experimental design that can be used to test the cost and benefit of such restoration actions.

Table 1: Parameter estimates for linear mixed effects models (LMEs), with a random effect of replicate transect nested within site, for live hard coral cover (LHC), macroalgae cover (MAC) and structural complexity (SCI). In all cases the intercept parameter corresponds to the predicted value of each response variable in a fished zone. All other terms represent effect sizes and colons indicate interactions. P values in bold are significant at the 0.05 level.

Response variable	Model	Transformation	Distribution	Effect	Estimate	SE	t-value	P
LHC	LME	Square-root	Gaussian	Intercept	523.616	53.465	9.794	< 0.001
				Year	-0.257	0.027	-9.669	< 0.001
				Zone (NTR 1987)	52.257	87.308	0.599	0.557
				Zone (NTR 2004)	158.327	100.024	1.583	0.132
				Year:Zone (NTR 1987)	-0.026	0.043	-0.606	0.545
				Year:Zone (NTR 2004)	-0.079	0.050	-1.590	0.112
MAC	LME	Log	Gaussian	Intercept	-278.467	44.219	-6.297	< 0.001
				Year	0.139	0.022	6.329	< 0.001
				Zone (NTR 1987)	89.144	72.209	1.235	0.234
				Zone (NTR 2004)	-57.734	82.726	-0.698	0.495
				Year:Zone (NTR 1987)	-0.044	0.036	-1.226	0.221
				Year:Zone (NTR 2004)	0.029	0.041	0.706	0.481
SCI	LME	NA	Gaussian	Intercept	250.852	52.233	4.803	< 0.001
				Year	-0.122	0.026	-4.689	< 0.001
				Zone (NTR 1987)	449.667	85.296	5.272	< 0.001
				Zone (NTR 2004)	217.914	97.719	2.230	0.040
				Year:Zone (NTR 1987)	-0.224	0.042	-5.270	< 0.001
				Year:Zone (NTR 2004)	-0.1088	0.04863	-2.23659	0.0257

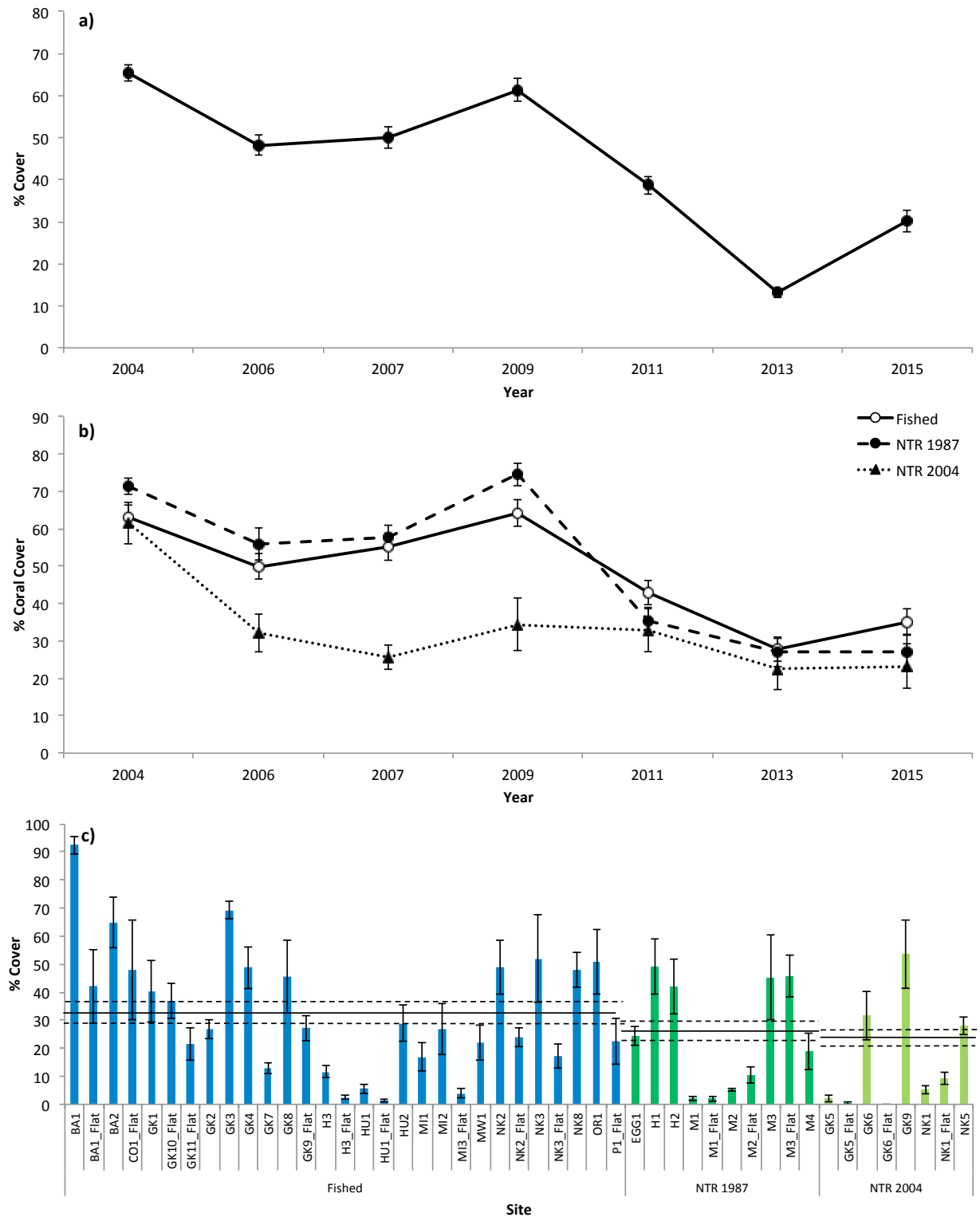


Figure 2: Live hard coral (LHC) cover in the Keppel Islands. a) Temporal dynamics in LHC cover from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in LHC cover from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of LHC cover across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (± 1 S.E.) for sites within each zone. Error bars are ± 1 S.E.

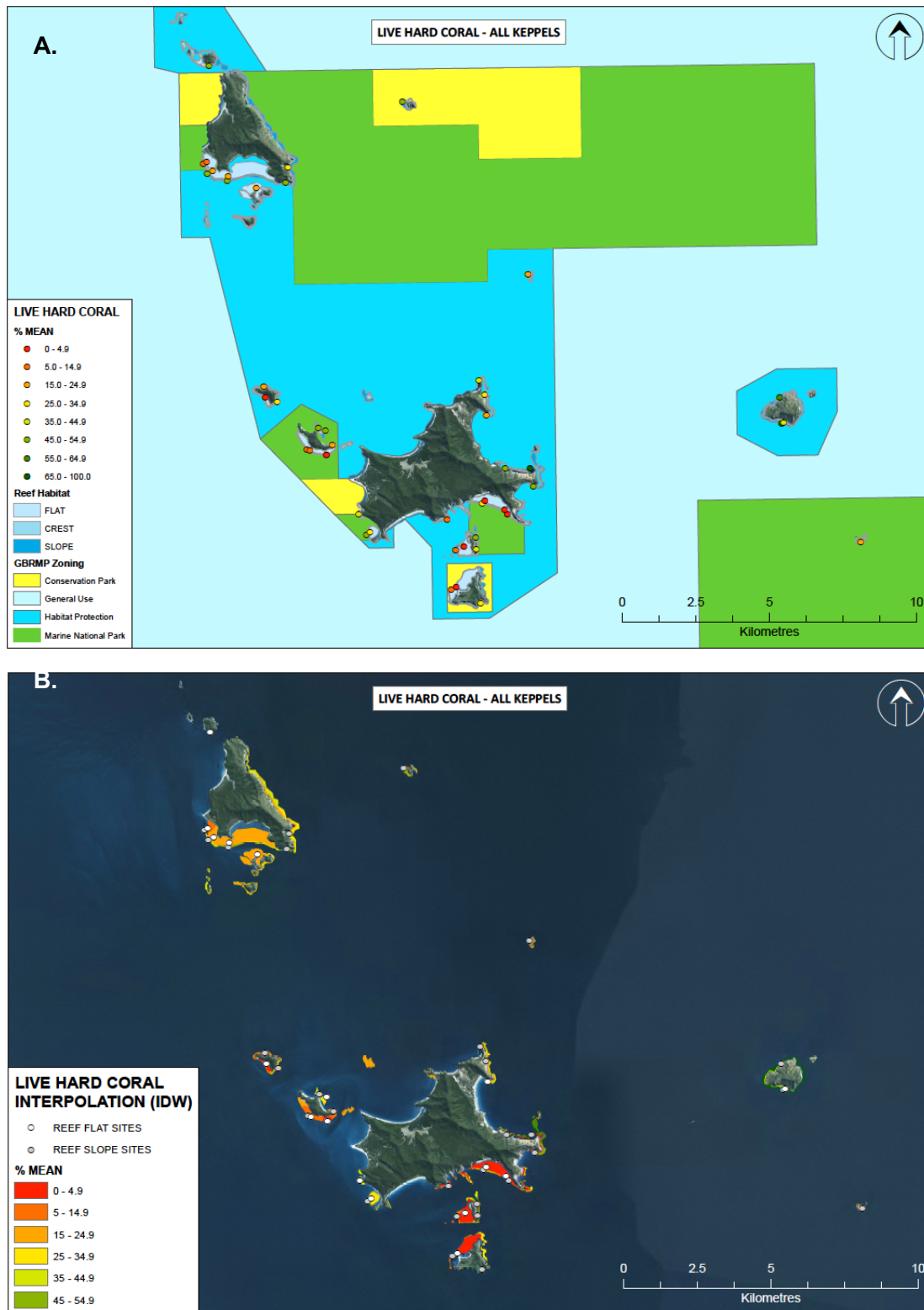


Figure 3: Maps of the Keppel Islands showing estimates of live hard coral (LHC) cover during October 2015. A. Site-specific LHC cover values and Marine Park zoning information. B. LHC cover site values interpolated across all reef habitat areas. Red shaded site markers and reefs represent the most heavily degraded sites/reefs with <5% LHC. Green shaded site markers and reefs represent refuge sites/reefs with > 45 % LHC cover.

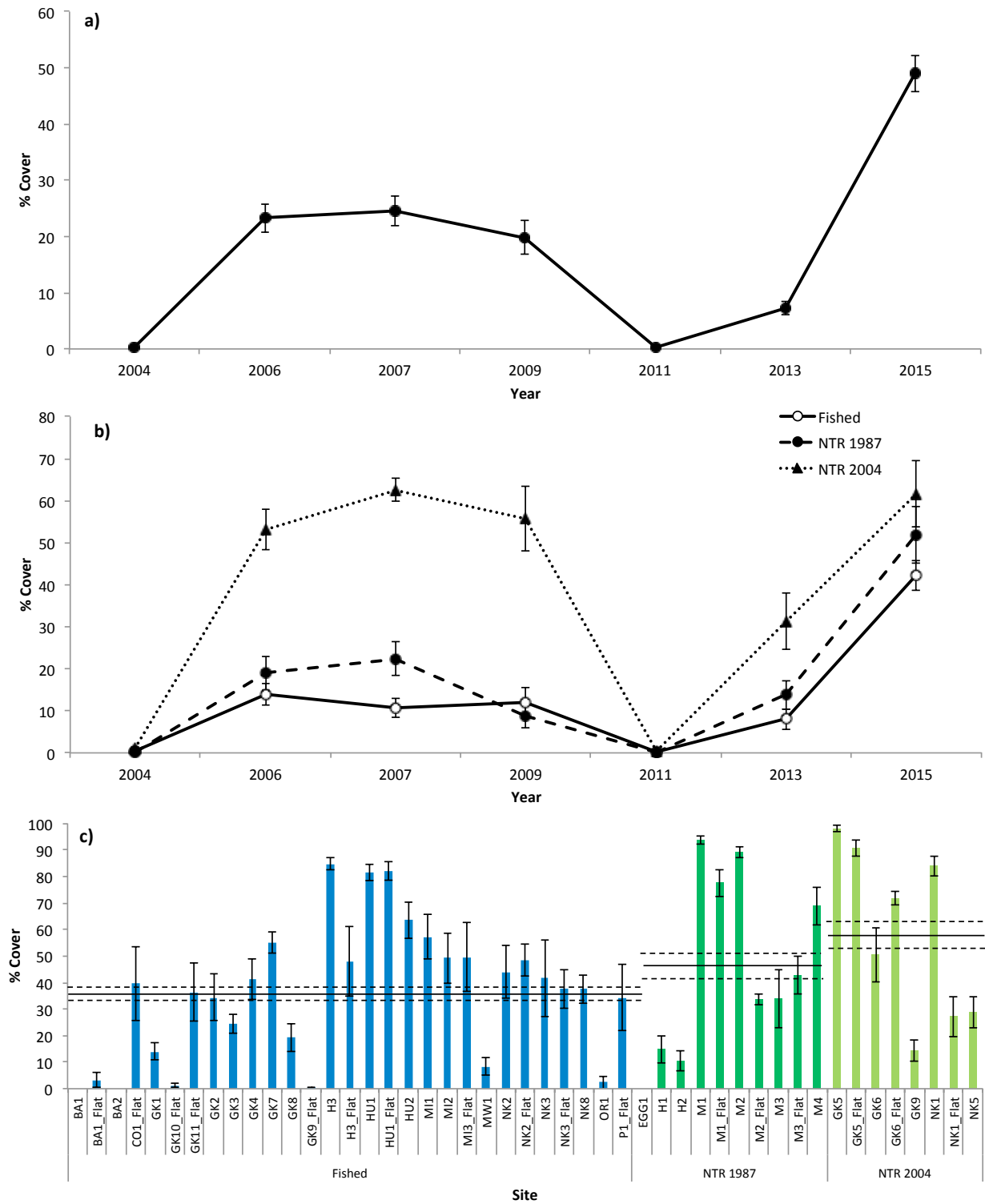


Figure 4: Macroalgae (MA) cover in the Keppel Islands. a) Temporal dynamics in MA cover from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in MA cover from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of MA cover across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (± 1 S.E.) for sites within each zone. Error bars are ± 1 S.E.

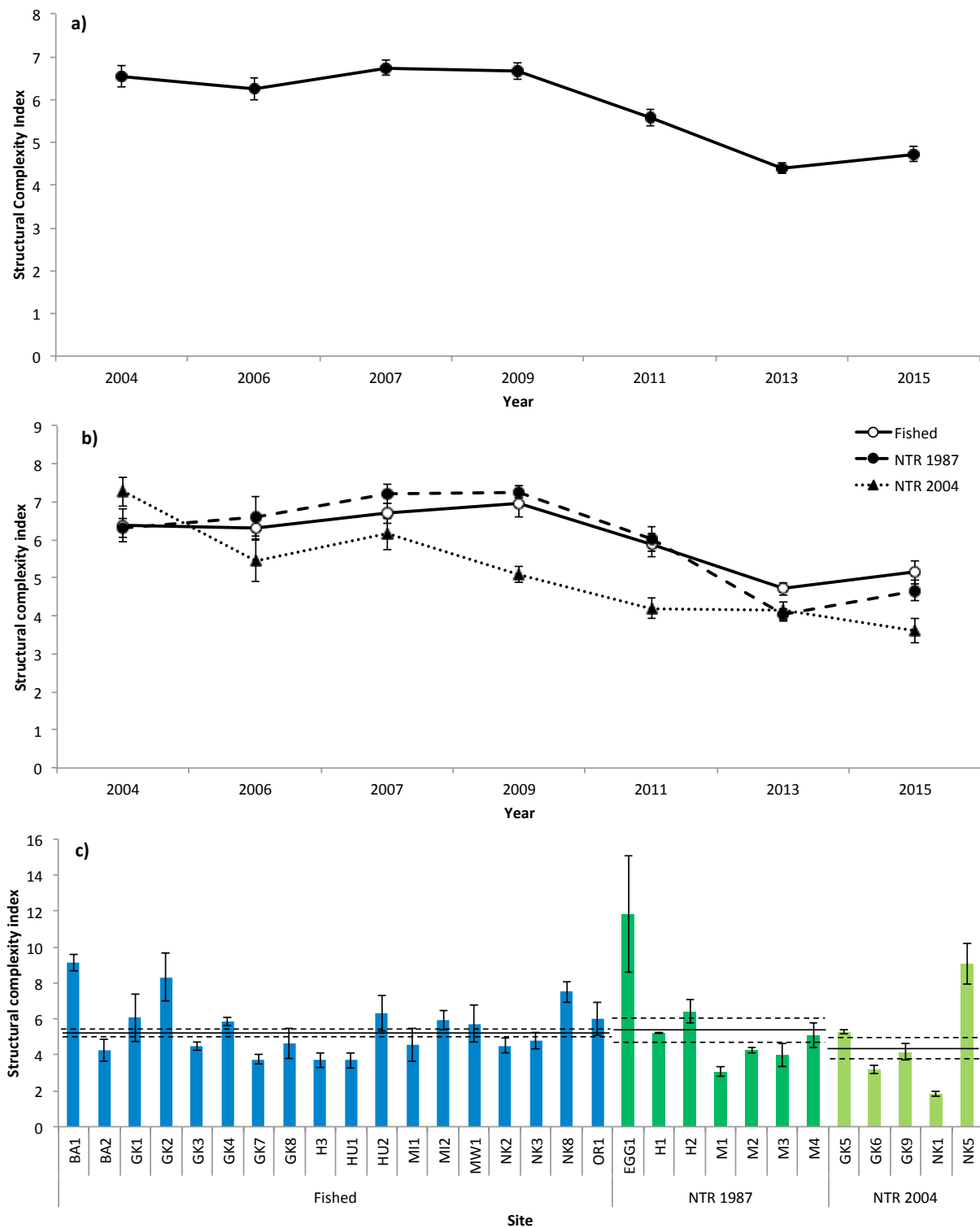


Figure 5: Structural complexity index (SCI) of reef slope habitats in the Keppel Islands. a) Temporal dynamics in SCI from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in SCI from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of SCI across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

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Table 2: SIMPER results of key benthic categories. The 2-way SIMPER was conducted by Zone and Year on the Site-averaged data, $\log(x+1)$ – transformed. Categories contributing up to 50% cumulative dissimilarity are presented.

