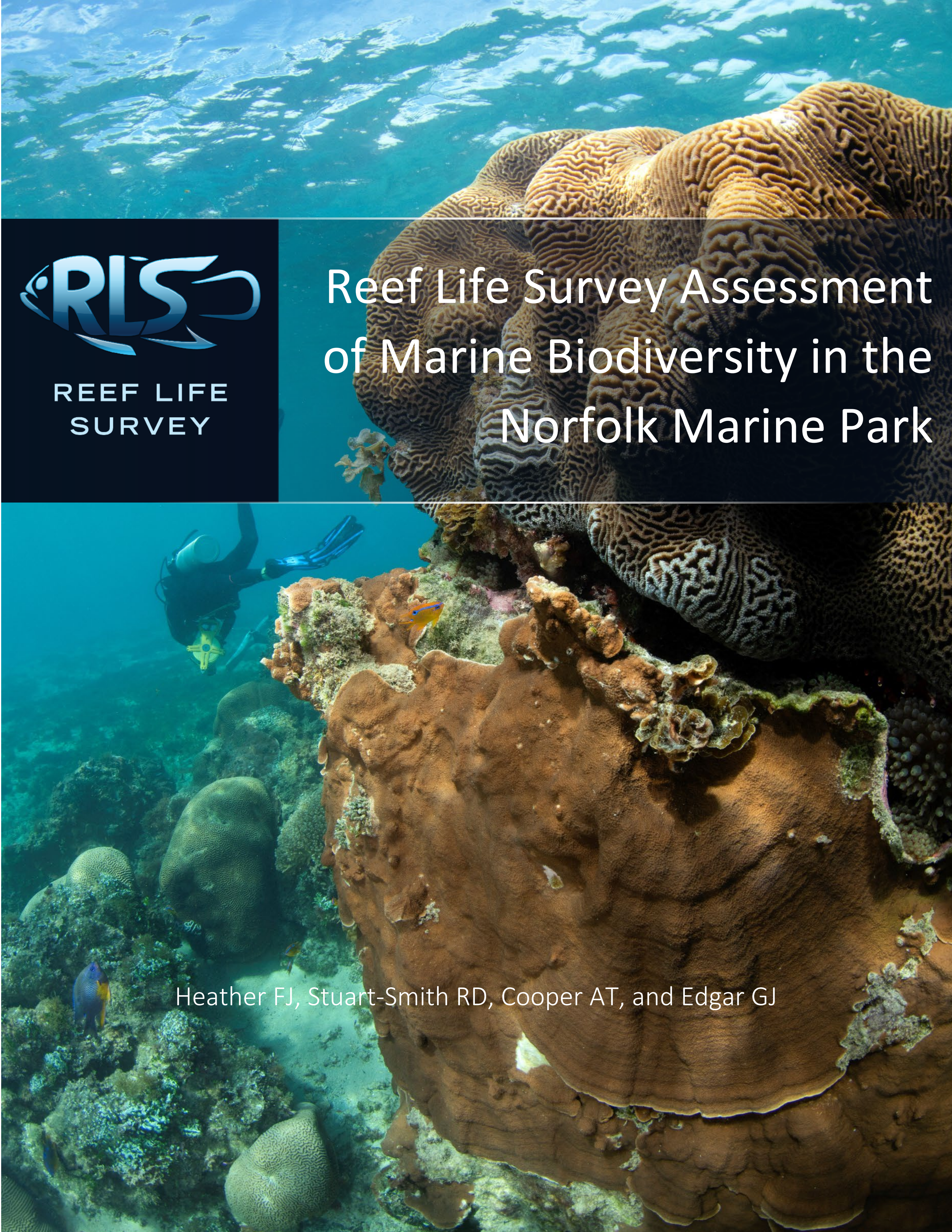

REEF LIFE SURVEY

Reef Life Survey Assessment of Marine Biodiversity in the Norfolk Marine Park

Heather FJ, Stuart-Smith RD, Cooper AT, and Edgar GJ

Citation

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Images

Antonia Cooper

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List of Acronyms

ACRONYM	DESCRIPTION
AMP	Australian Marine Park
IUCN	International Union for Conservation of Nature
RLS	Reef Life Survey
B20	Biomass of fish greater than or equal to 20 cm in total length
CTI	Community Temperature Index
CCA	Crustose Coralline Algae
EPBC	Environment Protection and Biodiversity Conservation
NMP	Norfolk Marine Park
SIMS	Sydney Institute of Marine Science

Glossary

TERM	DESCRIPTION
B20	Biomass estimates are summed for all fish recorded on transects that are 20 cm or larger. B20 is designed to track changes in reef fish stocks of greatest importance to recreational, commercial and subsistence fisheries. The basis is that increasing exploitation typically removes larger fishes first, causing the indicator to decline. See https://reeflifesurvey.com/indicators/
COMMUNITY TEMPERATURE INDEX (CTI)	The mean thermal affinity of fish recorded on transects. The thermal affinity value for each species is calculated from the range of the sea surface temperatures across all sites the species has been observed in RLS surveys. See https://reeflifesurvey.com/indicators/ and references provided, including (Stuart-Smith et al., 2015).
CRYPTIC FISHES	Fishes within a pre-defined list of taxonomic families that are inconspicuous and closely associated with the seabed (and thus disproportionately overlooked during general Method 1 fish surveys). The global list of families defined as cryptic for the purpose of RLS surveys can be found in the online methods manual (www.reeflifesurvey.com/methods).

Executive Summary

Surveys of shallow reef biodiversity were undertaken in the Norfolk Marine Park (NMP) in 2009, 2013 and 2021 by a team of skilled divers participating in the Reef Life Survey program (www.reeflifesurvey.com) and from the University of Tasmania. A total of 74 transects were surveyed for reef fishes, mobile invertebrates and benthic cover at 16 sites in 2009 (n = 31 transects), 2013 (n = 11), and 2021 (n = 32).

Relatively little change was observed in most elements of reef biodiversity, although large variation in measures of reef fish biomass and benthic cover within sites reduced the ability of the surveys to quantify subtle regional changes. Qualitative declines in fish biomass at Phillip Island sites, and increases along the southern exposed coast, from 2009 to 2021 were not statistically significant. Doubleheader (*Coris bulbifrons*) and black cod (*Epinephelus daemelii*) became less frequently observed. Fewer mobile invertebrate and cryptic fish species were observed per transect in 2021 than in earlier surveys, and differences in invertebrate and cryptic fish community structure between localities around the island were reduced (i.e. making communities more similar across sites around the island). Benthic cover changed little through time in most locations around the island, but a shift from turfs to macroalgae and a slight increase in coral cover were observed at the lagoon sites. Ongoing surveys through the long-term are needed to determine if these trends continue and require targeted management intervention.

Recommendations

Under the NMP management plan enacted on 1 July 2018, all shallow reefs are now included within a Special Purpose Zone that allows traditional fishing practices to continue largely unchanged, but provides opportunities to regulate marine dumping, structures and works. Given the short time frame and limited opportunities for zoning-related responses in biodiversity to accrue, no substantial change in reef fish or invertebrate communities were expected to be observed in the present investigation. Nevertheless, reef systems in the NMP are subject to multiple environmental stressors with potential to reduce biodiversity values. An ongoing ecological monitoring program is needed to understand the distribution and magnitude of impacts from human stressors, and to identify appropriate management actions to reduce such impacts. To this end, we make the following recommendations:

- Survey effort should be increased for future monitoring of NMP shallow reefs, either through the establishment and survey of more sites or increased temporal frequency of surveys. The inherent site-to-site variability in the local fauna (e.g. the patchiness in the abundance of species which form large schools in the water column), but apparent stability through time, mean that the detection of nuanced biodiversity change will require more data than presently available.
- Given some possibly worrying signs of ecosystem health in the lagoon (e.g. low fish biomass and high cover of fleshy macroalgae observed in this study, plus observations of coral disease and bleaching from other studies), particular consideration should be given to targeted research on the drivers of ecological change in the lagoon.
- RLS transect surveys should be extended with additional methods that directly target mobile pelagic sharks and deeper water reef species (i.e. reef components not well covered by current methods), which could be experiencing declines from local fishing pressure that may otherwise go undetected.

Introduction

The Norfolk Marine Park (NMP) is one of eight Australian Marine Parks (AMPs) that make up the Temperate East Marine Park Network. It is located approximately 1600 km northeast of Sydney (New South Wales) and extends for ~700 km distance and across an area of ~188,000 km^2. Depths range from 5000 m to high water mark. NMP is currently the only Australian Marine Park directly adjacent to a human settlement and accessible to residents from shore. A Special Purpose Zone (IUCN VI) surrounds Norfolk Island, as part of the broader multi-zoned marine park.

The oceanography and ecology of the region are both strongly influenced by the East Australian Current, which flows southwards from the Coral Sea to east of Tasmania, and the South Equatorial Current (SEC), which carries tropical Pacific waters towards the Coral and Tasman Seas. The Tasman Front and offshore Tasmantid, Lord Howe and Norfolk Ridge seamount chains are recognised as key ecological features of this Australian Marine Park. Seamounts, in particular, have attracted scientific research for their volcanic, geological, biological, ecological and biogeographic attributes (Clark et al., 2012). Emergent reefs and shallow shoals have formed at the tops of these seamounts, and sustain a rich biodiversity including pelagic fauna.

The shallow reefs of the Norfolk Marine Park have developed on the southern margin of coral reef formation, supporting a mix of tropical, temperate and endemic flora and fauna. Reef communities are further structured by gradients in wave exposure around the coastline of Norfolk Island and nearby islands and emergent rocks. Large prevailing swells, winds from multiple directions, and few enclosed bays, allow moderate to strongly wave exposed reef habitats to predominate, with only a small lagoon in the south supporting a sheltered shallow coral reef habitat. The isolation of NMP reefs from other reefs has also contributed to the presence of regional endemic species, and a high abundance in some species that are rare or unusual elsewhere (de Forges et al., 2000).

Previous research on biodiversity in the coastal waters around Norfolk Island has mostly focussed on a few charismatic or important species, although this has expanded this century to include discovery of the biodiversity of the deeper shelf reefs in the Norfolk Marine Park (Williams et al., 2006). For example, extensive high-resolution sea-floor mapping and Baited Underwater Video Stations (BRUVS) have been used by scientists at Deakin University to identify important deep-water hotspots for marine biodiversity, including habitats supporting deep water corals, sponges, and diverse communities of fish and other marine species (Parks Australia, 2021).

Few systematic surveys, and no long-term monitoring of biodiversity, has occurred for the shallow water reef habitats around Norfolk Island, although a number of biodiversity discovery and inventory studies have been undertaken (Francis, 1991, Francis and Randall, 1993, Francis, 1993, Veron, 1986). Reef Life Survey biodiversity assessments of shallow reefs were undertaken in 2009 and 2021, with a limited subset of sites resurveyed in 2013. The Sydney Institute of Marine Science (SIMS) also surveyed coral health in the lagoon in 2020 (Ainsworth et al., 2021). The SIMS study described impacts of a coral bleaching event in 2020, but previous bleaching events also likely occurred in 2005, 2011 and 2017 (based on satellite derived data; Ainsworth et al., 2021), with impacts on biodiversity largely unknown and unquantified.

Since commencement of the Temperate East Marine Parks Network Management Plan in 2018, the need to document such changes has become even more important to better understand biodiversity responses to local impacts and the consequences of particular management actions (e.g., marine park zoning, local education and awareness activities), against a background of broader environmental stressors including climate change. Building on previous work describing patterns in biodiversity values, this report outlines the results of an assessment of change in reef biodiversity on shallow reefs in the Norfolk Marine Park from 2009 to 2021, based on the reef surveys conducted by the Reef Life Survey program.

Methods

Reef Life Survey (RLS) and University of Tasmania divers surveyed a total of 74 transects across 16 sites within the Norfolk Marine Park during visits to Norfolk Island in 2009 (n = 31), 2013 (n = 11) and 2021 (n = 32) (Figure 1). The 16 sites were grouped into four broad geographical regions based on faunal community structure (i.e. different compositions and abundance of reef fish and invertebrate species): north-west (n = 5 sites); south (n = 4 sites); lagoon (n = 4 sites), and; Phillip Island (n = 3 sites) (Figure 1). All surveys were conducted following the standardized underwater visual census methods applied globally in the RLS program.

RLS includes recreational divers trained to a scientific level of data-gathering to make it possible to conduct ecological surveys across broad geographic areas in a cost-effective manner. RLS divers partner with management agencies and university researchers to undertake detailed assessments of biodiversity on coral and rocky reefs, with all divers and boat crew doing so in a voluntary capacity. A summary of these methods is provided here. Full details can be downloaded at: www.reeflifesurvey.com/methods.

Although focussed on reef habitats, RLS surveys do not only survey the coral cover and reef substrate but collect scientific data on all conspicuous reef fauna and flora that can be surveyed by SCUBA divers using visual census methods. Each RLS survey involves three distinct searches undertaken along a 50 m transect line. Divers estimate: (i) the abundances and body sizes of fishes (Method 1), and (ii) the abundances of large mobile macroinvertebrates and cryptic fishes (Method 2); including photo-quadrats along the transect line for subsequent estimations of (iii) percent cover of sessile biota (Method 3). Where possible, two transects were surveyed per site, generally parallel at different depths. Depth contours were restricted by depth variations in individual reefs, but, where possible, were selected to encompass a wide depth range (e.g., 1 – 14 m). Underwater visibility and depth were recorded at the time of each survey, with visibility measured as the furthest distance at which large objects could be seen along the transect line, and depth as the depth contour followed by the diver when setting the transect line.

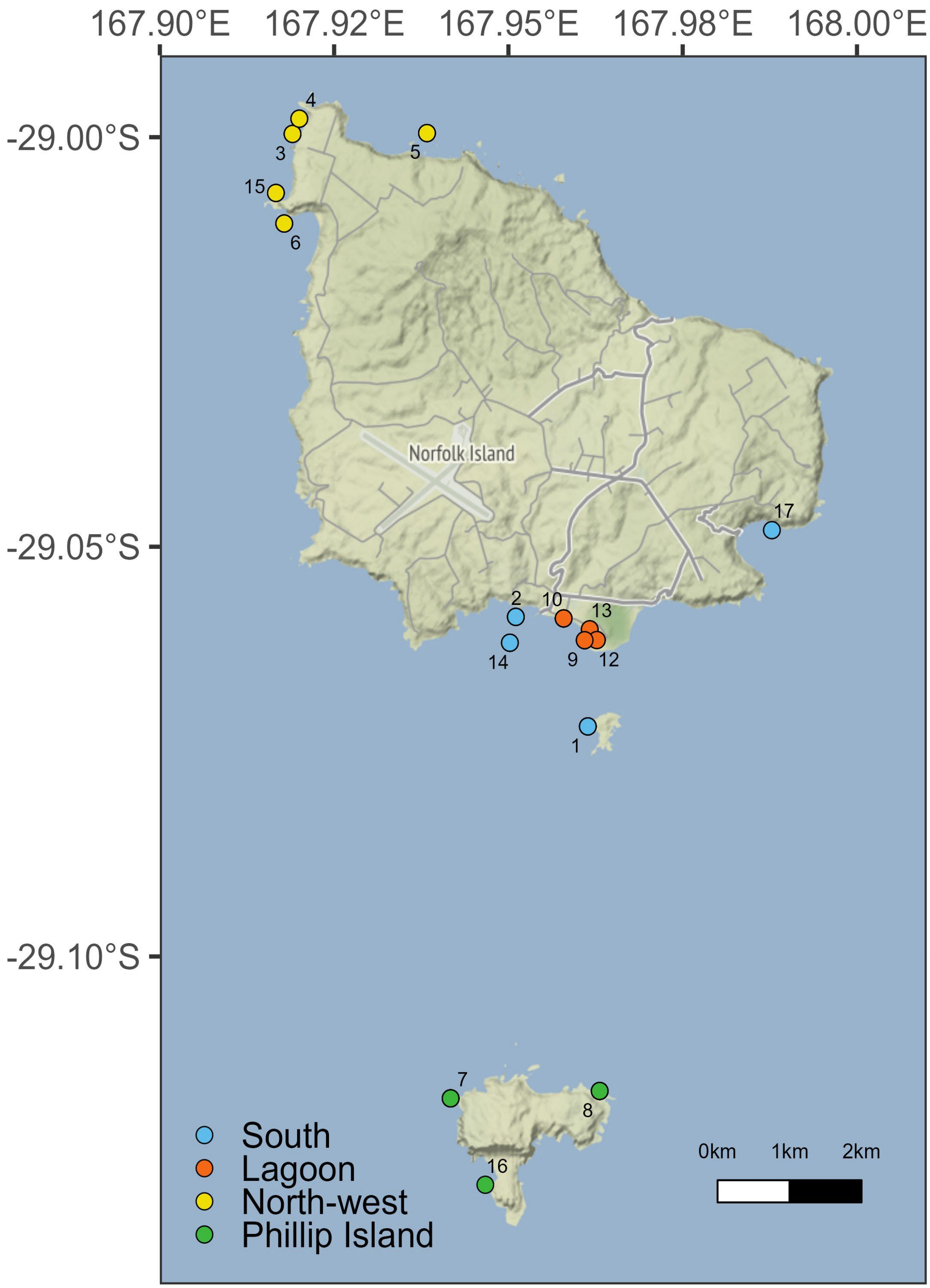

Figure 1. Map of all site locations surveyed by RLS divers in the Norfolk marine Park in 2009, 2013 and 2021. Sites are grouped into four geographical regions based on different faunal communities.

Fish Surveys (Method 1)

All fish species sighted within 5 m x 50 m blocks either side of the transect line were recorded on waterproof paper as divers swam slowly along the line (Figure 2). The number and estimated size category of each species were also recorded. Size categories used were 25, 50, 75, 100, 125, 150, 200, 250, 300, 350, 400, 500, 625 mm, and 125 mm categories above, which represent total fish length (from snout to tip of tail). All species sighted within the blocks were recorded, including those with unknown identity. Photographs were used to later confirm identities with appropriate taxonomic experts, as necessary. In occasional circumstances when no photograph was available, taxa were recorded to the highest taxonomic resolution for which there was confidence (e.g. genus or family, if not species). Other large pelagic animals such as turtles and cephalopods were also recorded during the Method 1 fish survey, but not considered here in analyses focusing on fishes. Species observed outside the boundaries of the survey blocks or after the fish survey had been completed were recorded as 'Method 0.' Such records are a presence record for the time and location but were not used in quantitative analyses at the site level. 'Method 0' sightings were also made of invertebrates and any other notable species.

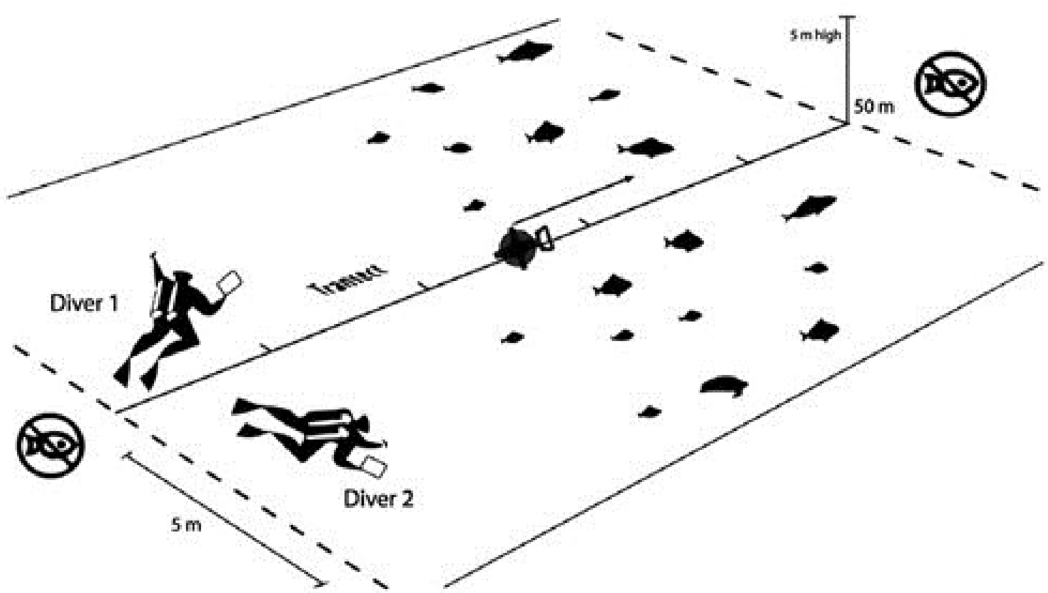

Figure 2. Summary of the Reef Life Survey fish survey (Method 1) approach

Macroinvertebrate and Cryptic fishes Survey (Method 2)

Large macroinvertebrates (echinoderms, and molluscs and crustaceans > 2.5 cm) and cryptic fishes were surveyed along the same transect lines set for fish surveys. Divers swam near the seabed, up each side of the transect line, recording all mobile macroinvertebrates and cryptic fishes on the reef surface within 1 m of the line (Figure 3). This required searching along crevices and undercuts, but without moving rocks or disturbing seaweeds. Cryptic fishes include those from pre-defined families that are inconspicuous and closely associated with the seabed (and are thus disproportionately overlooked during general Method 1 fish surveys). The global list of families defined as cryptic for the purpose of RLS surveys can be found in the online methods manual (www.reeflifesurvey.com/methods). As data from Method 2 were collected in blocks of a different width to Method 1, and were analysed separately from those data, individuals of cryptic fishes known to already be recorded on Method 1 were still recorded as part of Method 2. Sizes were estimated for cryptic fishes using the same size classes as for Method 1.