2004 & 2006 - Average dissimilarity = 51.28			2004 & 2007 - Average dissimilarity = 52.68		
Benthic category	Contrib.%	Cum.%	Benthic category	Contrib.%	Cum.%
macroalgae	15.02	15.02	macroalgae	14.26	14.26
plate live	8.97	23.99	branching dead	10.07	24.33
branching dead	8.91	32.9	plate live	8.48	32.8
sand	8.85	41.75	rubble	8.27	41.07
rubble	8.29	50.05	sand	7.83	48.9
			branching live	7.51	56.42
2006 & 2007 - Average dissimilarity = 44.89			2004 & 2009 - Average dissimilarity = 50.93		
Benthic category	Contrib.%	Cum.%	Benthic category	Contrib.%	Cum.%
macroalgae	11.35	11.35	macroalgae	11.9	11.9
branching dead	9.47	20.82	branching dead	11.61	23.5
rubble	9.23	30.05	plate live	9.43	32.93
branching live	9.02	39.07	rubble	8.34	41.27
sand	8.48	47.55	sand	8.14	49.41
digitate live	8.15	55.7	encrusting	7.76	57.17
2006 & 2009 - Average dissimilarity = 47.78			2007 & 2009 - Average dissimilarity = 47.00		
Benthic category	Contrib.%	Cum.%	Benthic category	Contrib.%	Cum.%
macroalgae	12.72	12.72	macroalgae	12.8	12.8
branching dead	9.92	22.64	branching dead	10.52	23.32
plate live	9.32	31.95	plate live	9	32.32
sand	9.09	41.04	rubble	8.88	41.2
rubble	8.55	49.6	branching live	8.61	49.81
branching live	8.34	57.94	digitate live	7.88	57.69
2004 & 2011 - Average dissimilarity = 49.15			2006 & 2011 - Average dissimilarity = 52.64		
Benthic category	Contrib.%	Cum.%	Benthic category	Contrib.%	Cum.%
rubble	14.07	14.07	macroalgae	14.4	14.4
branching dead	11.36	25.43	rubble	11.84	26.24
branching live	10.01	35.43	branching dead	10.62	36.86
plate live	9.02	44.46	branching live	8.82	45.68
sand	8.21	52.66	sand	7.48	53.16
2007 & 2011 - Average dissimilarity = 52.63			2009 & 2011 - Average dissimilarity = 52.37		
Benthic category	Contrib.%	Cum.%	Benthic category	Contrib.%	Cum.%
macroalgae	14.08	14.08	branching dead	14.43	14.43
branching dead	12.64	26.71	rubble	12.82	27.26
rubble	11.29	38.01	macroalgae	11.44	38.69
branching live	9.31	47.31	branching live	9.83	48.52
plate live	6.77	54.08	plate live	7.95	56.47
2004 & 2013 - Average dissimilarity = 56.01			2006 & 2013 - Average dissimilarity = 50.05		
Benthic category	Contrib.%	Cum.%	Benthic category	Contrib.%	Cum.%
branching live	11.75	11.75	branching dead	12.76	12.76
branching dead	11.38	23.13	macroalgae	11.68	24.44
rubble	10.26	33.38	branching live	11.67	36.11
macroalgae	10.03	43.42	rubble	10.51	46.62
plate live	8.67	52.09	digitate live	8.03	54.65

Table 2 (cont.): SIMPER results of key benthic categories. The 2-way SIMPER was conducted by Zone and Year on the Site-averaged data, $\log(x+1)$ – transformed. Categories contributing up to 50% cumulative dissimilarity are presented.

2007 & 2013 - Average dissimilarity = 51.20			2009 & 2013 - Average dissimilarity = 53.80		
<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>	<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>
branching dead	14.33	14.33	branching dead	15.17	15.17
branching live	12.2	26.52	branching live	12.78	27.95
macroalgae	11.21	37.73	macroalgae	11.25	39.2
rubble	9.61	47.34	rubble	10.48	49.68
pavement	7.7	55.04	plate live	8.66	58.34
2011 & 2013 - Average dissimilarity = 47.85			2004 & 2015 - Average dissimilarity = 63.91		
<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>	<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>
branching live	12.41	12.41	macroalgae	21.03	21.03
macroalgae	11.53	23.94	branching live	11.5	32.53
rubble	10.82	34.76	branching dead	9.54	42.08
branching dead	9.73	44.49	plate live	7.93	50
sand	8.58	53.08			
2006 & 2015 - Average dissimilarity = 50.16			2007 & 2015 - Average dissimilarity = 50.20		
<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>	<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>
branching live	13.16	13.16	branching live	13.88	13.88
macroalgae	13.05	26.21	macroalgae	13.88	27.77
rubble	9.87	36.08	rubble	9.43	37.19
branching dead	9.33	45.41	branching dead	9.41	46.6
sand	9.05	54.46	sand	7.53	54.13
2009 & 2015 - Average dissimilarity = 54.92			2011 & 2015 - Average dissimilarity = 62.44		
<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>	<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>
macroalgae	16.84	16.84	macroalgae	21.01	21.01
branching live	13.89	30.74	branching dead	13.49	34.5
rubble	9.35	40.08	branching live	10.48	44.98
plate live	9.05	49.13	rubble	10.21	55.2
branching dead	8.65	57.78			
2013 & 2015 – Average dissimilarity = 54.33			Fished & NTR 2004 - Average dissimilarity = 50.68		
<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>	<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>
branching dead	16.57	16.57	branching live	12.96	12.96
macroalgae	16.31	32.88	macroalgae	12.38	25.34
branching live	12.57	45.46	rubble	10.55	35.89
rubble	9.45	54.9	branching dead	10	45.9
			sand	9.4	55.29
Fished & NTR 1987 - Average dissimilarity = 45.44			NTR 2004 & NTR 1987 - Average dissimilarity = 45.81		
<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>	<i>Benthic category</i>	<i>Contrib.%</i>	<i>Cum.%</i>
branching dead	9.95	9.95	branching live	14.54	14.54
rubble	9.88	19.84	macroalgae	13.02	27.56
branching live	9.74	29.58	rubble	12.04	39.6
sand	9.51	39.09	branching dead	11.85	51.45
macroalgae	9.39	48.48			
encrusting	7.86	56.34			

3.2 Fish community dynamics

3.2.1 Total fish density and species richness

An overall significant decline in total fish density was recorded between 2004 and 2015 (Table 2, Figure 7a). Total fish density declined dramatically in all zones in 2006 following the coral bleaching disturbance event, and in 2011 and 2013 following the flood plume disturbances (Figure 7a, 7b). Total fish abundance increased significantly on reefs within old and new NTRs between 2007 and 2009, but not in the fished zones (**Figure b**). Fish density had declined to its lowest point in all zones in 2013, and began to recover on reefs within fished zones and old NTRs between 2013 and 2015 (Figure 7b). Mirroring the lack of coral recovery, there was negligible increase in total fish density on new NTR reefs between 2013 and 2015 (Figure 7b). In 2015, mean total fish density was highest on reefs within fished zones and lowest on reefs within new NTRs (Figure 7c). The most abundant fish species on Keppel reefs is *Chromis nitida* (Pomacentridae). This species displayed highly dynamic variability in abundance throughout the monitoring period. Although *C. nitida* are associated with live coral, it appears that dead coral that provides habitat complexity at a scale suitable for these fish to avoid predators can also support high abundances in the Keppel Islands. The reef adjoining the sheltered side of Halfway Island (H3) was in an extremely degraded state in 2015, yet this site supported the highest recorded abundance of *C. nitida* (Figure 7c). Interestingly, a similarly degraded reef adjoining the western side of North Keppel Island (NK1) supported the lowest abundances of *C. nitida*. Maps displaying total fish density estimates on Keppel reefs in October 2015 are provided in Figure 8.

Fish species richness declined between 2004 and 2015, with a temporary recovery in 2007 on reefs within old NTRs and fished zones, followed by subsequent declines in all zones (Table 2, Figure 9a, 9b). As with total fish density, recovery failed to occur in new NTRs, and from 2007 until 2015 species richness remained significantly lower in new NTRs than in old NTRs and fished zones (Figure 9b). Species richness reached its lowest point in all three zones in 2013, and then began to recover in new NTRs and stabilised in fished zones and old NTRs through to 2015 (Figure 9b). In 2015, fish species richness was lowest on the most highly degraded reefs, typically with less than 12 species recorded (Figure 9c). Sites that had retained relatively high species richness (> 20 species) in 2015 included GK1, MW1, NK2, OR1, EGG1 and M4. These sites were generally those where live coral cover and habitat structural complexity remained moderate to high. Maps displaying fish species richness estimates on Keppel reefs in October 2015 are provided in Figure 10.

Table 3: Parameter estimates for linear mixed effects models (LMEs), with a random effect of replicate transect nested within site, for total fish density, prey fish density (minus *C. nitida*) and fish species richness. In all cases the intercept parameter corresponds to the predicted value of each response variable in a fished zone. All other terms represent effect sizes and colons indicate interactions. *P* values in bold are significant at the 0.05 level.

Response variable	Model	Transformation	Distribution	Effect	Estimate	SE	<i>t</i> -value	<i>P</i>
Total fish density	LME	Log	Gaussian	Intercept	251.473	39.549	6.358	< 0.001
				Year	-0.121	0.020	-6.170	< 0.001
				Zone (NTR 1987)	-170.897	50.969	-3.353	0.004
				Zone (NTR 2004)	68.880	57.682	1.194	0.249
				LHC	0.010	0.002	5.067	< 0.001
				MAC	0.006	0.002	3.603	< 0.001
				Rugosity	-0.035	0.041	-0.839	0.402
				SCI	0.094	0.023	4.040	< 0.001
				Year:Zone (NTR 1987)	0.085	0.025	3.353	< 0.001
				Year:Zone (NTR 2004)	-0.034	0.029	-1.193	0.233
Species richness	LME	NA	Gaussian	Intercept	1673.643	189.079	8.852	< 0.001
				Year	-0.824	0.094	-8.754	< 0.001
				Zone (NTR 1987)	205.858	242.526	0.849	0.408
				Zone (NTR 2004)	410.717	274.208	1.498	0.153
				LHC	0.029	0.010	2.893	0.004
				MAC	0.017	0.008	2.094	0.037
				Rugosity	-0.238	0.201	-1.182	0.238
				SCI	0.559	0.113	4.949	< 0.001
				Year:Zone (NTR 1987)	-0.103	0.121	-0.849	0.396
				Year:Zone (NTR 2004)	-0.206	0.136	-1.511	0.131

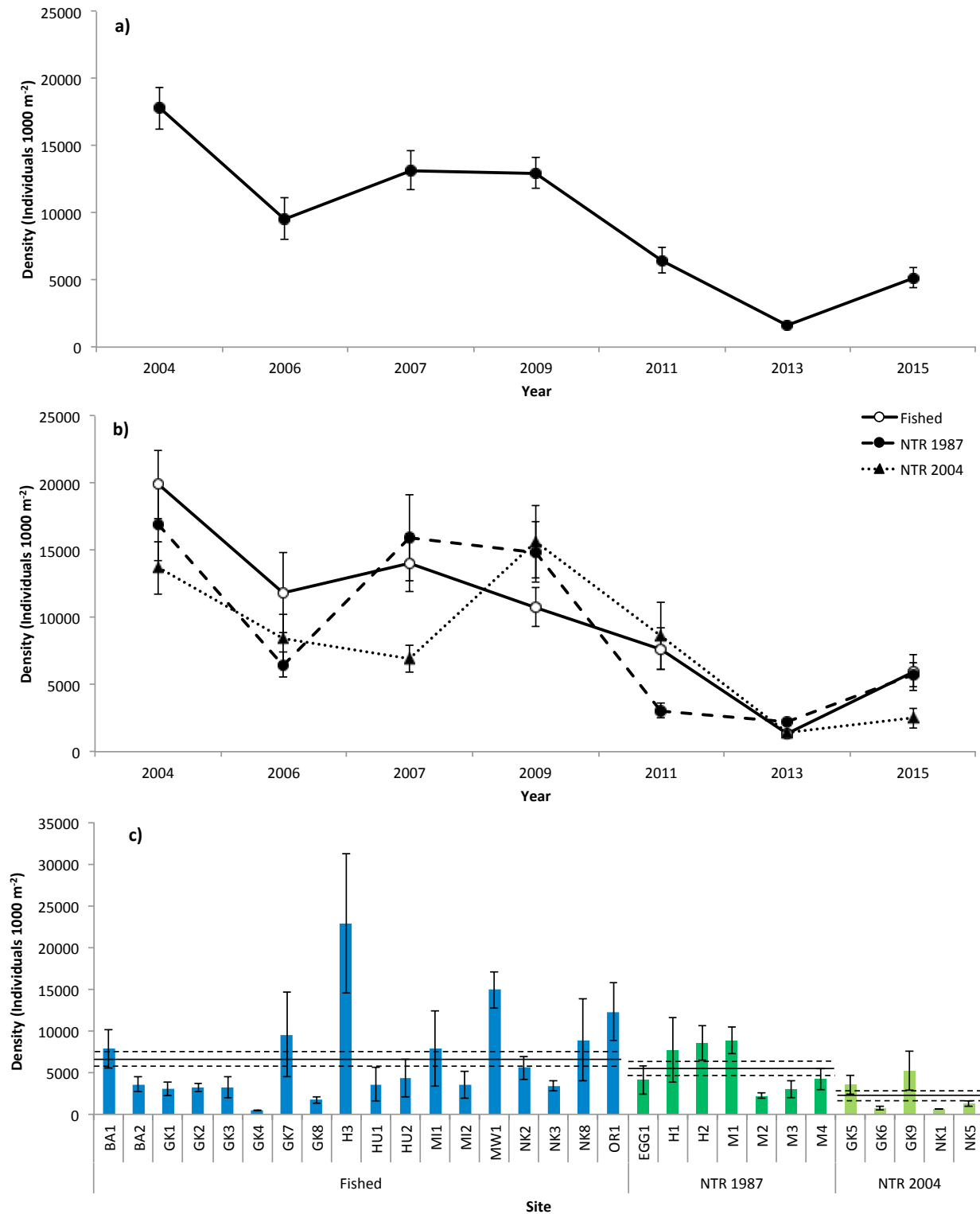


Figure 7: Total fish density in the Keppel Islands. a) Temporal dynamics in total fish density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in total fish density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of total fish density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

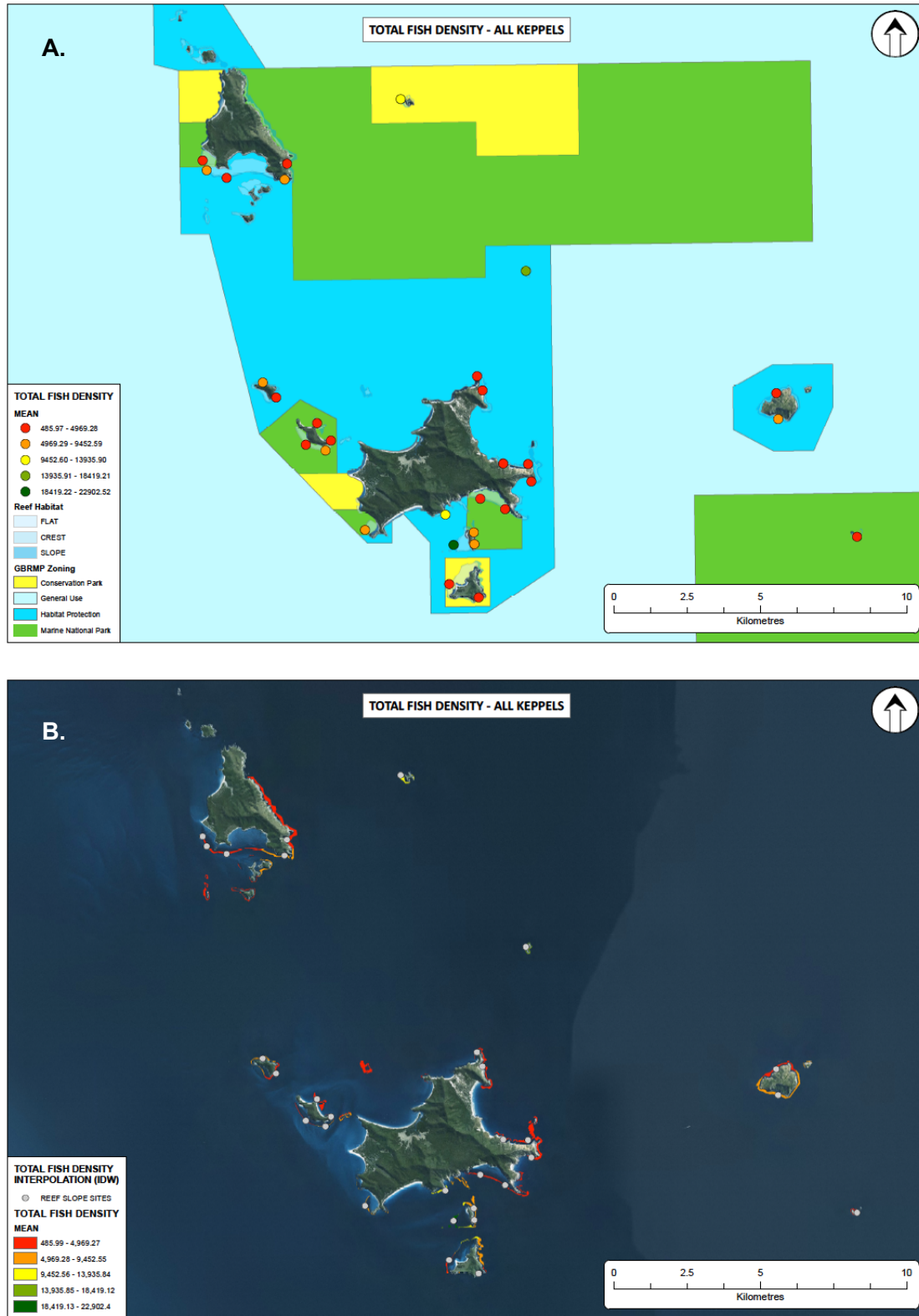


Figure 8: Maps of the Keppel Islands showing estimates of total fish density during October 2015. A. Site-specific total fish density values and Marine Park zoning information. B. Total fish density site values interpolated across all reef habitat areas. Red shaded site markers and reefs represent the areas with the lowest fish densities. Green shaded site markers and reefs represent areas with the highest fish densities.