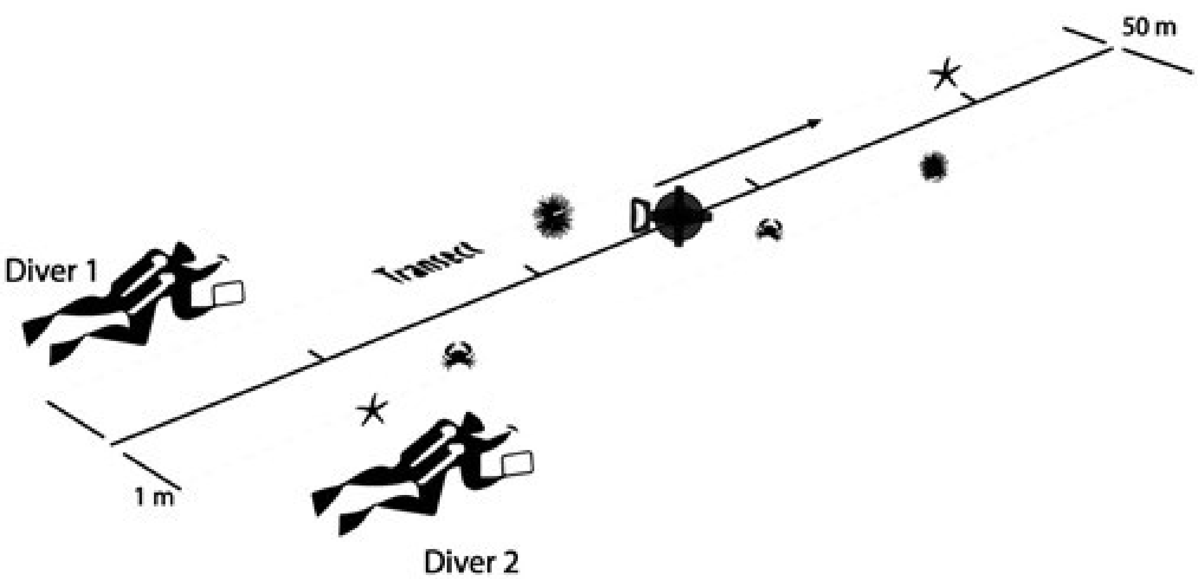

Figure 3. Summary of the Reef Life Survey macroinvertebrate and cryptic fish survey (Method 2) approach.

Photo-quadrats of benthic cover (Method 3)

Information on the percentage cover of sessile animals and macroalgae along the transect lines set for fish and invertebrate surveys was obtained using photo-quadrats taken every 2.5 m along the 50 m transect. Digital photo-quadrats were taken vertically-downward from a height sufficient to encompass an area of approximately 0.3 m x 0.3 m.

The percentage cover of different macroalgal, coral, sponge and other attached invertebrate species was obtained from photo-quadrats by recording the coral species or functional group observed under each of five points overlaid on each image, such that 100 points were usually counted for each transect (thus percentage cover was calculated as the number of points each group was scored under).

Functional groups for photo-quadrat processing comprised the standard 50 categories applied in broadscale analysis of RLS data, which are aligned with the CATAMI benthic imagery classification system (Althaus et al. 2015). For this report, a coral specialist, Dr Emre Turak, was engaged to provide the highest possible taxonomic resolution for corals. Images have been archived and are available for processing at any resolution through the future.

Statistical analyses

For most sites, two transects were surveyed, each at a different depth. Due to the relative importance of depth in defining the community composition, each transect was regarded as an independent sample in analyses. Thus, the unit of replication was total value(s) per transect (i.e. per 500 m^2 for fishes and per 100 m^2 for mobile macroinvertebrates). Sessile biota percent cover was expressed as percent cover per transect.

Collection of body length data of fishes, along with species identity and abundance, allows for the calculation of species-specific biomass estimates. Fish body mass was calculated from body length estimates using species-level length-weight relationships obtained from Fishbase (Froese and Pauly, 2010; www.fishbase.org). In cases where species-level length-weight coefficients are not available they are taken from similar-shaped species. When length–weight relationships were described in Fishbase in terms of standard length or fork length rather than total length, additional length-length relationships provided in Fishbase allowed conversion to total length, as estimated by divers. For improved accuracy in biomass estimates, the bias in divers' perception of fish size underwater was additionally corrected using the mean relationship provided in Edgar et al. (2004), where a consistent bias was found amongst divers that led to underestimation of small fish sizes and overestimation of large fish sizes. Note that estimates of fish abundance made by divers can be greatly affected by fish behaviour for many species (Edgar et al., 2004); consequently, biomass determinations, like abundance estimates, can reliably be compared only in a relative sense (i.e. for comparisons with data collected using the same methods) rather than providing an accurate absolute estimate of fish biomass for a patch of reef.

Univariate statistics

A range of univariate metrics were calculated from the survey data. For fishes these included total biomass estimates, species richness, biomass within trophic groups, and two indicators of reef condition: the biomass of large fishes (B20) and community temperature index (CTI). B20 is an indicator of fishing impacts, with previous analyses revealing lower values in regions of higher fishing impact around Australia (Stuart-Smith et al., 2017). It is calculated as the sum of biomass for all individuals on any survey that are in the 20 cm size class or larger, regardless of species identity. CTI is an indicator of the thermal affinities of the species and responds to sea temperature changes (Stuart-Smith et al., 2015). CTI is calculated as the mean of the thermal affinity of the species present within a survey, weighted by the log of the abundance of the species on the survey. The thermal affinity of the species is the midpoint of each species' thermal distribution (i.e., the temperature range experienced across its geographic distribution). For both mobile macroinvertebrate and cryptic fishes, metrics calculated included total abundance and species richness. For sessile biota, metrics included percent cover of various functional/taxonomic groups (crustose coralline algae (CCA), live coral, macroalgae, and turf). All metrics represent mean values per transect area, that is per 500 m^2 for fishes (Method 1), and per 100 m^2 for mobile macroinvertebrates and cryptic fishes (Method 2).

Statistical significance of univariate analyses was assessed using fixed-effects analysis of variance (ANOVA) models, with the locality of the site (see Figure 1) and the survey year as fixed effects. To assess change in biomass of trophic groups, species were aggregated into four broad trophic groups; herbivores, higher carnivores, invertivores and planktivores, and analysed in separate ANOVA models. ANOVA models were fitted using the 'Anova' function of the 'car' package in R (Fox and Weisberg, 2019).

Multivariate statistics

Fish, cryptic fish, macroinvertebrate and sessile biota communities were investigated using nonmetric multi-dimensional scaling (nMDS). nMDS is a dimension reduction approach, minimising many dimensions (e.g., the abundance of species A, abundance of species B… etc.) into two dimensions here (termed nMDS1 and nMDS2) whilst minimising dissimilarity as much as possible. The loss of information when reducing dimensions is termed 'stress,' which ranges from 0 to 1, with values less than 0.15 representing a 'good fit' (Dugard et al., 2010). nMDS was performed using the 'metaMDS' function within the 'vegan' package (Oksanen et al., 2020) in R using Bray-Curtis distances. Raw abundance data were first log(x+1) transformed to reduce the relative importance of dominant species at a site.

Statistical significance of nMDS analyses was assessed using fixed-effects permutational multivariate analysis of variance (PERMANOVA) models, with the locality of the site (see Figure 1) and the survey year as fixed effects. PERMANOVA models were fitted using the 'adonis' function of the 'vegan' package in R (Oksanen et al., 2020).

Results

Fishes

Community structure

A total of 111 fish taxa were recorded on surveys from 2009 to 2021, including 85 in the latest set of 32 surveys in 2021. The fish community within the lagoon was distinctively different from those surveyed at the other three localities (Figure 4, Appendix Table 2) in 2009 and 2021. A distinct and significant shift in the fish community structure occurred between 2009 and 2021 overall, but the lagoon fish community remained unique from all other sites (Figure 4), characterised by more tropical species associated with coral reefs (Figure 5).

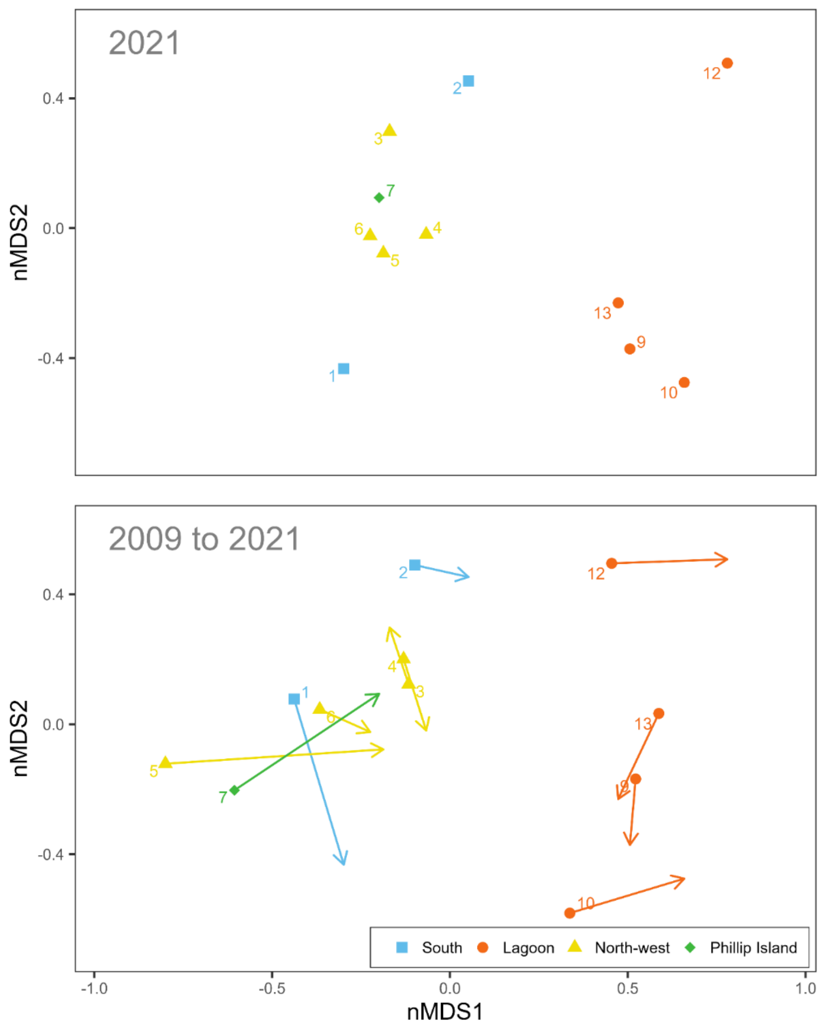

Figure 4. Non-metric multidimensional scaling (nMDS) plot of fish communities surveyed in 2021 (top), grouped by site locality. Numbers next to the points refer to the site number shown in Figure 1. Stress = 0.16. Change in sites from 2009 to 2021 surveys is shown in the bottom plot, where arrows represent the change in position of each site on the plot. Fish community structure was significantly different between years (p = 0.008) and localities (p < 0.001). full statistics can be found in Table 2.

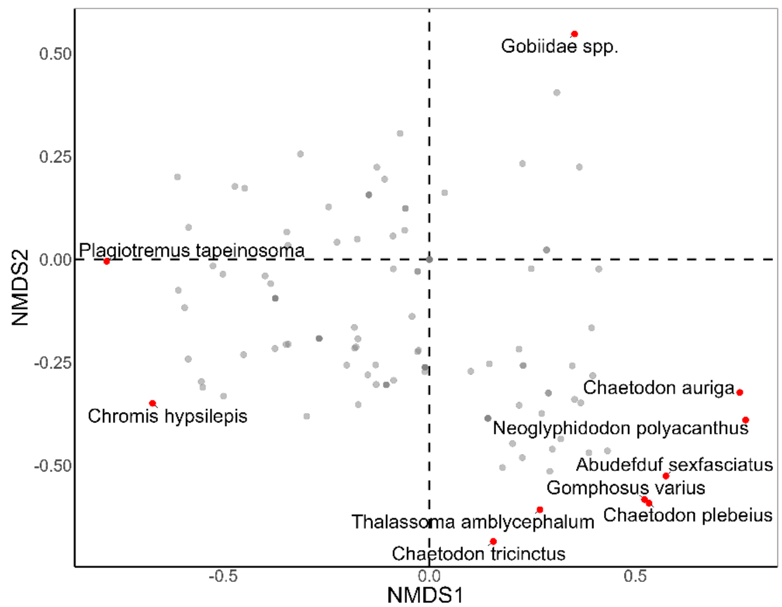

Figure 5. Key fish species, and their directional pull, driving the community structure change observed in the non-metric multidimensional scaling of Figure 4.

Biomass and richness

Fish biomass also differed significantly between sites in each of the four localities, and changes in fish biomass between 2009 and 2021 were dependent upon the locality (Figure 6). Fish biomass at the Phillip Island sites declined by 78% between 2009 and 2013, and despite a slight increase again between 2013 and 2021, remained 64% less in 2021 than in original RLS surveys in 2009. The reduction in fish biomass at the Phillip Island sites appeared to be the result of relatively higher abundances of Galapagos sharks (*Carcharhinus galapagensis*) and schooling sea chubs (*Kyphosus* spp.) in 2009 surveys (Figure 7). Fish biomass was 58% lower in the Lagoon in 2021 compared to 2009 (Figure 6), although this was not significantly significant. No significant change in fish biomass was observed at the North-west and South sites between the years 2009 and 2021. High biomass in the South sites in 2021 was largely driven by schools of the Onespot puller (*Chromis hypsilepis*) and the Yellowspotted sawtail (*Prionurus maculatus*) (Figure 7). Species richness varied significantly between site localities, but no significant change was observed from 2009 to 2021 (Figure 6).

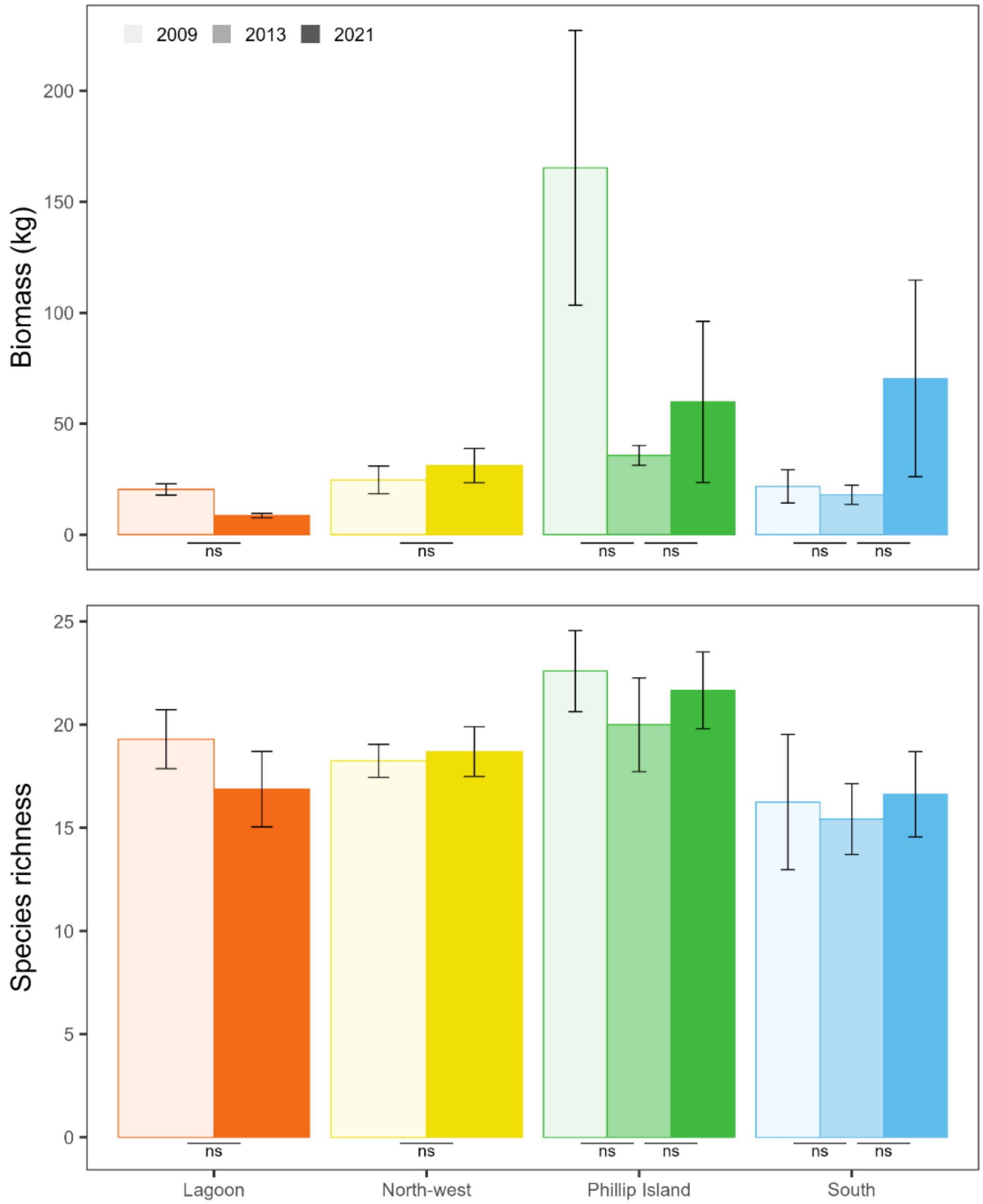

Figure 6. total biomass and species richness of fishes in 2009, 2013, and 2021. Overall biomass varied significantly between localities ($p < 0.001$) but not years, species richness also varied significantly between localities ($p = 0.028$) but not years. see Table 3 for full statistics. "ns" refers to no statistically significant difference ($p < 0.05$).