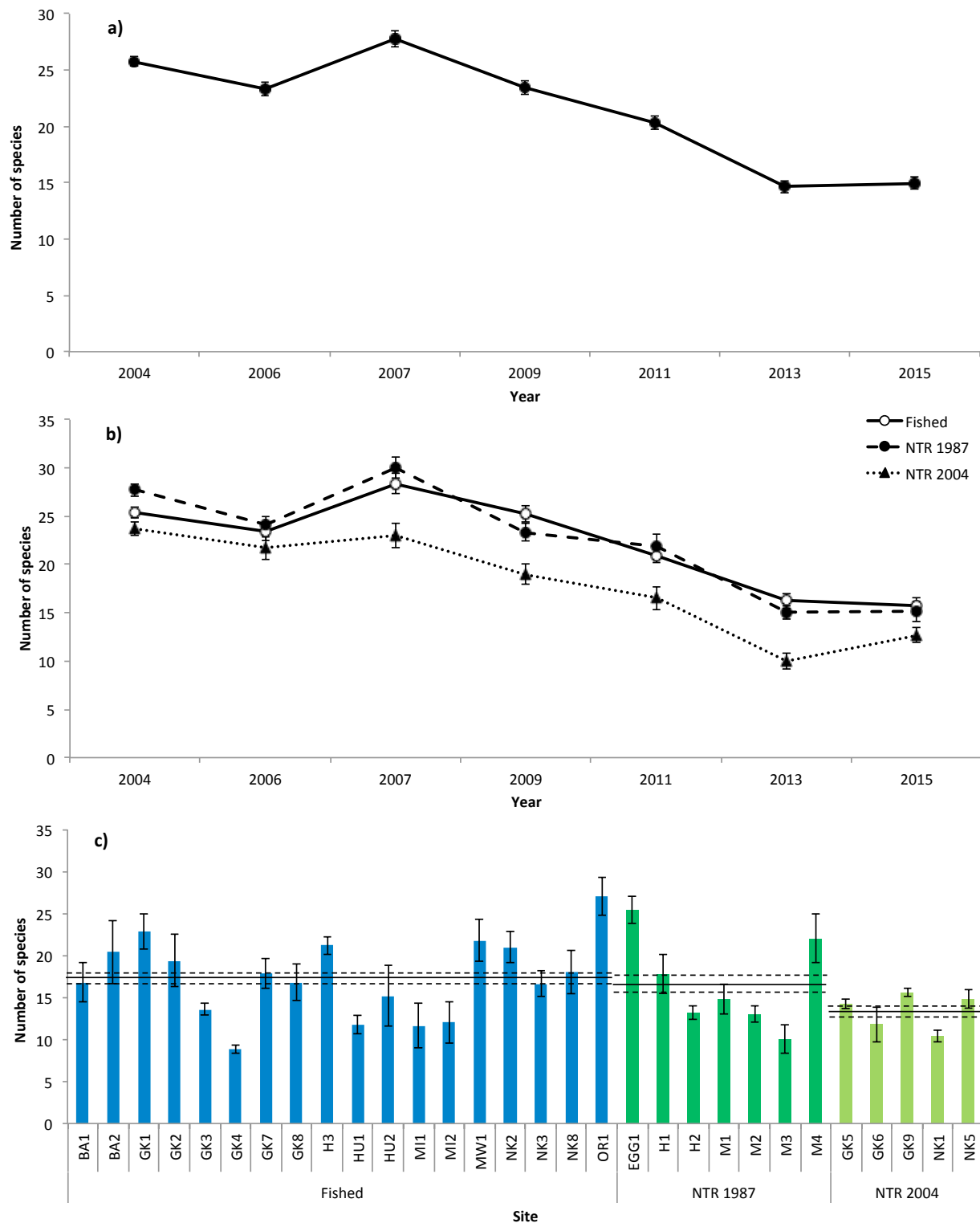


Figure 9: Fish species richness in the Keppel Islands. a) Temporal dynamics in species richness from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in species richness from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of species richness across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

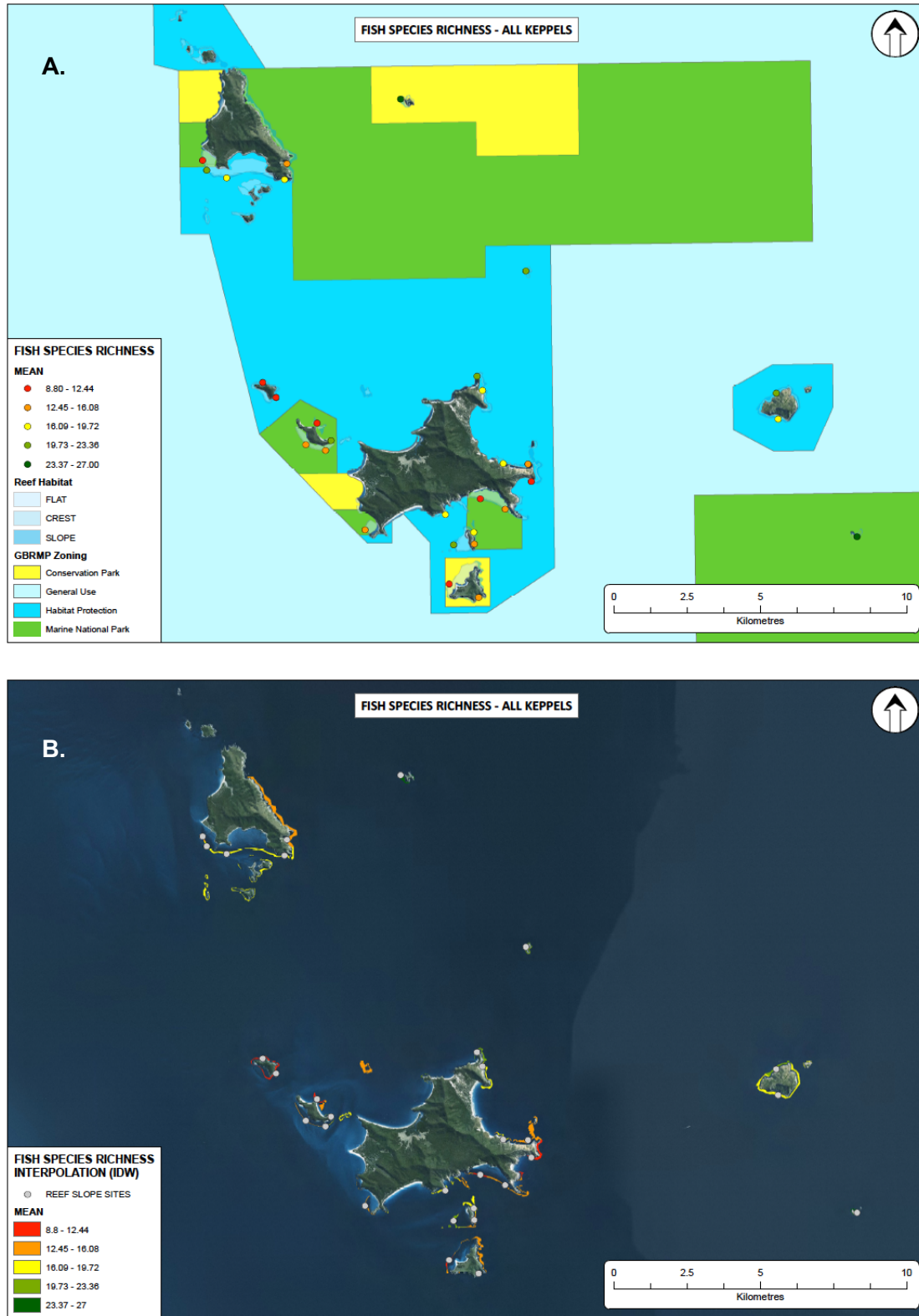


Figure 10: Maps of the Keppel Islands showing estimates of fish species richness during October 2015. A. Site-specific species richness values and Marine Park zoning information. B. Species richness site values interpolated across all reef habitat areas. Red shaded site markers and reefs represent the areas with the lowest species richness. Green shaded site markers and reefs represent areas with the highest species richness.

3.2.2 Coral trout (*Plectropomus spp.*)

Mean coral trout density and biomass was highly variable on reefs in the Keppel Islands throughout the monitoring period, however a general decline was recorded from 2004 to 2015 (Table 3, Figure 11, 12). Mean coral trout density declined in 2006, 2011 and 2013, with a phase of recovery between 2007 and 2009 (Figure 11a). The magnitude of the 2009 to 2013 decline was much larger than the decline from 2004 to 2006 (Figure 11a, 11b). This large decline reflected the dramatic declines in coral cover, habitat structural complexity and the abundance of prey fish species following the flood plume disturbances of 2011 and 2013. Early stages of recovery were evident between 2013 and 2015, however coral trout densities had essentially only increased in new NTRs, and the majority of those new fish were sub-adults (< 30cm TL) (Figure 11a, 11b). From 2004 to 2011, coral trout densities were consistently higher on reefs within both old and new NTRs than on reefs that are open to fishing (Figure 11b).

Trajectories of coral trout biomass were similar on reefs within all three zones (highest in 2009, lowest in post-bleaching 2006 and post-flood 2013; with a further decline recorded between 2013 and 2015 (Figure 12a, 12b). Coral trout biomass was consistently lower on fished reefs than on NTR reefs throughout the monitoring period (Figure 12b). However in 2013, there was no significant difference in coral trout density or biomass between NTR and fished reefs (Figure 11b, 12b).

In October 2015, the highest density and biomass of coral trout were recorded at Egg Rock (old NTR), with 30 individuals 1000 m^{-2} (Figure 11c, 12c). Egg Rock has been identified as an extremely important source reef for the supply of juvenile coral trout to reefs in the Keppel Islands (Harrison *et al.* 2012). Above average coral trout density and biomass was also recorded on the reef within the new NTR at Clam Bay, Great Keppel Island (sites GK5 and GK6). Clam Bay has previously been identified as a recruitment hotspot for coral trout, with consistently high densities of juvenile and sub-adult fishes (Evans & Russ 2004; Wen *et al.* 2013). In contrast, several NTR reefs supported densities that were on a par with the lowest-density fished reefs (M3, M4, NK1 and NK5). Most fished reefs supported coral trout densities below 5 individuals 1000m^{-2} (Figure 11c).

The density of coral trout was significantly influenced by zone, coral cover, macroalgae cover, rugosity and the density of prey (Table 4, Figure 13). The strongest predictor variables for coral trout biomass were rugosity, SCI and prey density (Table 4). There was a negative correlation with rugosity, but a positive relationship with SCI and prey density (Figure 14). Clearly, the density and biomass of coral trout is strongly influenced by both the condition of the reef habitat and the availability of prey on reefs in the Keppel Islands (Williamson *et al.* 2014).

Several post-disturbance refuge reefs for coral trout populations were identified within NTR zones in 2011 following the first of the two major flood plume events (Williamson *et al.* 2014). However, in 2013, when the majority of Keppel reefs were in a highly degraded state, most of the previously identified refuge reefs were no longer supporting above average abundances of coral trout. It appears that a lag phase occurred in the decline of coral trout between 2011 and 2013. Such lag phases in population decline and recovery have been previously documented in coral reef systems (Graham *et al.* 2007). Evidently, repeated severe disturbances reduced coral trout density and biomass on both NTR and fished reefs,

however the magnitude of the decline was larger on NTR reefs than fished reefs. These findings present further compelling evidence that disturbance events can undermine many of the accrued benefits of NTRs. There is considerable capacity for coral trout populations to recover in the Keppel Islands, however the recovery of hard coral will be a precursor for the recovery of the entire fish community. Maps displaying fish coral trout density and biomass estimates on Keppel reefs in October 2015 are provided in Figures 15 and 16.

Table 4: Parameter estimates for linear mixed effects models (LMEs), with a random effect of replicate transect nested within site, for coral trout (*Plectropomus* spp.) density and biomass. In all cases the intercept parameter corresponds to the predicted value of each response variable in a fished zone. All other terms represent effect sizes and colons indicate interactions. *P* values in bold are significant at the 0.05 level.

Response variable	Model	Transformation	Distribution	Effect	Estimate	SE	<i>t</i> -value	<i>P</i>
Coral trout density	LME	Square-root	Gaussian	Intercept	-108.813	69.122	-1.574	0.116
				Year	0.055	0.034	1.586	0.113
				Zone (NTR 1987)	35.761	87.886	0.407	0.689
				Zone (NTR 2004)	327.255	99.361	3.294	0.004
				LHC	0.011	0.003	3.100	0.002
				MAC	0.026	0.003	8.874	< 0.001
				Rugosity	0.199	0.071	2.791	0.005
				SCI	0.076	0.040	1.890	0.059
				All prey	0.0002	0.00001	3.903	< 0.001
				Year:Zone (NTR 1987)	-0.018	0.044	-0.403	0.687
				Year:Zone (NTR 2004)	-0.162	0.049	-3.281	0.001
Coral trout biomass	LME	Square-root	Gaussian	Intercept	46.558	63.652	0.731	0.465
				Year	-0.023	0.032	-0.715	0.475
				Zone (NTR 1987)	114.681	80.869	1.418	0.174
				Zone (NTR 2004)	-49.767	91.427	-0.544	0.593
				LHC	0.006	0.003	1.952	0.052
				MAC	0.002	0.003	0.701	0.484
				Rugosity	-0.132	0.066	-2.017	0.044
				SCI	0.136	0.037	3.687	< 0.001
				All prey	0.00001	0.00001	2.427	0.016
				Year:Zone (NTR 1987)	-0.056	0.040	-1.404	0.161
				Year:Zone (NTR 2004)	0.025	0.046	0.555	0.579

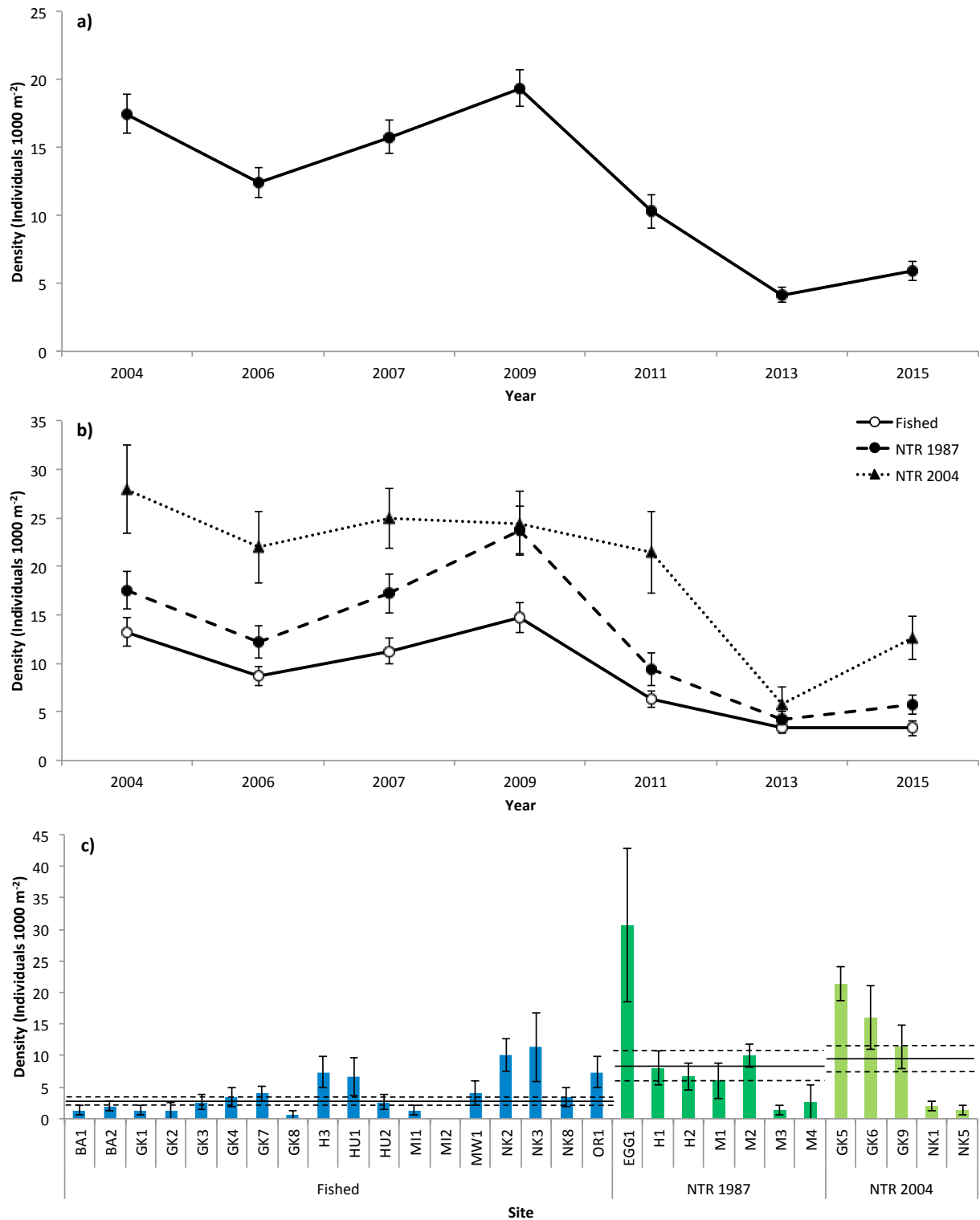


Figure 11: Coral trout (*Plectropomus* spp.) density in the Keppel Islands. a) Temporal dynamics in mean coral trout density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in coral trout density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of coral trout density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value ($\pm 95\%$ CI) for sites within each zone. Error bars are ± 1 S.E.