Biomass by species

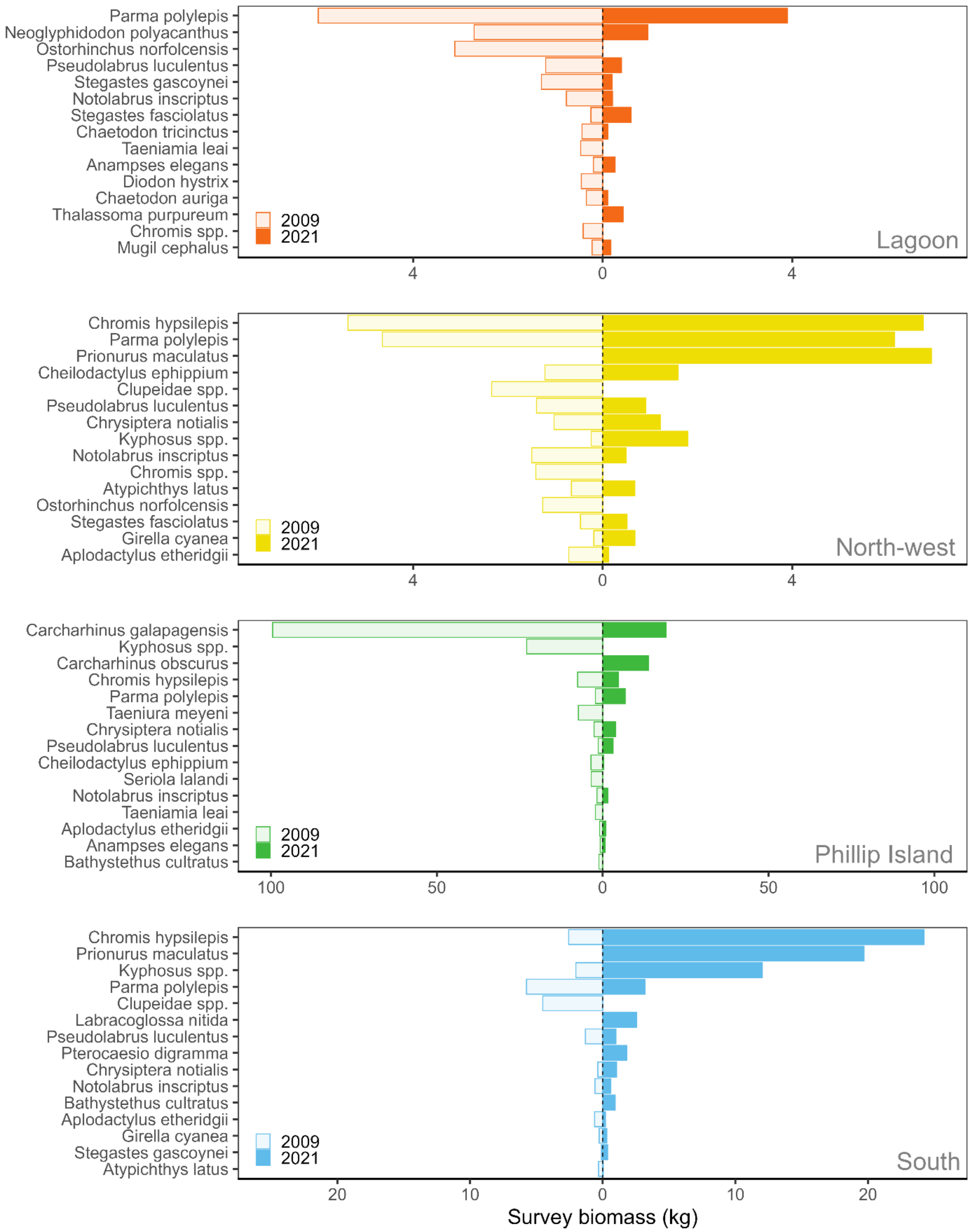

Figure 7. 15 fish taxa with greatest biomass within each locality for 2009 and 2021.

Biomass by trophic group

The relative biomass of trophic groups varied through the years (Figure 8), with trends for decreased biomass of higher carnivores and invertivores, and increased biomass of herbivores and planktivores. None of these changes were statistically significant, however, with large variation in biomass of trophic groups between sites suggesting that the functional structure of Norfolk Island communities is quite variable through space and time (Appendix Table 4).

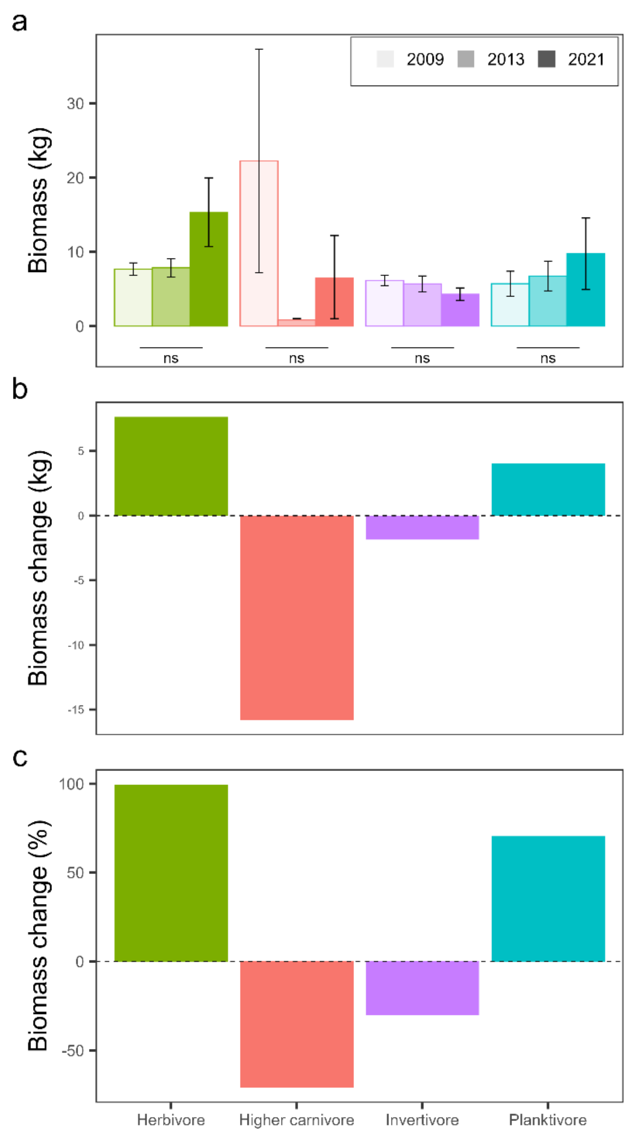

Figure 8. Biomass per trophic group (a), and the change in survey biomass (b, c) from 2009 to 2021. Overall biomass varied significantly between trophic groups ($p < 0.001$) but not years. See Table 4 for full statistics. “ns” refers to no statistically significant difference.

Fish B20 and CTI

Trends in the biomass of fishes greater than or equal to 20 cm in total length (B20) largely reflected those in total fish biomass. B20 values were highest at Phillip Island in 2009 (Figure 9) but dropped substantially by 2021. As for total fish biomass, this change was not statistically significant (Appendix Table 5) and was driven by fewer Galapagos sharks and sea chubs in 2021. The lagoon sites supported more tropical fish assemblages, with warmer temperature preferences and a significantly higher value of the community temperature index (CTI) compared to the other three localities.

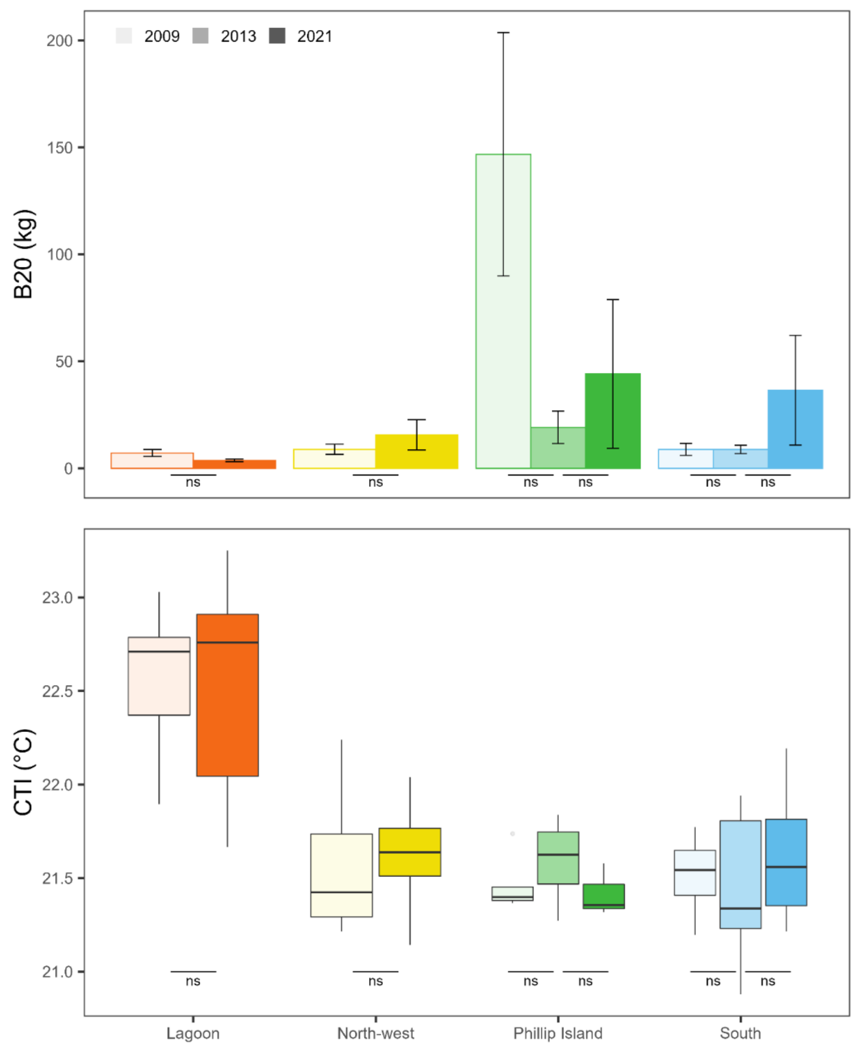

Figure 9. the biomass of fishes 20 cm and over (B20) and the community temperature index (CTI) of fish communities from 2009 to 2021. Both B20 and CTI varied significantly between localities (both $p < 0.001$) but not years. See Table 5 for full statistics. “ns” refers to no statistically significant difference.

Mobile macroinvertebrates

Community structure

Norfolk Island reefs tend to have relatively few large mobile invertebrates compared with mainland Australian locations at similar latitudes. A total of 47 mobile macroinvertebrate taxa were recorded across all surveys from 2009 to 2021, including 27 recorded during the latest round of 32 surveys in 2021. Macroinvertebrate communities were generally much more similar across localities than the fish communities were (Figure 10). Although the Lagoon macroinvertebrate community structure was slightly different to that at sites in other localities in 2009, this changed by 2021; macroinvertebrates at Slaughter Bay in the Lagoon (sites 9, 10) became more similar to sites in the North-west than to the other two Lagoon sites, and their 2009 composition.

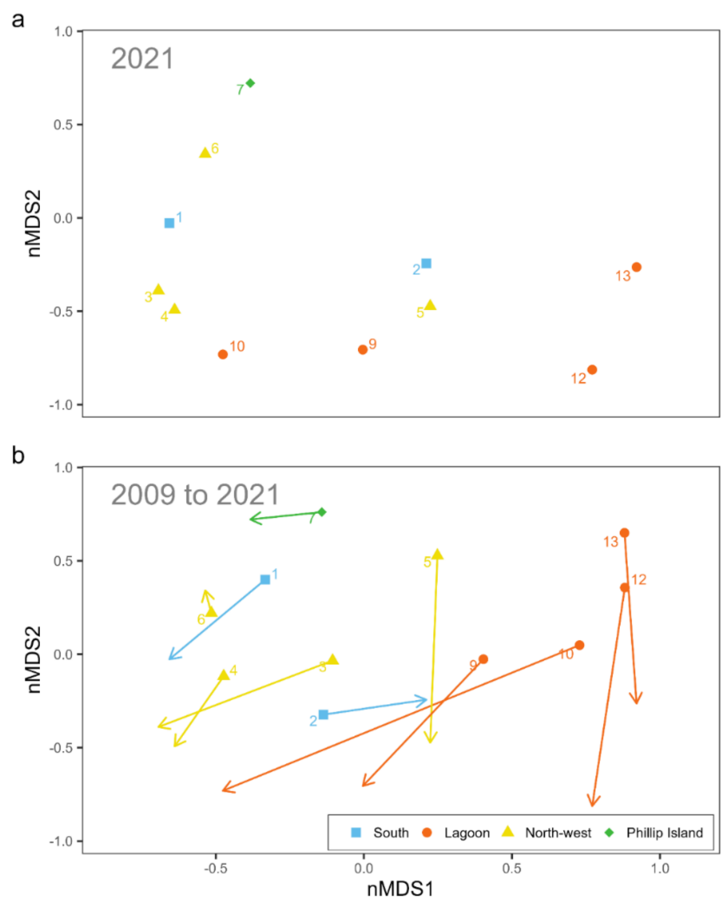

Figure 10. Non-metric multidimensional scaling (nMDS) plot of macroinvertebrate communities surveyed in 2021, grouped by site locality. Numbers next to the points refer to the site number shown in Figure 1. Stress = 0.22. Macroinvertebrate community structure was significantly different between years ($p < 0.001$) and localities ($p = 0.021$). see Table 6 for full statistics.

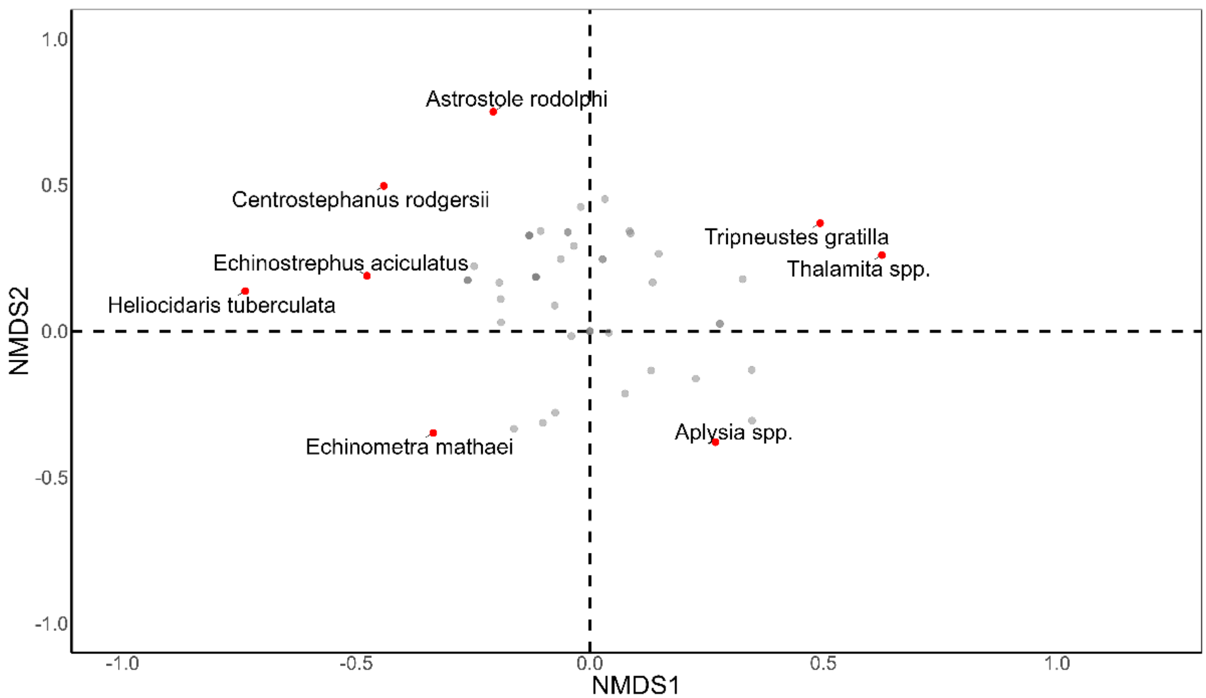

Figure 11. Key macroinvertebrate species, and their directional pull, driving the community structure change observed in the non-metric multidimensional scaling of Figure 10.

Density and richness

Macroinvertebrate density was an order of magnitude lower at Lagoon sites than those outside the lagoon (Figure 12). Sites within the Lagoon, North-west and South localities tended to decrease in macroinvertebrate densities, whilst sites around Phillip Island tended to increase in density, however none of these changes were statistically significant. Macroinvertebrate densities across all sites were very heavily dominated by sea urchins, mostly *Heliocidaris tuberculata*, *Centrostephanus rodgersii*, and *Tripneustes gratilla* (Figure 13). Invertebrate species richness varied significantly between localities, with the fewest species per transect recorded in the Lagoon (Figure 12). Invertebrate species richness was also marginally lower in 2021 compared to 2009 (marginal statistical significance; $p = 0.051$), by an average of one fewer species per survey in 2021.

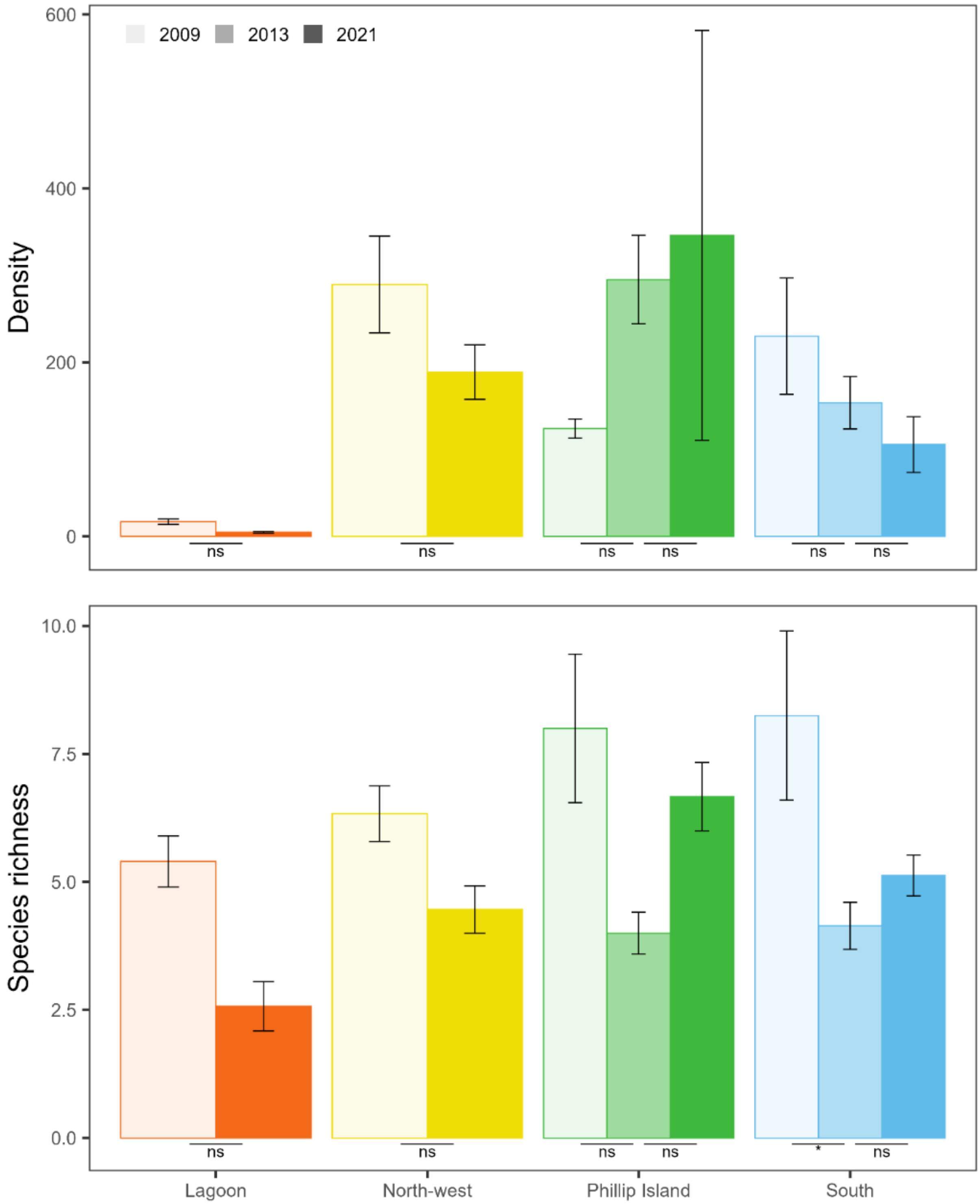

Figure 12. Macroinvertebrate total density and species richness in 2009, 2013 and 2021. Overall, both density ($p = 0.013$) and species richness ($p < 0.001$) declined significantly between years. See Table 7 for full statistics. “ns” refers to no statistical significance, “*” refers to statistical significance ($0.05 > p > 0.01$).