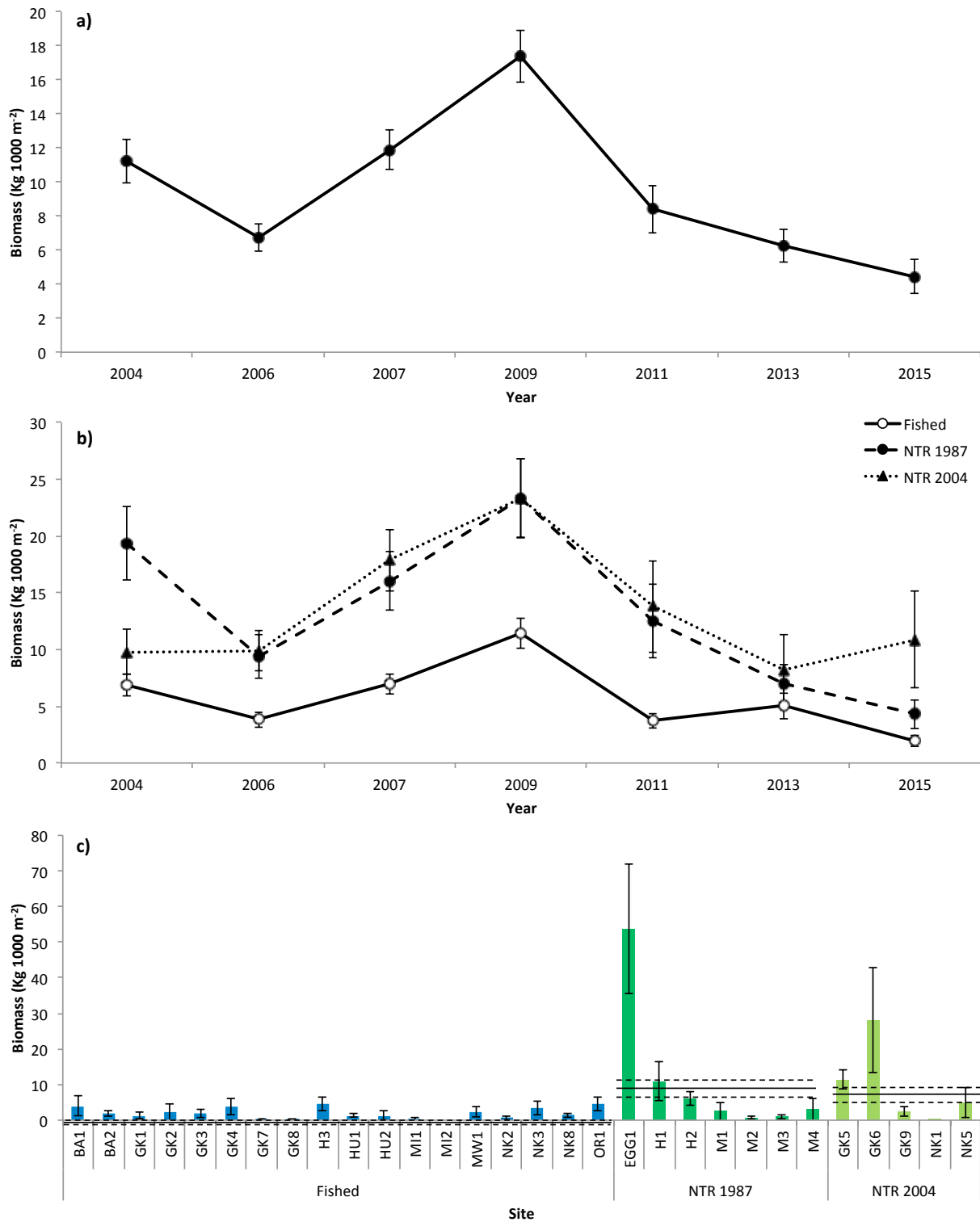


Figure 12: Coral trout (*Plectropomus* spp.) biomass in the Keppel Islands. a) Temporal dynamics in mean coral trout biomass from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in coral trout biomass from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of coral trout biomass across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

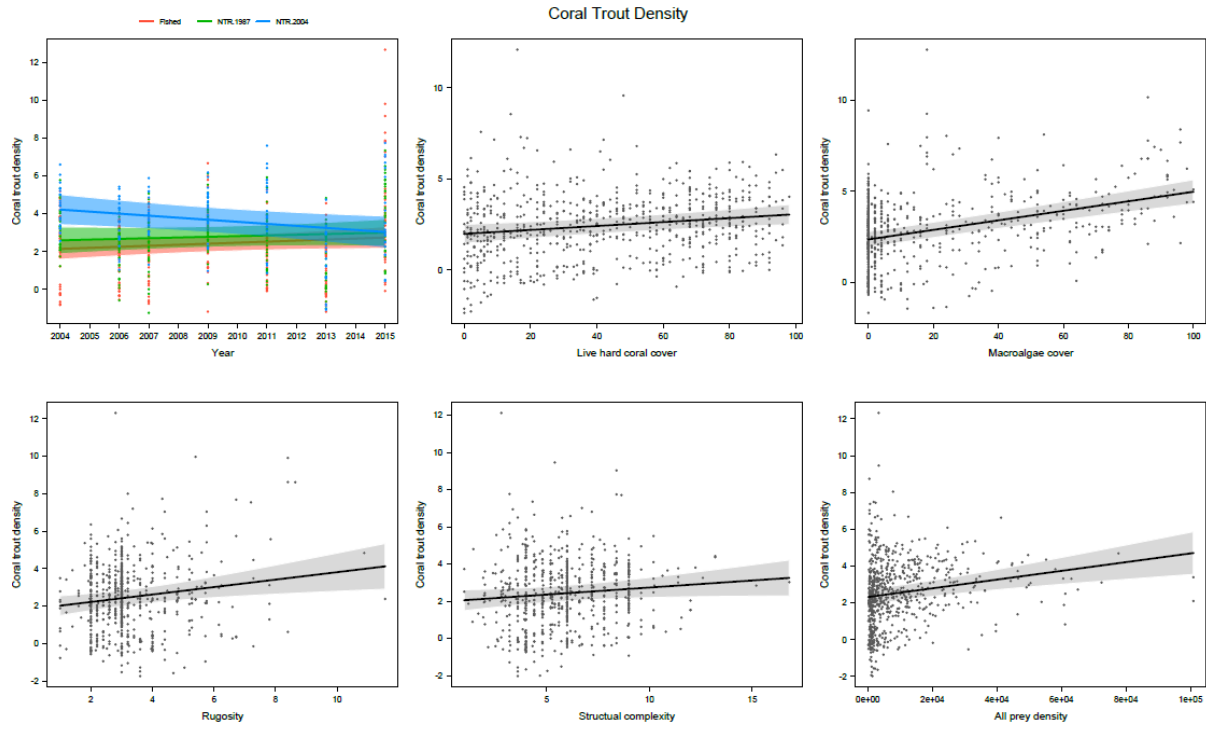


Figure 13: Modelled relationship between *Plectropomus* spp. density and explanatory variables. Shading represents 95% confidence intervals and points are partial residuals.

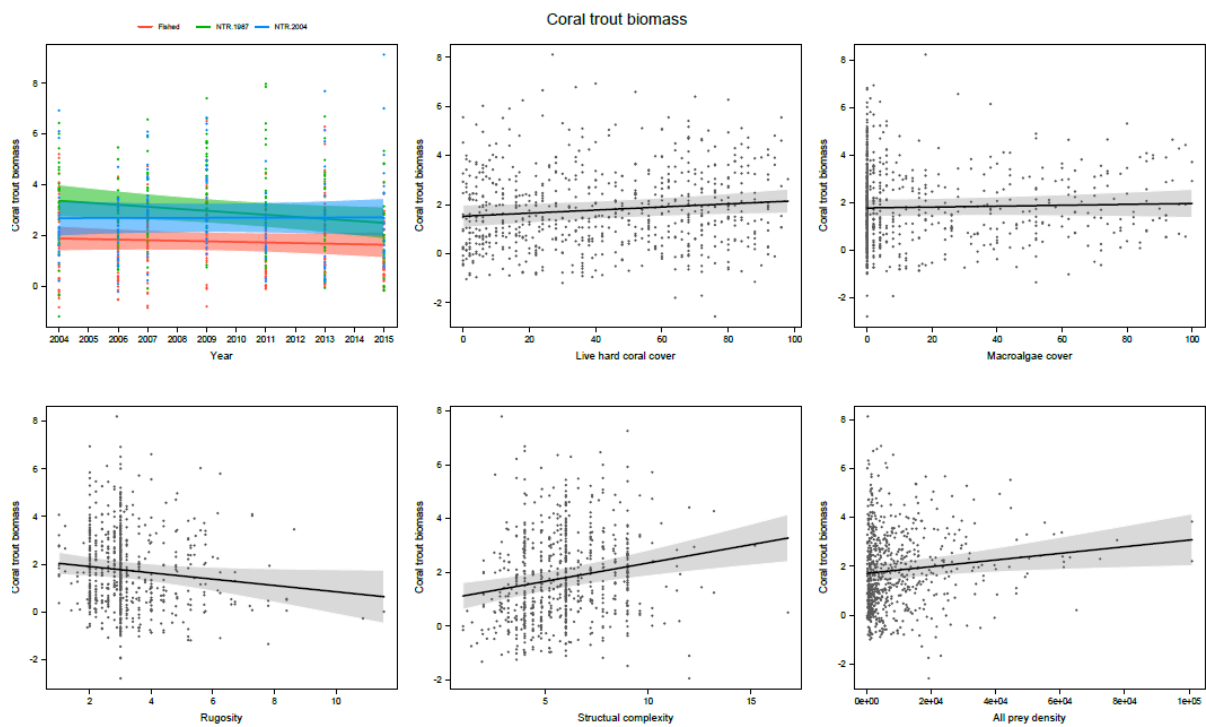


Figure 14: Modelled relationship between *Plectropomus* spp. biomass and explanatory variables. Shading represents 95% confidence intervals and points are partial residuals.

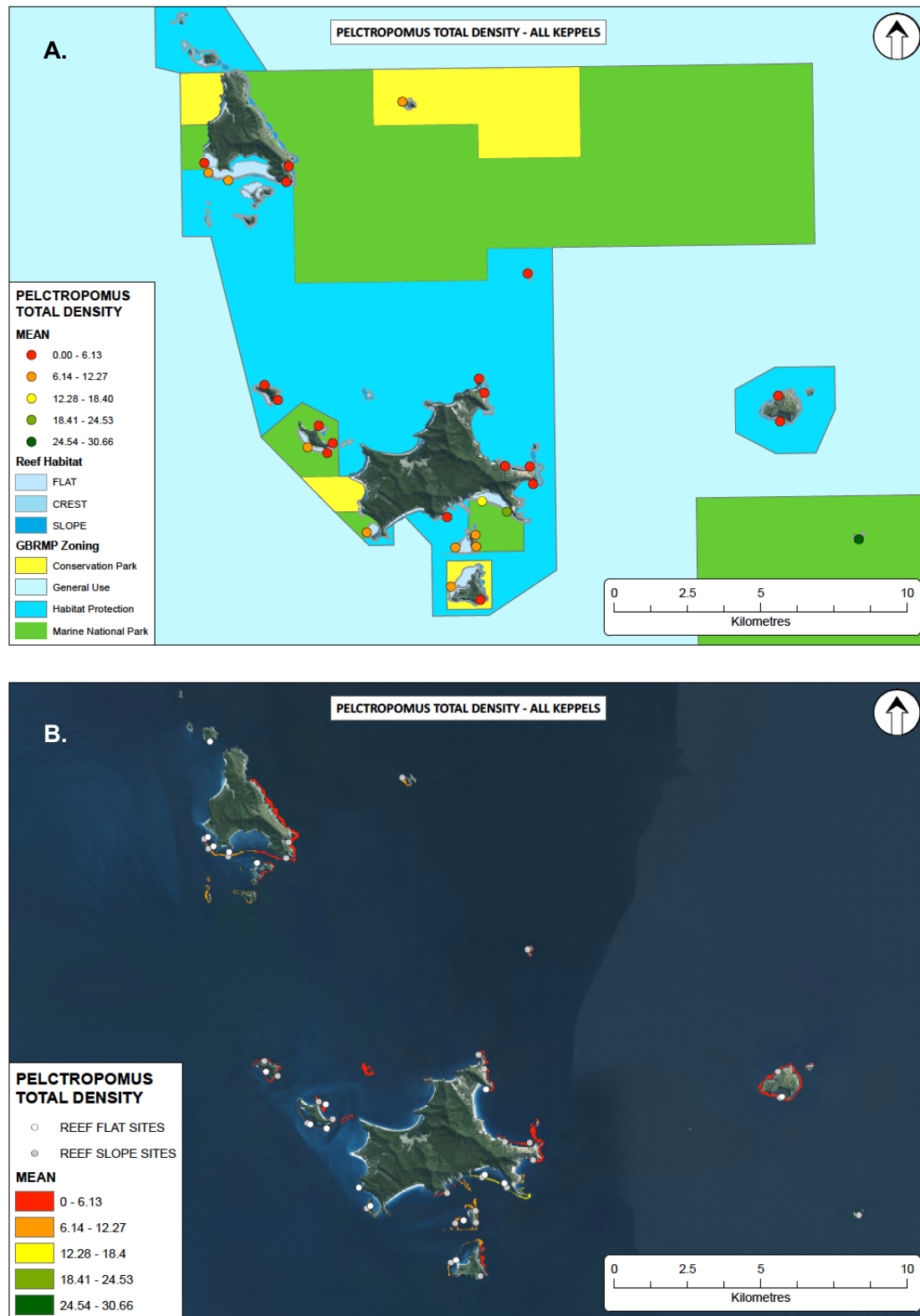


Figure 15: Maps of the Keppel Islands showing estimates of mean coral trout (*Plectropomus* spp.) density during October 2015. A. Site-specific coral trout density values and Marine Park zoning information. B. Coral trout density site values interpolated across all reef habitat areas. Red shaded site markers and reefs represent the areas with the lowest fish densities. Green shaded site markers and reefs represent areas with the highest fish densities.