Abundance by species

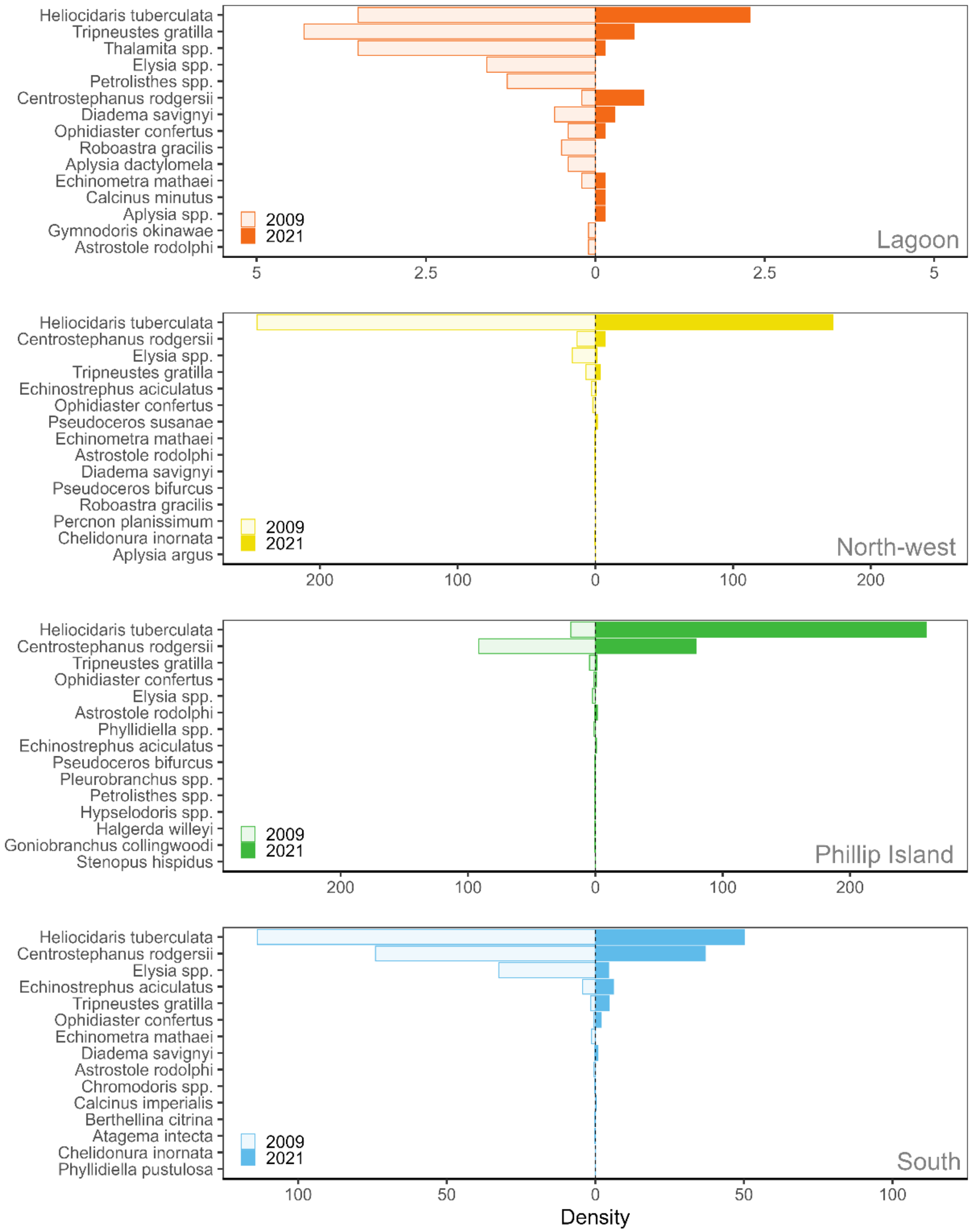

Figure 13. mean densities of the 15 most abundant macroinvertebrate species in each locality for 2009 and 2021.

Cryptic fishes

Community structure

A total of 36 cryptic fish species were recorded on surveys from 2009 to 2021, including 28 in the latest expedition of 32 surveys in 2021. The cryptic fish community at the Lagoon sites differed from that recorded at the other three localities (Figure 14, Table 8), but all sites surveyed in 2021 converged towards a more similar cryptic fish community structure (Figure 14).

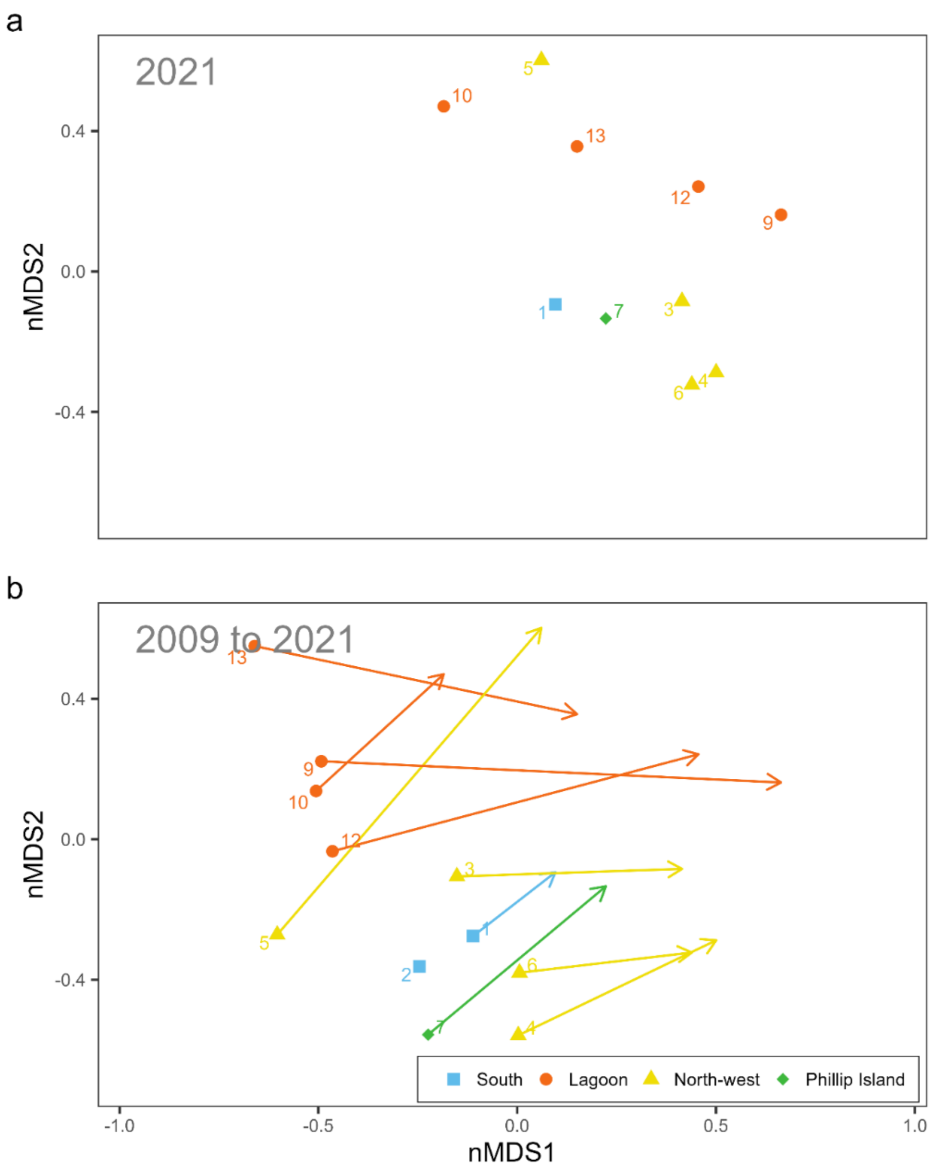

Figure 14. Non-metric multidimensional scaling (nMDS) plot of cryptic fish community structure in 2021, grouped by site locality. Numbers next to the points refer to the site number shown in Figure 1. Cryptic fish community structure was significantly different between years ($p < 0.001$) and localities ($p < 0.001$). see Table 8 for full statistics.

Density and species richness

The total densities of cryptic fishes varied between site localities. Sites around Phillip Island and in the South generally had fewer cryptic fishes, with the exception of Phillip Island in 2021, although none of these differences were statistically significant. This high cryptic fish density around Phillip Island in 2021 was driven by a single survey with high counts of Redcap triplefin (*Enneapterygius rufopileus*) and the Norfolk Island blenny (*Parablennius serratolineatus*) (Figure 15). The species richness of cryptic fishes significantly decreased between 2009 and 2021.

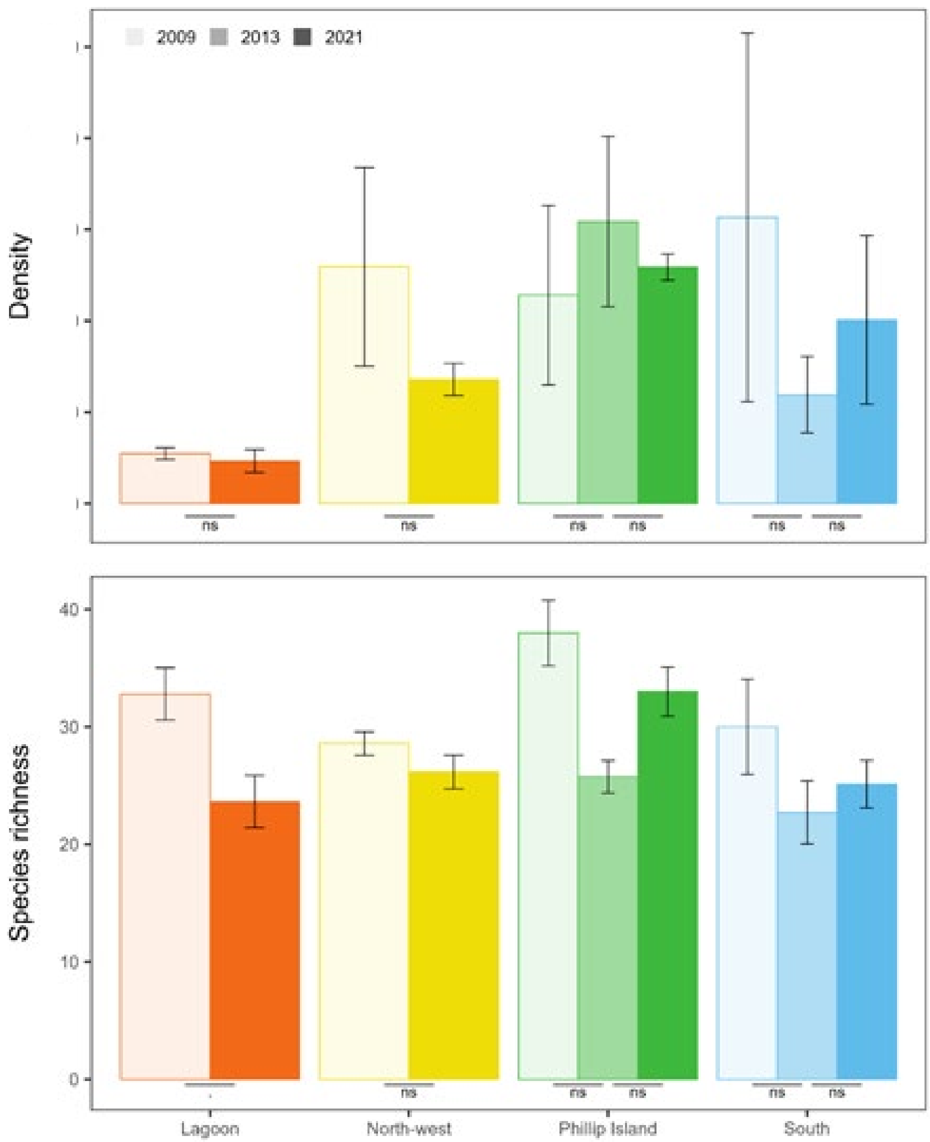

Figure 15. Cryptic fish densities and species richness in 2009, 2013, and 2021. Overall density varied significantly between localities ($p < 0.001$) but not Years, species richness varied significantly both between localities ($p = 0.01$) and years ($p < 0.001$). See Table 9 for full statistics. "ns" refers to no statistical significance, "." refers to marginal significance ($p = 0.055$).