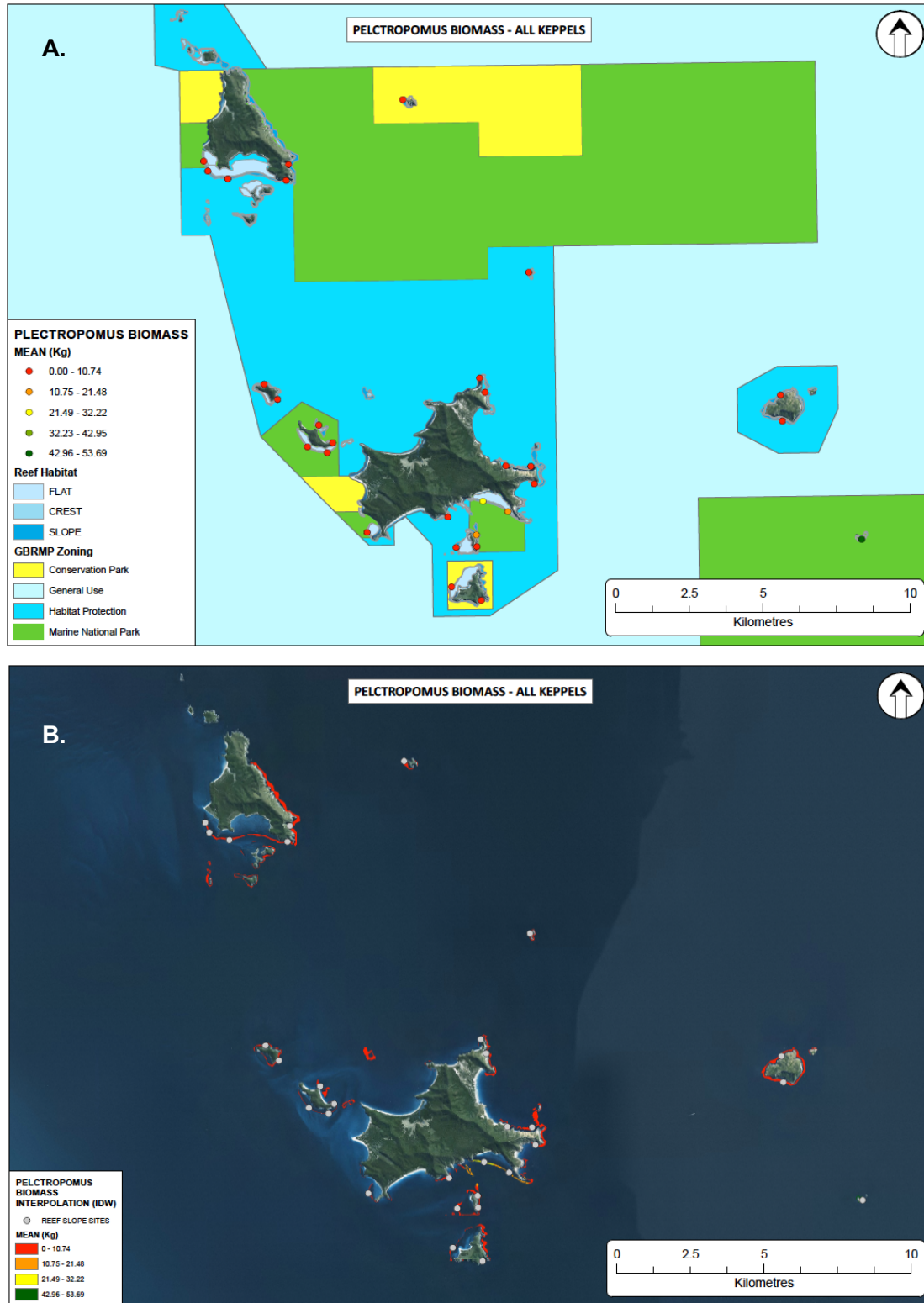


Figure 16: Maps of the Keppel Islands showing estimates of mean coral trout (*Plectropomus* spp.) biomass during October 2015. A. Site-specific coral trout biomass values and Marine Park zoning information. B. Coral trout biomass site values interpolated across all reef habitat areas. Red shaded site markers and reefs represent the areas with the lowest fish biomass. Green shaded site markers and reefs represent areas with the highest fish biomass.

3.2.3 Fish functional groups and associations with the benthic community

Significant temporal variation was recorded in the density of all fish functional groups throughout the monitoring period (Table 5). In response to the loss of live hard coral from Keppel reefs, the vast majority of fish species and groups declined in abundance between 2004 and 2015 (Table 5, Figures 17 – 24). One functional group of fishes, the benthic carnivores, maintained relatively stable density from 2004 to 2015, and increased in density from 2009 to 2011 when most other fishes experienced pronounced declines in density (Figure 19a, 19b). Most of the fishes within the benthic carnivore group are highly opportunistic, generalist feeding species (predominantly wrasses, Labridae) (Appendix 1.1). This group of fishes clearly has significant capacity to weather the impacts of severe disturbances, adapt to changing reef conditions and maintain population densities on degraded reefs (Williamson *et al.* 2014). In contrast, highly coral-associated groups such as the corallivores (predominantly butterfly fishes, Chaetodontidae) and the omnivorous pomacentrids, were unsurprisingly heavily impacted by the loss of hard coral from these reefs (Figure 21, 22). The most abundant corallivore species on Keppel reefs is *Chaetodon aureofasciatus*, which is an obligate corallivore that almost exclusively feeds on live coral tissue (Pratchett *et al.* 2006). In October 2015, mean corallivore abundance remained below 20 individuals 1000 m⁻², and there was little indication of recovery (Figure 21).

The trajectories of change in several fish functional groups were similar between reefs within NTR and fished zones (e.g. benthic carnivores and planktivorous pomacentrids), while trajectories were more variable among zones for other groups (e.g. corallivores and territorial pomacentrids) (Figures 17 – 24). Apart from the large predator group, and to a lesser degree, the intermediate predator group, most fish functional groups present in the Keppel Islands are not targeted by fishers (Williamson *et al.* 2014). Observed differences in the abundance of these fishes between NTR and fished reefs were generally closely related to the cover of live hard coral and macroalgae, and the complexity of reef habitats (Table 5). Relationships between fishes and corals, macroalgae and SCI varied between trophic groups. Live hard coral cover was significantly correlated with the density of intermediate predators, benthic carnivores, detritivores, all grazers, all corallivores, and omnivorous, planktivorous and territorial pomacentrids (Table 5). Macroalgae cover showed significant relationships with benthic carnivores, detritivores, all grazers, and omnivorous and territorial pomacentrids (Table 5). Habitat structural complexity (SCI) was a significant predictor for large and intermediate predators, and omnivorous and territorial pomacentrids (Table 5).

At the community level, sites were split among those with fewer fish or more fish overall, and further separated by a predominance of either grazers and benthic carnivores, or predators and omnivorous pomacentrids (Figure 25a; ANOSIM Global R = 0.321, $p > 0.001$). Dramatic changes in fish community structure were observed throughout the monitoring period (Figure 25b, ANOSIM Global R = 0.22, $p > 0.001$). High densities of all functional groups were recorded in 2004, while the most extreme collapse of all groups occurred during 2011 and 2013, with partial recovery recorded in 2015. The 2013 to 2015 trajectory suggested a community shift towards higher abundances of piscivores (large predators) and territorial (algal farming) pomacentrids (Figure 25b). This early stage recovery from 2013 to 2015 was predominantly driven by two fish species, the territorial damselfish *Pomacentrus wardii*, and the coral trout *Plectropomus maculatus*. There were differences between zones in the community-level temporal changes, but this accounted for a very small proportion of the

variability in the fish assemblage (ANOSIM Global $R = 0.025$, $p = 0.02$). Due primarily to their high abundances, planktivorous pomacentrids consistently accounted for the majority of the dissimilarity in fish assemblage structure between years and zones (Table 6).

4. CONCLUSION

Inshore coral reefs in the Great Barrier Reef Marine Park (GBRMP) are subject to chronic impacts from reduced water quality and sedimentation, as well as acute climatic disturbances. Monitoring the status and condition of GBRMP reefs and the environmental conditions affecting them is crucial for identifying key stressors, quantifying the effects of management actions, and assessing the viability of additional measures to enhance biodiversity conservation and resilience.

Long-term monitoring of coral and fish communities at 20 sites revealed significant declines in live hard coral cover and fish abundances on both no-take reserve (green zone) and fished reefs between 2004 and 2015. Approximately 21% of the total reef area in the Keppels was identified as highly degraded in October 2015, with less than 5% cover of live hard coral, high cover of fleshy brown algae (often > 50%), low abundances of fishes, and low fish species diversity. Conversely, approximately 13% of the reef area had retained at least 45% cover of live hard coral cover in 2015. These remaining relatively healthy reefs were identified as key refuges for live hard coral (predominantly *Acropora* sp.). Refuge reefs generally also had low cover of macroalgae and relatively high abundances of a range of small to medium-bodied reef fishes.

Throughout the monitoring period, green zone reefs consistently supported higher abundances of key fishery-targeted species such as coral trout (*Plectropomus* spp.) than reefs that are open to fishing. However, coral trout abundance declined markedly on reefs that were severely impacted by the disturbances, irrespective of whether those reefs were protected within green zones or not. Our findings further demonstrate that high frequency severe climatic disturbance events can progressively undermine many of the accrued benefits of green zones.

Protection of live coral and reef habitat structural complexity must remain a high priority in the Keppel Islands, and more broadly within the GBRMP. Keppel reefs that continue to support relatively high levels of live coral are evidently the most resilient reefs within the island group. These refuge reefs provide important local stores of coral reef biodiversity and they should contribute to the replenishment and recovery of the degraded reefs through larval supply. We recommend that additional management resources (e.g. no anchoring reef protection markers) should be allocated to key remaining refuge reefs to improve current levels of habitat protection.

Our observations of decline and recovery dynamics on Keppel reefs suggest that there is considerable capacity for recovery from the recent series of disturbances. If conditions favourable to recovery prevail, live coral cover, fish abundances and biodiversity on Keppel reefs may potentially return to 2004 'healthy state' levels within 5 – 10 years. However, given the recent disturbance history, and projections for increasing frequency of extreme climatic events as climate change progresses, it is expected that Keppel, and GBRMP reefs more generally, will be subject to escalating disturbance regimes in future years. Improved integration of targeted ecosystem monitoring with a proactive approach to management, should lead to actions that effectively protect biodiversity and enhance resilience of the GBRMP ecosystem.

Table 5: Parameter estimates for linear mixed effects models (LMEs), with a random effect of replicate transect nested within site, for all trophic groups. In all cases the intercept parameter corresponds to the predicted value of each response variable in a fished zone. All other terms represent effect sizes and colons indicate interactions. *P* values in bold are significant at the 0.05 level.

Response variable	Model	Transformation	Distribution	Effect	Estimate	SE	<i>t</i> -value	<i>P</i>
Large predators	LME	Square-root	Gaussian	Intercept	333.941	46.527	7.177	< 0.001
				Year	-0.165	0.023	-7.139	< 0.001
				Zone (NTR 1987)	98.433	71.391	1.379	0.186
				Zone (NTR 2004)	91.621	80.248	1.142	0.269
				LHC	0.001	0.003	0.222	0.825
				MAC	0.001	0.003	0.455	0.649
				SCI	0.078	0.032	2.412	0.016
				Year:Zone (NTR 1987)	-0.049	0.036	-1.369	0.171
				Year:Zone (NTR 2004)	-0.045	0.040	-1.125	0.261
Intermediate predators	LME	Log (x + 1)	Gaussian	Intercept	157.825	27.208	5.801	< 0.001
				Year	-0.077	0.014	-5.708	< 0.001
				Zone (NTR 1987)	24.053	41.698	0.577	0.572
				Zone (NTR 2004)	103.820	46.862	2.215	0.041
				LHC	0.004	0.002	2.471	0.014
				MAC	0.003	0.002	1.828	0.068
				SCI	0.078	0.019	4.130	< 0.001
				Year:Zone (NTR 1987)	-0.012	0.021	-0.574	0.567
				Year:Zone (NTR 2004)	-0.052	0.023	-2.221	0.027

Table 5 (cont.): Parameter estimates for linear mixed effects models (LMEs), with a random effect of replicate transect nested within site, for all trophic groups. In all cases the intercept parameter corresponds to the predicted value of each response variable in a fished zone. All other terms represent effect sizes and colons indicate interactions. *P* values in bold are significant at the 0.05 level.

Response variable	Model	Transformation	Distribution	Effect	Estimate	SE	<i>t</i> -value	<i>P</i>
Benthic carnivores	LME	Square-root	Gaussian	Intercept	433.240	101.061	4.287	< 0.001
				Year	-0.209	0.050	-4.154	< 0.001
				Zone (NTR 1987)	-13.344	156.024	-0.086	0.933
				Zone (NTR 2004)	124.496	175.556	0.709	0.488
				LHC	-0.028	0.006	-4.585	< 0.001
				MAC	-0.032	0.006	-5.654	< 0.001
				SCI	-0.001	0.068	-0.009	0.993
				Year:Zone (NTR 1987)	0.007	0.078	0.085	0.932
				Year:Zone (NTR 2004)	-0.062	0.087	-0.706	0.480
Grazers	LME	Log (x + 1)	Gaussian	Intercept	268.247	45.911	5.843	< 0.001
				Year	-0.132	0.023	-5.775	< 0.001
				Zone (NTR 1987)	65.371	70.805	-0.923	0.369
				Zone (NTR 2004)	86.291	79.653	1.083	0.294
				LHC	-0.013	0.003	-4.779	< 0.001
				MAC	-0.005	0.003	-2.024	0.043
				SCI	0.041	0.031	1.305	0.192
				Year:Zone (NTR 1987)	0.033	0.035	0.923	0.356
				Year:Zone (NTR 2004)	-0.043	0.040	-1.090	0.276

Table 5 (cont.): Parameter estimates for linear mixed effects models (LMEs), with a random effect of replicate transect nested within site, for all trophic groups. In all cases the intercept parameter corresponds to the predicted value of each response variable in a fished zone. All other terms represent effect sizes and colons indicate interactions. *P* values in bold are significant at the 0.05 level.

Response variable	Model	Transformation	Distribution	Effect	Estimate	SE	<i>t</i> -value	<i>P</i>
Corallivores	LME	Square-root	Gaussian	Intercept	580.633	67.538	8.597	< 0.001
				Year	-0.287	0.034	-8.537	< 0.001
				Zone (NTR 1987)	270.545	104.333	2.601	0.019
				Zone (NTR 2004)	-63.883	117.015	-0.546	0.592
				LHC	0.017	0.004	4.217	< 0.001
				MAC	0.002	0.004	0.493	0.622
				SCI	0.004	0.046	0.077	0.939
				Year:Zone (NTR 1987)	-0.135	0.052	-2.598	0.010
				Year:Zone (NTR 2004)	0.031	0.058	0.528	0.598
Omnivorous pomacentrids	LME	Square-root	Gaussian	Intercept	1820.754	206.820	8.804	< 0.001
				Year	-0.899	0.103	-8.745	< 0.001
				Zone (NTR 1987)	308.881	318.942	0.968	0.346
				Zone (NTR 2004)	883.403	358.803	2.462	0.025
				LHC	0.059	0.013	4.747	< 0.001
				MAC	0.040	0.012	3.458	0.001
				SCI	0.291	0.141	2.067	0.039
				Year:Zone (NTR 1987)	-0.153	0.159	-0.964	0.336
				Year:Zone (NTR 2004)	-0.440	0.179	-2.465	0.014

Table 5 (cont.): Parameter estimates for linear mixed effects models (LMEs), with a random effect of replicate transect nested within site, for all trophic groups. In all cases the intercept parameter corresponds to the predicted value of each response variable in a fished zone. All other terms represent effect sizes and colons indicate interactions. *P* values in bold are significant at the 0.05 level.

Response variable	Model	Transformation	Distribution	Effect	Estimate	SE	<i>t</i> -value	<i>P</i>
Planktivorous pomacentrids	LME	Log ($x + 1$)	Gaussian	Intercept	453.938	78.091	5.813	< 0.001
				Year	-0.223	0.039	-5.744	< 0.001
				Zone (NTR 1987)	-232.964	120.430	-1.934	0.070
				Zone (NTR 2004)	167.793	135.482	1.238	0.232
				LHC	0.015	0.005	3.239	0.001
				MAC	0.006	0.004	1.274	0.203
				SCI	0.085	0.053	1.600	0.110
				Year:Zone (NTR 1987)	0.116	0.060	1.938	0.053
				Year:Zone (NTR 2004)	-0.084	0.067	-1.239	0.216
Territorial pomacentrids	LME	NA	Gaussian	Intercept	779.630	5960.792	0.131	0.896
				Year	-0.280	2.963	-0.094	0.925
				Zone (NTR 1987)	-40860.230	9190.018	-4.446	< 0.001
				Zone (NTR 2004)	63880.950	10338.232	6.179	< 0.001
				LHC	-0.780	0.360	-2.155	0.032
				MAC	0.870	0.333	2.608	0.009
				SCI	8.160	4.055	2.012	0.045
				Year:Zone (NTR 1987)	20.340	4.574	4.448	< 0.001
				Year:Zone (NTR 2004)	-31.720	5.145	-6.165	< 0.001

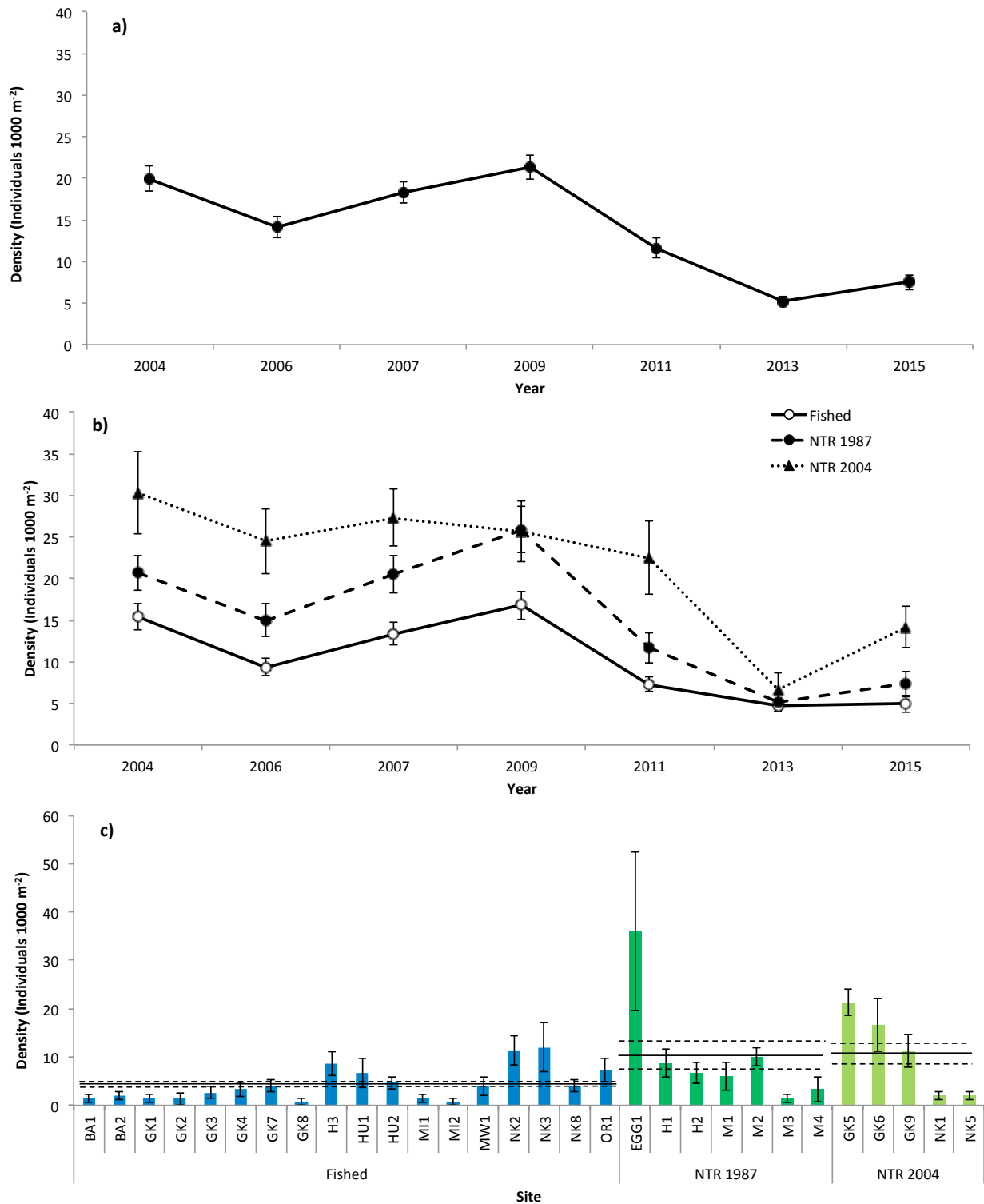


Figure 17: Mean density of large predatory fishes in the Keppel Islands. a) Temporal dynamics in large predator density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in large predator density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of large predator density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

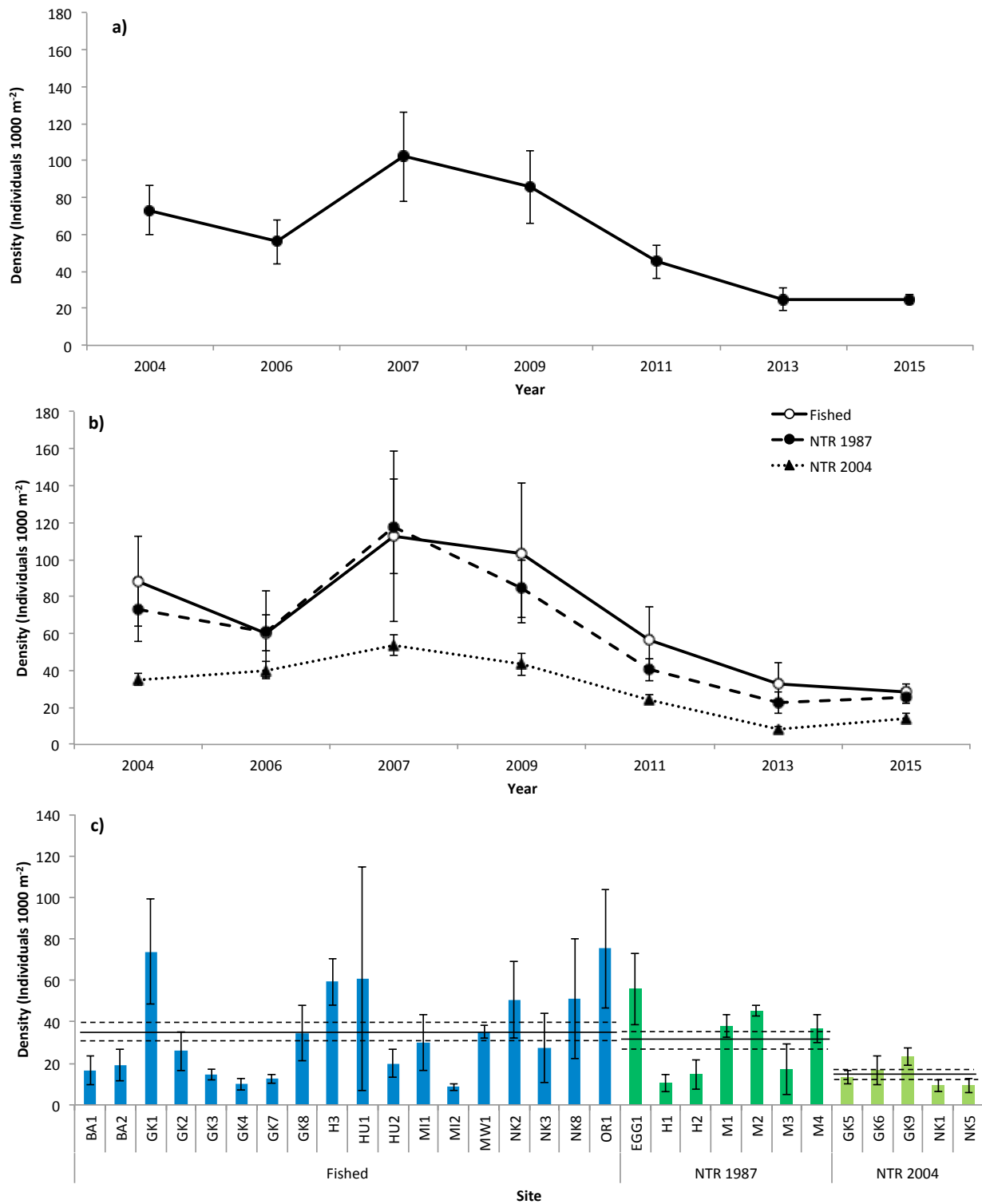


Figure 18: Mean density of intermediate predatory fishes in the Keppel Islands. a) Temporal dynamics in intermediate predatory density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in intermediate predatory density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of intermediate predatory density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value ($\pm 95\%$ CI) for sites within each zone. Error bars are ± 1 S.E.

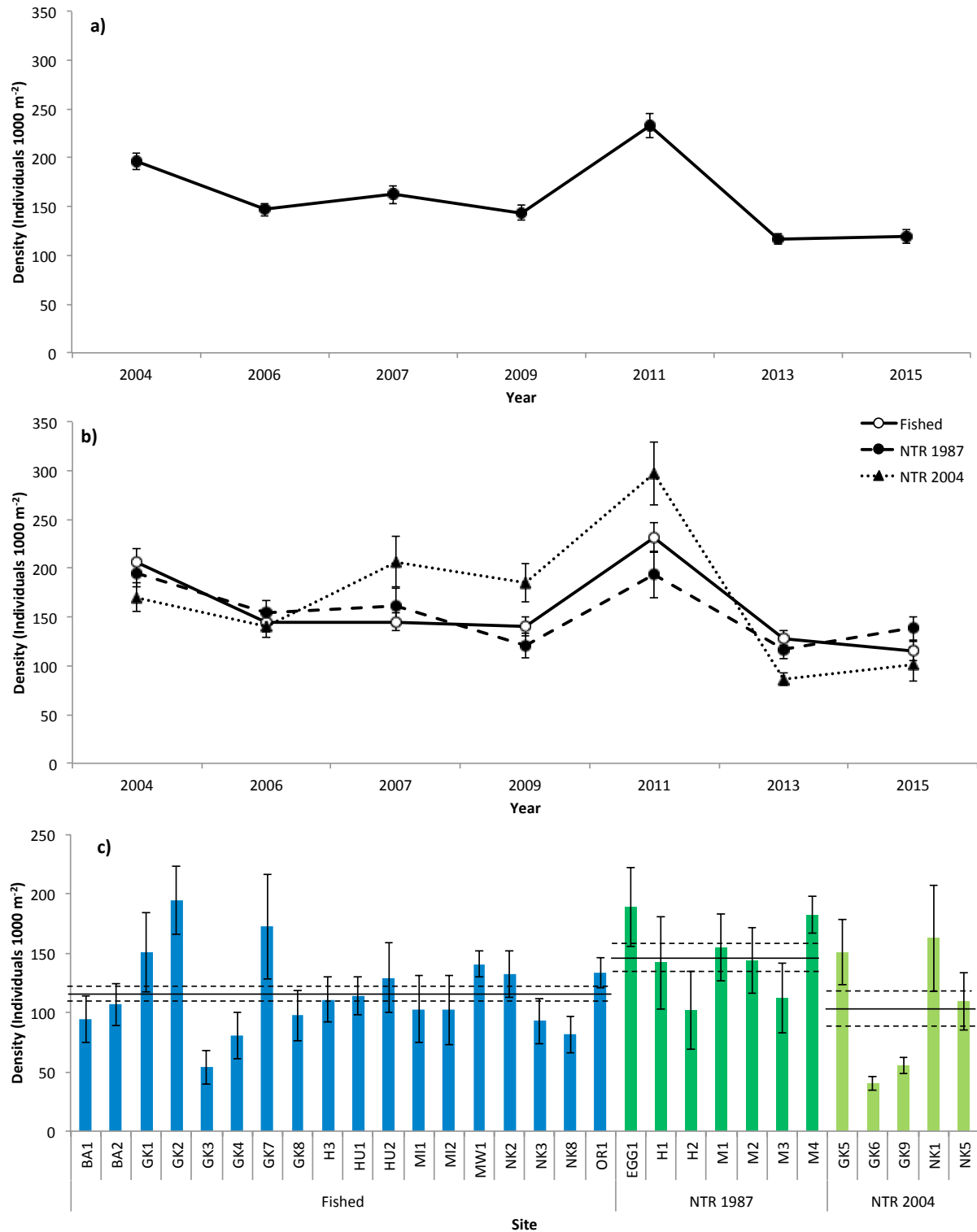


Figure 19: Mean density of benthic carnivore fishes in the Keppel Islands. a) Temporal dynamics in benthic carnivore density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in benthic carnivore density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of benthic carnivore density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

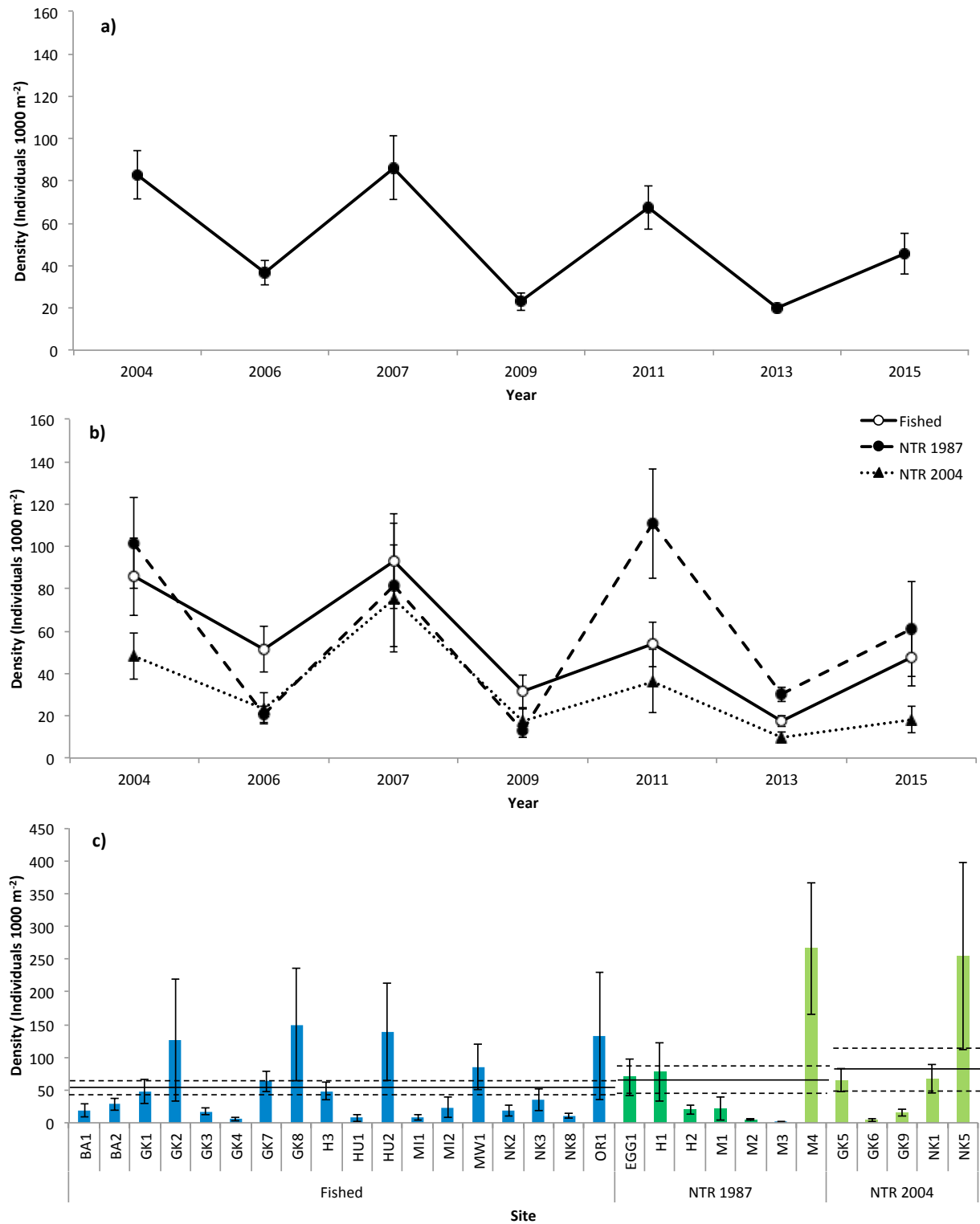


Figure 20: Mean density of grazing fishes in the Keppel Islands. a) Temporal dynamics in grazer density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in grazer density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of grazer density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value ($\pm 95\%$ CI) for sites within each zone. Error bars are ± 1 S.E.

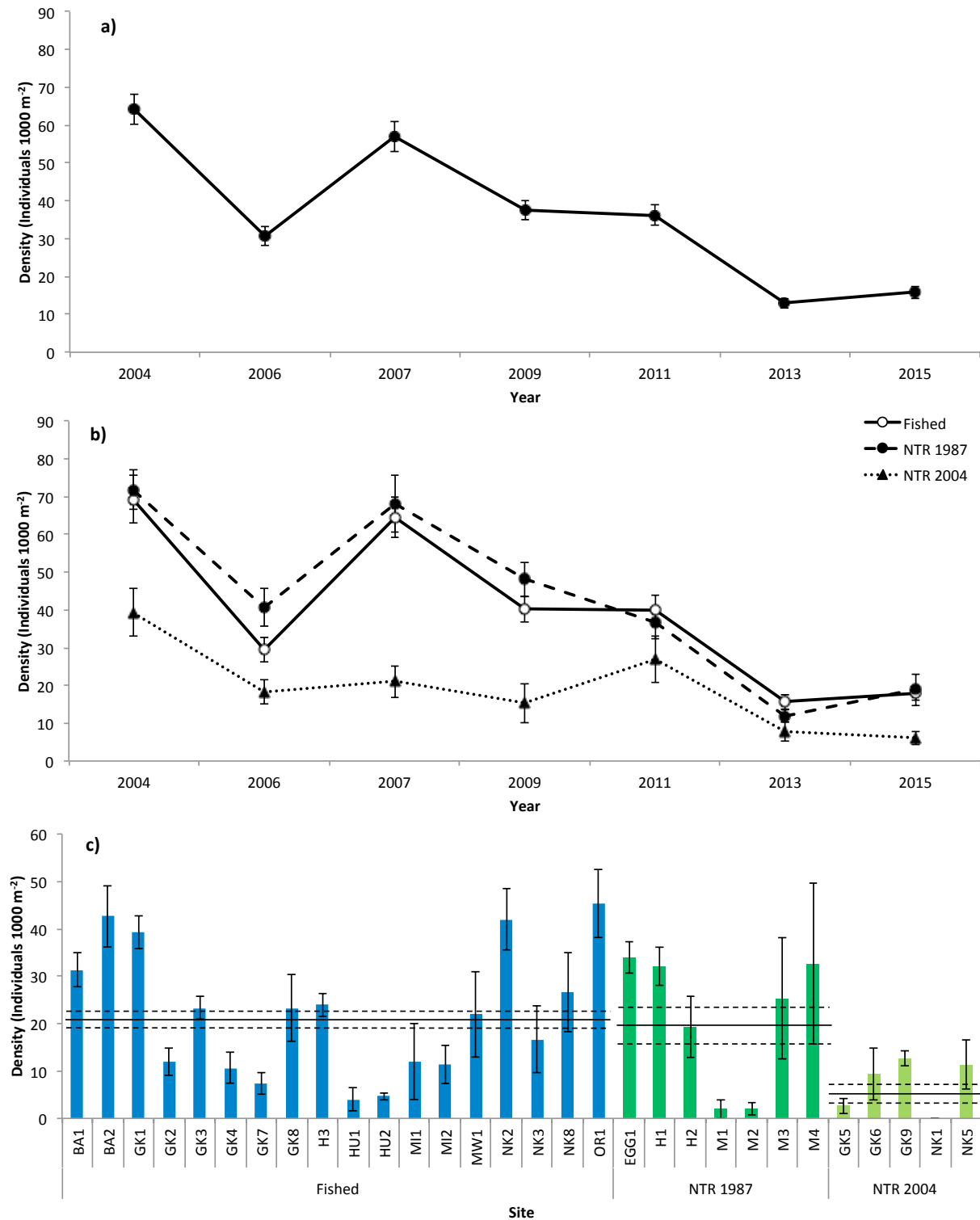


Figure 21: Mean density of coralivore fishes in the Keppel Islands. a) Temporal dynamics in coralivore density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in coralivore density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of coralivore density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

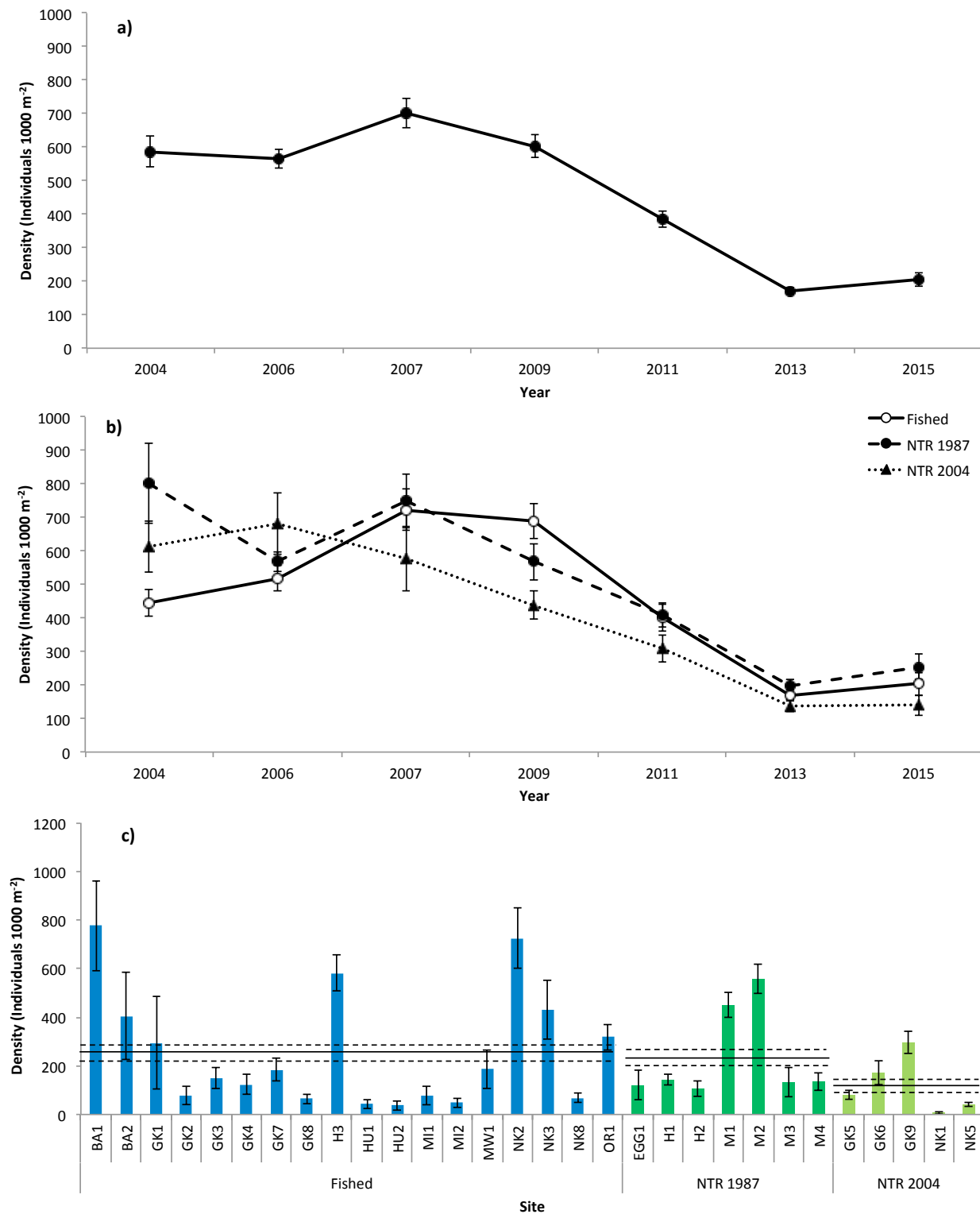


Figure 22: Mean density of omnivorous pomacentrids in the Keppel Islands. a) Temporal dynamics in omnivorous pomacentrid density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in omnivorous pomacentrid density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of omnivorous pomacentrid density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

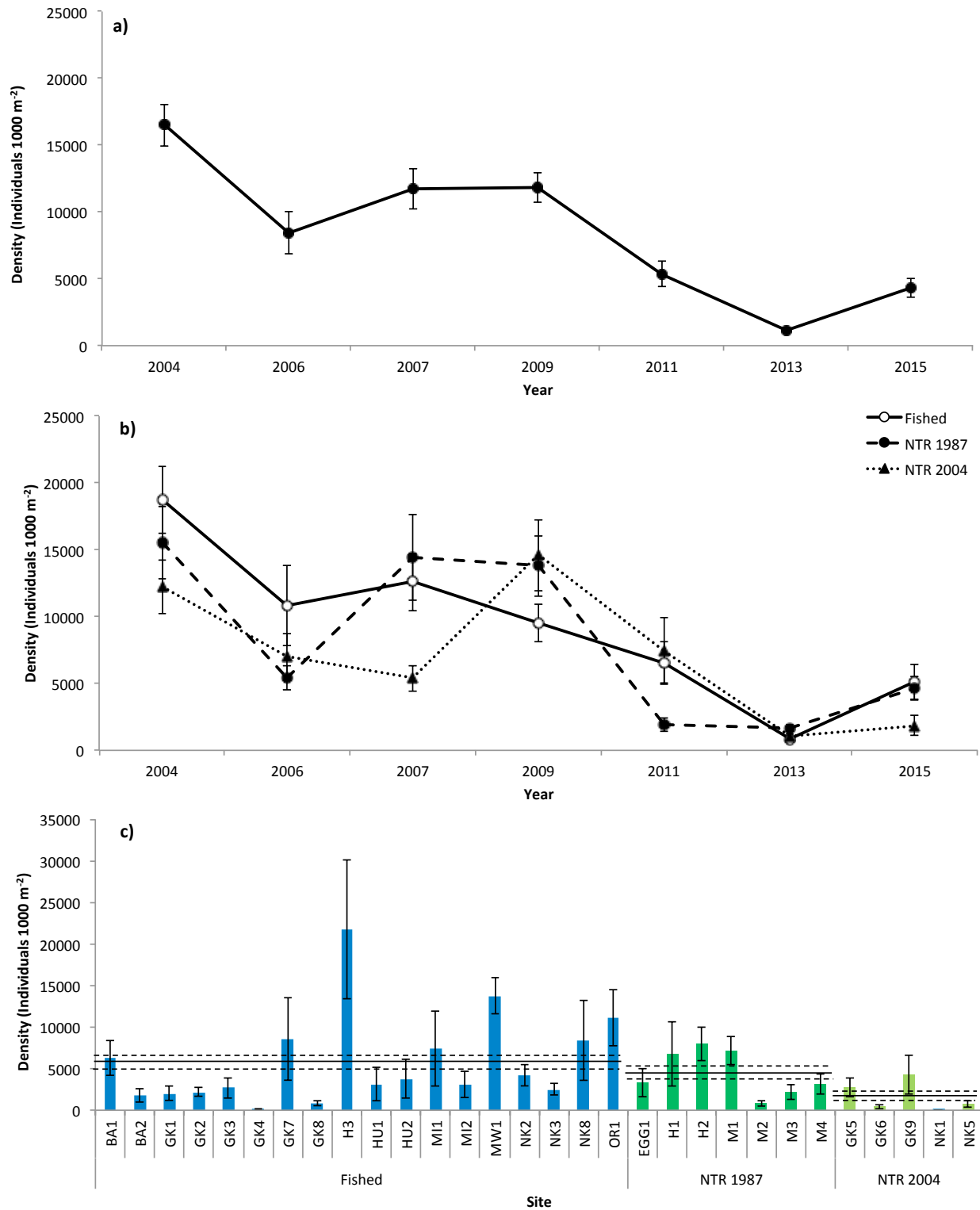


Figure 23: Mean density of planktivorous pomacentrids in the Keppel Islands. a) Temporal dynamics in planktivorous pomacentrid density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in planktivorous pomacentrid density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of planktivorous pomacentrid density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value (+/- 95% CI) for sites within each zone. Error bars are ± 1 S.E.

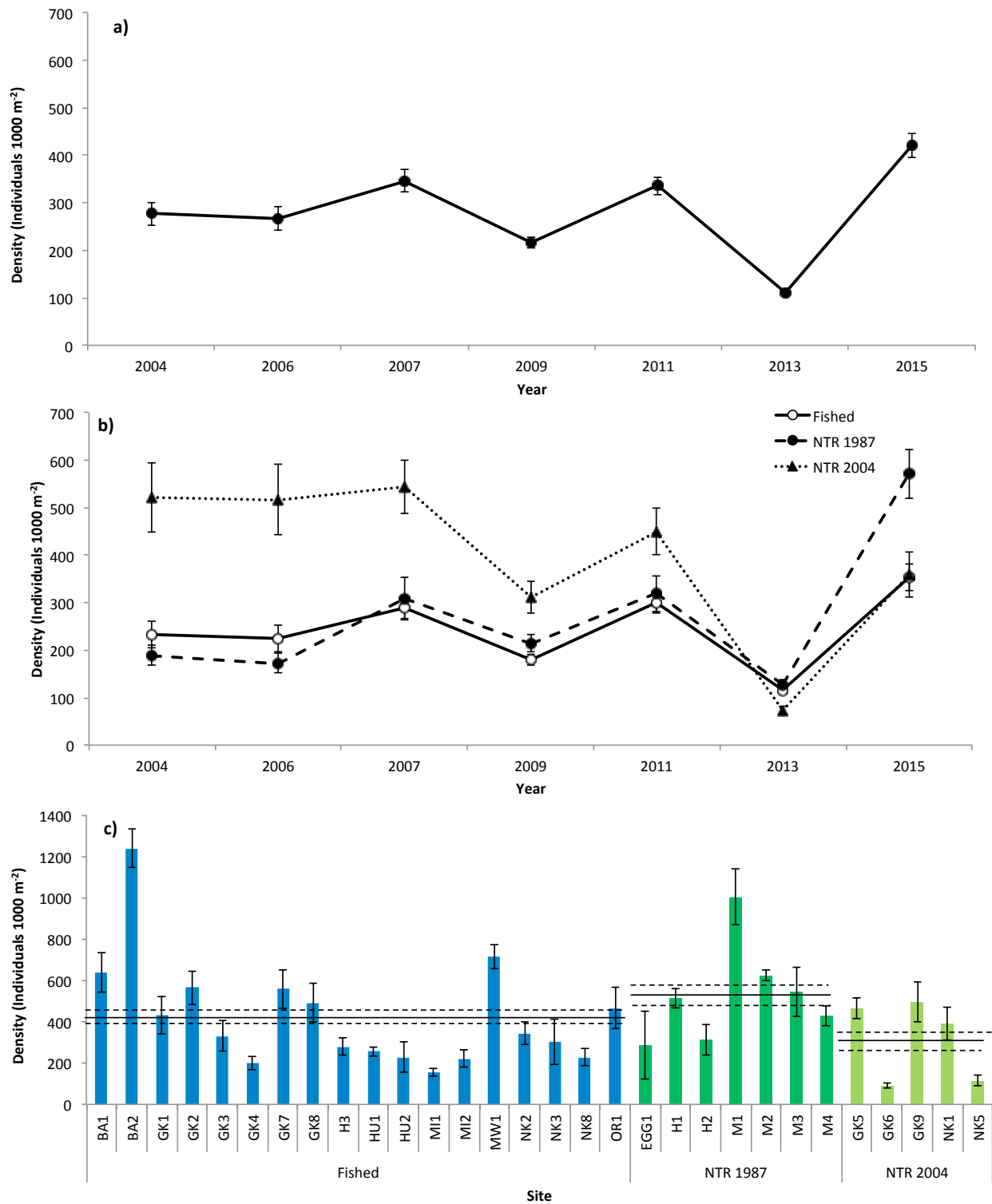


Figure 24: Mean density of territorial pomacentrids in the Keppel Islands. a) Temporal dynamics in territorial pomacentrid density from 2004 to 2015 across 20 core monitoring sites, b) Temporal dynamics in territorial pomacentrid density from 2004 to 2015 split by GBRMP zones, and c) 2015 snapshot of territorial pomacentrid density across all surveyed sites in fished zones (blue bars), NTR 1987 zones (dark green bars) and NTR 2004 zones (light green bars). The solid horizontal line represents the mean value ($\pm 95\%$ CI) for sites within each zone. Error bars are ± 1 S.E.

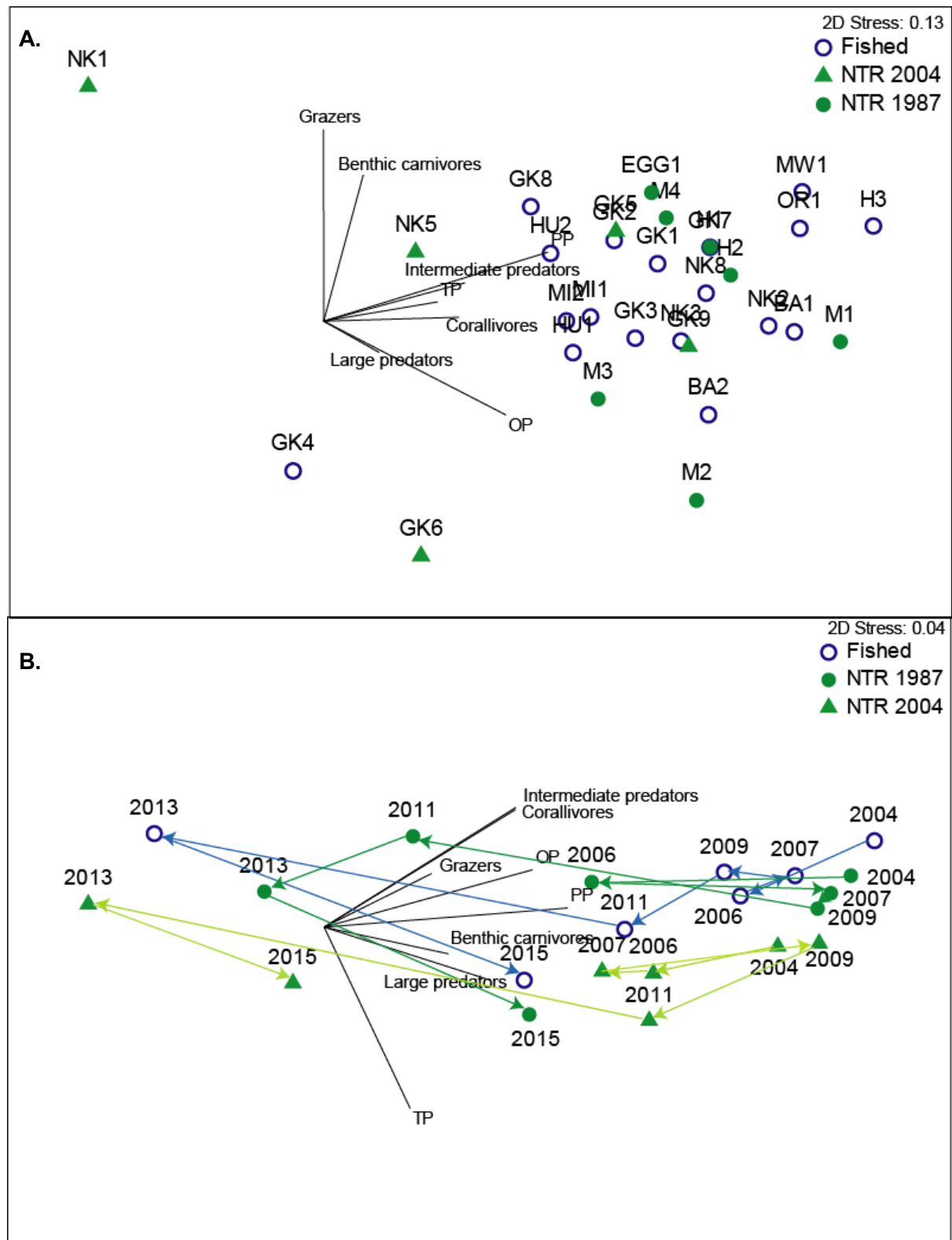


Figure 25: Multi-dimensional Scaling (MDS) plots of fish community composition **A.** Spatial variability among all surveyed sites in October 2015. **B.** Temporal trajectories of fish communities on reefs within new NTRs, old NTRs and fished zones from 2004 to 2015.

Table 6: SIMPER results of fish functional groups. The 2-way SIMPER was conducted by Zone and Year on the Site-averaged data, square-root – transformed. Only functional groups contributing at least 10% to the dissimilarity are presented here.

2004 & 2006 - Average dissimilarity = 32.97			2004 & 2007 - Average dissimilarity = 29.67		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	69.8	69.8	PP	66.81	66.81
2006 & 2007 - Average dissimilarity = 32.55			2004 & 2009 - Average dissimilarity = 30.19		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	65.68	65.68	PP	67.66	67.66
2006 & 2009 - Average dissimilarity = 32.55			2007 & 2009 - Average dissimilarity = 31.23		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	68.06	68.06	PP	66.32	66.32
2004 & 2011 - Average dissimilarity = 37.19			2006 & 2011 - Average dissimilarity = 34.59		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	69.46	69.46	PP	62.52	62.52
2007 & 2011 - Average dissimilarity = 35.50			2009 & 2011 - Average dissimilarity = 36.56		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	63.97	63.97	PP	65.68	65.68
2004 & 2013 - Average dissimilarity = 46.46			2006 & 2013 - Average dissimilarity = 38.36		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	68.52	68.52	PP	58.58	58.58
			OP	13.6	72.18
2007 & 2013 - Average dissimilarity = 43.32			2009 & 2013 - Average dissimilarity = 42.72		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	58.78	58.78	PP	64.04	64.04
OP	12.92	71.7	OP	12.97	77.01
2011 & 2013 - Average dissimilarity = 36.36			2004 & 2015 - Average dissimilarity = 42.02		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	51.16	51.16	PP	64.89	64.89
OP	11.65	62.81	OP	10.04	74.93
TP	11.19	74			
2006 & 2015 - Average dissimilarity = 38.74			2007 & 2015 - Average dissimilarity = 39.98		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	58.3	58.3	PP	58.92	58.92
OP	13.47	71.77	OP	13.64	72.56
2009 & 2015 - Average dissimilarity = 40.46			2011 & 2015 - Average dissimilarity = 37.96		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	61.36	61.36	PP	56.48	56.48
OP	13.4	74.76	OP	11.76	68.24
2013 & 2015 - Average dissimilarity = 37.23			Fished & NTR 1987 - Average dissimilarity = 30.66		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	52.37	52.37	PP	62.13	62.13
TP	14.5	66.87			
OP	10.69	77.56			
Fished & NTR 2004 - Average dissimilarity = 32.89			NTR 1987 & NTR 2004 - Average dissimilarity = 31.15		
Species	<i>Contrib.</i>	Cum.%	Species	<i>Contrib.</i>	Cum.%
PP	59.23	59.23	PP	58.75	58.75
OP	10.11	69.34			

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APPENDIX 1 – FISH SPECIES CLASSIFICATION

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
Acanthuridae	<i>Acanthurus albipectoralis</i>	Planktivore	Planktivore	Non-target
	<i>Acanthurus auranticavus</i>	Detritivore	Detritivore	Non-target
	<i>Acanthurus blochii</i>	Grazer	Detritivore	Non-target
	<i>Acanthurus dussumieri</i>	Grazer	Detritivore	Non-target
	<i>Acanthurus grammoptilus</i>	Grazer	Detritivore	Non-target
	<i>Acanthurus lineatus</i>	Grazer	Algal cropper	Non-target
	<i>Acanthurus mata</i>	Planktivore	Planktivore	Non-target
	<i>Acanthurus nigricans</i>	Grazer	Algal cropper	Non-target
	<i>Acanthurus nigricauda</i>	Grazer	Detritivore	Non-target
	<i>Acanthurus nigrofuscus</i>	Grazer	Algal cropper	Non-target
	<i>Acanthurus nigroris</i>	Grazer	Detritivore	Non-target
	<i>Acanthurus olivaceus</i>	Grazer	Detritivore	Non-target
	<i>Acanthurus pyroferus</i>	Grazer	Algal cropper	Non-target
	<i>Acanthurus thompsoni</i>	Planktivore	Planktivore	Non-target
	<i>Acanthurus triostegus</i>	Grazer	Algal cropper	Non-target
	<i>Acanthurus xanthopterus</i>	Grazer	Detritivore	Non-target
	<i>Ctenochaetus binotatus</i>	Grazer	Detritivore	Non-target
	<i>Ctenochaetus striatus</i>	Grazer	Detritivore	Non-target
	<i>Naso annulatus</i>	Grazer	Algal cropper	Non-target
	<i>Naso brevirostris</i>	Planktivore	Planktivore	Non-target
	<i>Naso lituratus</i>	Grazer	Algal cropper	Non-target
	<i>Naso tonganus</i>	Grazer	Algal cropper	Non-target
	<i>Naso unicornis</i>	Grazer	Algal cropper	Non-target
	<i>Naso vlamingii</i>	Planktivore	Planktivore	Non-target
	<i>Paracanthurus hepatus</i>	Planktivore	Planktivore	Non-target
	<i>Prionurus microlepidotus</i>	Grazer	Algal cropper	Non-target

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
Chaetodontidae	<i>Zebrasoma scopas</i>	Grazer	Algal cropper	Non-target
	<i>Zebrasoma veliferum</i>	Grazer	Algal cropper	Non-target
	<i>Chaetodon aureofasciatus</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon auriga</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon baronessa</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon bennetti</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon citrinellus</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon ephippium</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon flavirostris</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon kleinii</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon lineolatus</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon lunula</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon lunulatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Chaetodon melannotus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Chaetodon mertensii</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Chaetodon meyeri</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon ornatissimus</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon pelewensis</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon plebeius</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon punctatofasciatus</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon rafflesi</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon rainfordi</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon reticulatus</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon speculum</i>	Corallivore	Facultative corallivore	Non-target
	<i>Chaetodon trifascialis</i>	Corallivore	Obligate corallivore	Non-target
	<i>Chaetodon ulietensis</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Chaetodon unimaculatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Chaetodon vagabundus</i>	Corallivore	Facultative corallivore	Non-target

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
	<i>Chelmon rostratus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Coradion altivelis</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Coradion chrysostomus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Forcipiger flavissimus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Forcipiger longirostris</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Hemitaenichthys polylepis</i>	Planktivore	Planktivore	Non-target
	<i>Heniochus acuminatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Heniochus monoceros</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Heniochus varius</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Parachaetodon ocellatus</i>	Benthic carnivore	Benthic carnivore	Non-target
Ehippidae	<i>Platax orbicularis</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Platax teira</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Platax pinnatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Platax teira</i>	Benthic carnivore	Benthic carnivore	Non-target
Haemulidae	<i>Diagramma pictum</i>	Predator	Large predator	Secondary target
	<i>Plectorhinchus chaetodontoides</i>	Predator	Large predator	Secondary target
	<i>Plectorhinchus flavomaculatus</i>	Predator	Large predator	Secondary target
	<i>Plectorhinchus gibbosus</i>	Predator	Large predator	Secondary target
	<i>Plectorhinchus lessonii</i>	Predator	Large predator	Secondary target
	<i>Plectorhinchus unicolor</i>	Predator	Large predator	Secondary target
Kyphosidae	<i>Kyphosus spp.</i>	Grazer	Algal cropper	Non-target
	<i>Microcanthus strigatus</i>	Benthic carnivore	Benthic carnivore	Non-target
Labridae	<i>Anampses geographicus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Anampses neoguinaicus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Bodianus axillaris</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Bodianus loxozonus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Bodianus mesothorax</i>	Benthic carnivore	Benthic carnivore	Prey

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
	<i>Cheilinus chlorurus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Cheilinus fasciatus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Cheilinus trilobatus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Cheilinus undulatus</i>	Benthic carnivore	Benthic carnivore	Protected
	<i>Choerodon anchorago</i>	Benthic carnivore	Benthic carnivore	Secondary target
	<i>Choerodon cyanodus</i>	Benthic carnivore	Benthic carnivore	Secondary target
	<i>Choerodon fasciatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Choerodon graphicus</i>	Benthic carnivore	Benthic carnivore	Secondary target
	<i>Choerodon monostigma</i>	Benthic carnivore	Benthic carnivore	Secondary target
	<i>Choerodon schoenleinii</i>	Benthic carnivore	Benthic carnivore	Secondary target
	<i>Choerodon vitta</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Coris gaimard</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Epibulus insidiator</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Gomphosus varius</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Halichoeres hortulanus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Halichoeres melanurus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Hemigymnus fasciatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Hemigymnus melapterus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Labrichthys unilineatus</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Labroides bicolor</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Labroides dimidiatus</i>			Prey
	<i>Labropsis australis</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Oxycheilinus diagramma</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Psuedolabrus guentheri</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Stethojulis bandanensis</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Stethojulis strigiventer</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Thalassoma hardwicke</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Thalassoma janssenii</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Thalassoma lunare</i>	Benthic carnivore	Benthic carnivore	Prey

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
Lethrinidae	<i>Thalassoma lutescens</i>	Benthic carnivore	Benthic carnivore	Prey
	<i>Gnathodentex aureolineatus</i>	Predator	Intermediate predator	Non-target
	<i>Gymnocranius spp.</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus atkinsoni</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus erythracanthus</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus harak</i>	Benthic carnivore	Benthic carnivore	Secondary target
	<i>Lethrinus laticaudis</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus lentjan</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus miniatus</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus nebulosus</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus obsoletus</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus olivaceus</i>	Predator	Large predator	Secondary target
	<i>Lethrinus ornatus</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus rubrioperculatus</i>	Predator	Intermediate predator	Secondary target
	<i>Lethrinus xanthochilus</i>	Predator	Intermediate predator	Secondary target
	<i>Monotaxis grandoculis</i>	Predator	Intermediate predator	Secondary target
Lutjanidae	<i>Lutjanus adetii</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus argentimaculatus</i>	Predator	Large predator	Primary target
	<i>Lutjanus biguttatus</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus bohar</i>	Predator	Large predator	Protected
	<i>Lutjanus carponotatus</i>	Predator	Intermediate predator	Primary target
	<i>Lutjanus fulviflamma</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus fulvus</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus gibbus</i>	Predator	Intermediate predator	Protected
	<i>Lutjanus kasmira</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus lemniscatus</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus lutjanus</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus monostigma</i>	Predator	Large predator	Secondary target

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
	<i>Lutjanus quinquelineatus</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus rivulatus</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus russelli</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus sebae</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus semicinctus</i>	Predator	Intermediate predator	Secondary target
	<i>Lutjanus vitta</i>	Predator	Intermediate predator	Secondary target
	<i>Symphorus nematophorus</i>	Predator	Large predator	Protected
Mullidae	<i>Parupeneus barberinus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Parupeneus bifasciatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Parupeneus ciliatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Parupeneus indicus</i>	Benthic carnivore	Benthic carnivore	Non-target
Muraenidae	<i>Echidna nebulosa</i>	Predator	Intermediate predator	Non-target
	<i>Gymnothorax favagineus</i>	Predator	Intermediate predator	Non-target
	<i>Gymnothorax javanicus</i>	Predator	Intermediate predator	Non-target
	<i>Gymnothorax meleagris</i>	Predator	Intermediate predator	Non-target
	<i>Gymnothorax undulatus</i>	Predator	Intermediate predator	Non-target
	<i>Gymnothorax javanicus</i>	Predator	Intermediate predator	Non-target
	<i>Gymnothorax meleagris</i>	Predator	Intermediate predator	Non-target
Nemipteridae	<i>Scolopsis bilineatus</i>	Predator	Intermediate predator	Non-target
	<i>Scolopsis margaritifer</i>	Predator	Intermediate predator	Non-target
	<i>Scolopsis monogramma</i>	Predator	Intermediate predator	Non-target
Pomacanthidae	<i>Centropyge bicolor</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Centropyge bispinosus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Centropyge nox</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Centropyge tibicen</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Centropyge vrolikii</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Chaetodontoplus douboulayi</i>	Benthic carnivore	Benthic carnivore	Non-target

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Pomacentridae	<i>Chaetodontoplus meredithi</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Pomacanthus imperator</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Pomacanthus semicirculatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Pomacanthus sexstriatus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Pomacanthus xanthometapon</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Pygoplites diacanthus</i>	Benthic carnivore	Benthic carnivore	Non-target
	<i>Abudefduf bengalensis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Abudefduf sexfasciatus</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Abudefduf vaigiensis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Abudefduf whitleyi</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Abudefduf sexfasciatus</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Abudefduf vaigiensis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Abudefduf whitleyi</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Acanthochromis polyacanthus</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amblyglyphidodon aureus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Amblyglyphidodon curacao</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amblyglyphidodon leucogaster</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amphiprion akindynos</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amphiprion chrysopterus</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amphiprion clarkii</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amphiprion melanopus</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amphiprion percula</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Amphiprion perideraion</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Cheiloprion labiatus</i>	Corallivore	Facultative corallivore	Prey
	<i>Chromis acares</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis agilis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis amboinensis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis atripectoralis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
	<i>Chromis atripes</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis chrysur</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis iomelas</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis lepidolepis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis lineata</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis margaritifer</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis nitida</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis retrofasciatus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis ternatensis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis vanderbiltil</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis viridis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis weberi</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chromis xanthura</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chrysiptera biocellata</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Chrysiptera flavipinnis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chrysiptera rex</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Chrysiptera rollandi</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Chrysiptera talboti</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Dascyllus aruanus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Dascyllus melanurus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Dascyllus trimaculatus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Dascyllus reticulatus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Dischistodus melanotus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Dischistodus perspicillatus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Dischistodus prosopotaenia</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Dischistodus pseudochrysopoecilus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Hemiglyphidodon plagiometapon</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Neoglyphidodon melas</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Neoglyphidodon nigroris</i>	Territorial pomacentrid	Territorial pomacentrid	Prey

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
	<i>Neoglyphidodon polyacanthus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Neopomacentrus asyzron</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Neopomacentrus bankieri</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Neopomacentrus cyanomos</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Plectroglyphidodon dickii</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Plectroglyphidodon johnstonianus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Plectroglyphidodon lacrymatus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomacentrus adelus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomacentrus amboinensis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Pomacentrus australis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Pomacentrus bankanensis</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomacentrus brachialis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Pomacentrus chrysurus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomacentrus coelestis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Pomacentrus grammorhynchus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomacentrus lepidogenis</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Pomacentrus moluccensis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Pomacentrus nagasakiensis</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Pomacentrus pavo</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Pomacentrus philippinus</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Pomacentrus tripunctatus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomacentrus vaiuli</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomacentrus wardi</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Pomachromis richardsoni</i>	Planktivorous pomacentrid	Planktivorous pomacentrid	Prey
	<i>Premnas biaculeatus</i>	Omnivorous pomacentrid	Omnivorous pomacentrid	Prey
	<i>Stegastes apicalis</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Stegastes fasciolatus</i>	Territorial pomacentrid	Territorial pomacentrid	Prey
	<i>Stegastes nigricans</i>	Territorial pomacentrid	Territorial pomacentrid	Prey

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
Scaridae	<i>Bolbometapon muricatum</i>	Grazer	Excavating scarid	Non-target
	<i>Calotomus carolinus</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Cetoscarus bicolor</i>	Grazer	Excavating scarid	Prey (juveniles)
	<i>Chlorurus bleekeri</i>	Grazer	Excavating scarid	Prey (juveniles)
	<i>Chlorurus japanensis</i>	Grazer	Excavating scarid	Prey (juveniles)
	<i>Chlorurus microrhinus</i>	Grazer	Excavating scarid	Prey (juveniles)
	<i>Chlorurus sordidus</i>	Grazer	Excavating scarid	Prey (juveniles)
	<i>Hipposcarus longiceps</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus altipinnis</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus chamaeleon</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus dimidiatus</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus flavipectoralis</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus forsteri</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus frenatus</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus ghobban</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus globiceps</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus niger</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus oviceps</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus psittacus</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus rivulatus</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus rubroviolaceus</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus schlegeli</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus spinus</i>	Grazer	Scraping scarid	Prey (juveniles)
	<i>Scarus tricolor</i>	Grazer	Scraping scarid	Prey (juveniles)
Serranidae	<i>Aethaloperca rogga</i>	Predator	Intermediate predator	Secondary target
	<i>Anyperodon leucogrammicus</i>	Predator	Large predator	Secondary target
	<i>Cephalopholis boenak</i>	Predator	Intermediate predator	Non-target
	<i>Cephalopholis cyanostigma</i>	Predator	Intermediate predator	Secondary target

Family	Species	Functional Group	Functional group detail	Fishery / Prey Status
	<i>Cephalopholis microprion</i>	Predator	Intermediate predator	Non-target
	<i>Cromileptes altivelis</i>	Predator	Large predator	Protected
	<i>Diploprion bifasciatus</i>	Predator	Intermediate predator	Non-target
	<i>Epinephelus caerulopunctatus</i>	Predator	Large predator	Secondary target
	<i>Epinephelus fasciatus</i>	Predator	Intermediate predator	Secondary target
	<i>Epinephelus fuscoguttatus</i>	Predator	Large predator	Secondary target
	<i>Epinephelus lanceolatus</i>	Predator	Large predator	Protected
	<i>Epinephelus merra</i>	Predator	Intermediate predator	Secondary target
	<i>Epinephelus ongus</i>	Predator	Intermediate predator	Secondary target
	<i>Epinephelus quoyanus</i>	Predator	Intermediate predator	Secondary target
	<i>Plectropomus areolatus</i>	Predator	Large predator	Primary target
	<i>Plectropomus laevis</i>	Predator	Large predator	Primary target
	<i>Plectropomus leopardus</i>	Predator	Large predator	Primary target
	<i>Plectropomus maculatus</i>	Predator	Large predator	Primary target
	<i>Variola albimarginata</i>	Predator	Large predator	Secondary target
	<i>Variola louti</i>	Predator	Large predator	Secondary target
Siganidae	<i>Siganus argenteus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus corallinus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus doliatus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus fuscescens</i>	Grazer	Algal cropper	Non-target
	<i>Siganus javus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus lineatus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus puellus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus punctatissimus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus punctatus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus spinus</i>	Grazer	Algal cropper	Non-target
	<i>Siganus vulpinus</i>	Grazer	Algal cropper	Non-target
Zanclidae	<i>Zanclus cornutus</i>	Benthic carnivore	Benthic carnivore	Non-target