Sessile biota

Community structure

A total of 45 species and morphologically distinct groups of coral taxa were identified from photo-quadrats from surveys spanning 2009 to 2021 (Figure 16). Benthic community structure significantly changed from 2009 to 2021 (Table 10), especially within the lagoon, which shifted to become more similar to the habitats recorded outside of the lagoon between 2009 and 2021 (Figure 16).

Figure 16. Top 15 Live hard coral taxa by site locality.

Percent cover per group

The percent cover of Macroalgae and Turf significantly varied across site localities (Table 11), and the cover of turf significantly declined from 2009 to 2021, when considered at the scale of the whole island. In particular, turf cover tended to be replaced by macroalgae at the lagoon sites. Increases in live coral cover from 2009 to 2021 in the lagoon and south were not statistically significant (Figure 17).

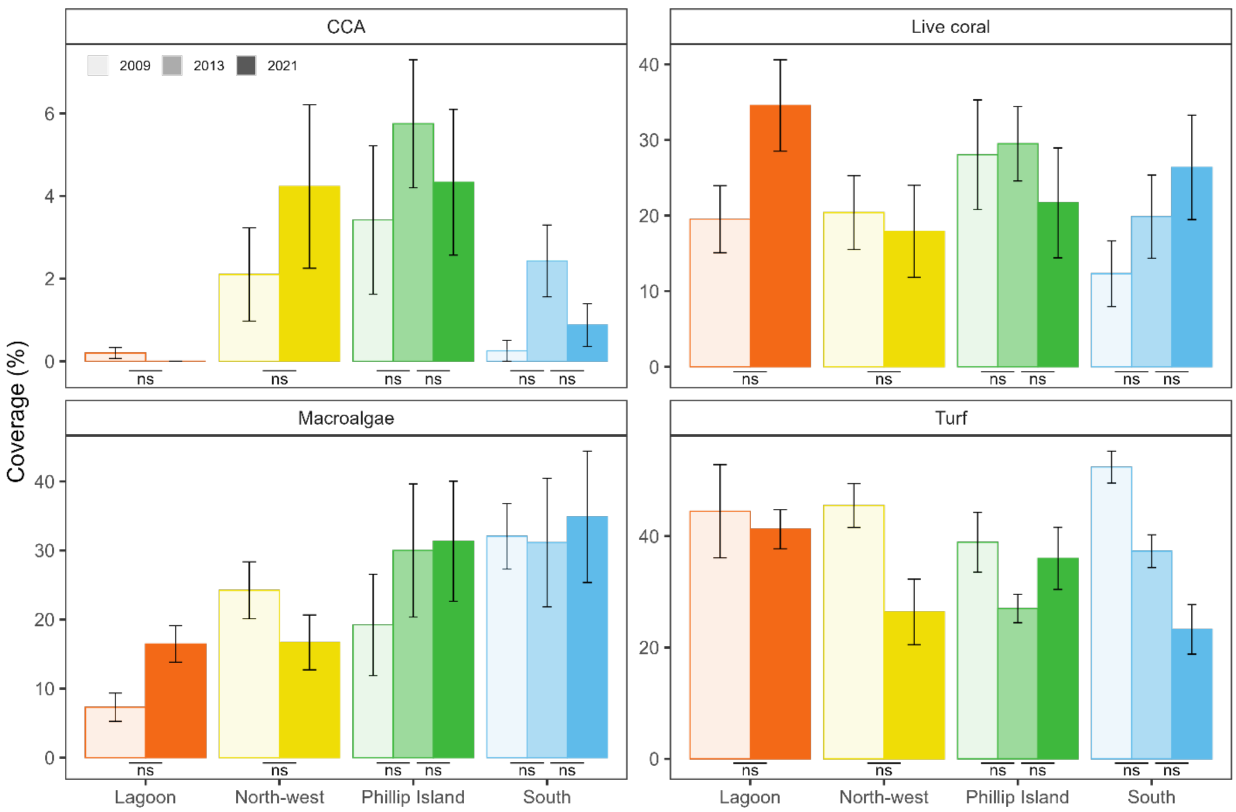

Figure 17. Percent cover of sessile benthic categories in 2009, 2013, and 2021, grouped by locality. CCA = crustose coralline algae. The cover of Turf varied between years ($p = 0.003$). See Table 11 for full statistics. “ns” refers to no statistically significant difference.

Threatened and endemic species

One threatened species listed under the EPBC Act (Vulnerable Green turtle, *Chelonia mydas*) and two additional species listed on the IUCN Red List (the doubleheader, *Coris bulbifrons*, and dusky whaler shark, *Carcharhinus obscurus*) were recorded on surveys (Figure 18, Figure 19). The doubleheader is also a regional endemic and declined in the number of transects it was recorded on in both Lagoon and Phillip Island surveys from 2009 to 2021. The black cod (*Epinephelus daemelii*) also showed a decline in observation frequency at Phillip Island sites. Other regional endemics showed only minor changes in frequency of observation.

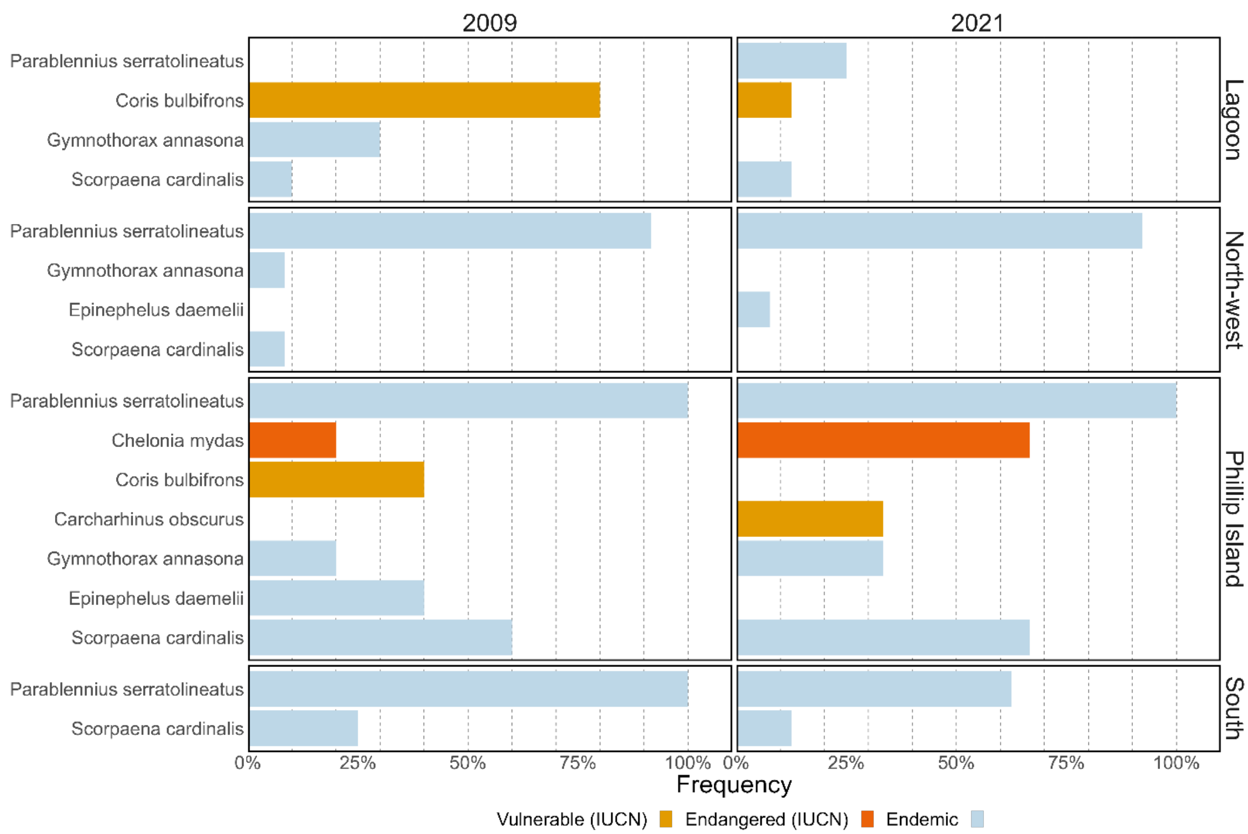

Figure 18. Frequency (% of surveys observed) of threatened and regionally endemic species on Norfolk Island reefs in 2009 and 2021.

Norfolk Island Blenny *(Parablennius serratolineatus)* (endemic)

Black cod *(Epinephelus daemelii)* (regional endemic)

Double header wrasse (*Coris bulbifrons*) (IUCN VU)

Green turtle (*Chelonia mydas*) (EPBC VU, IUCN EN)

Lord Howe Moray (*Gymnothorax annasona)* (regional endemic)

Scorpionfish (*Scorpaena cardinalis)* (regional endemic)

Dusky shark (*Carcharhinus obscurus)* (IUCN VU)

Figure 19. IUCN threatened and endemic species of Norfolk Island.

Discussion

Biodiversity surveys of reefs in the Norfolk Marine Park in 2009 and 2021 revealed relatively little change in the flora and fauna observed on shallow reefs that could be considered of ecological, conservation or management significance. Few clear signals of biodiversity change may indicate that more survey effort is needed to detect signals of importance; nevertheless, the lack of detectable change provides confidence that any change on shallow NMP reefs from 2009 to 2021 was not large, whether as a result of management intervention (e.g. marine park zoning) or environmental change.

An absence of major biodiversity change linked to marine park zoning is not surprising. The 2018 management plan for the Norfolk Marine Park includes three major zones: National Park (IUCN II), Habitat Protection (IUCN IV) and Special Purpose (IUCN VI). The coastal waters surrounding the Norfolk Island and satellite islands fall into the Special Purpose Zone, which has few restrictions on fishing activities. In the absence of other reforms to local fishing regulations around the island, management-associated changes to fish communities are not expected for the shallow reefs. In addition to this, the three year interval between management plan enactment and the 2021 surveys is less than the period generally required for significant ecological change to be observed, even in situations where fishing pressure was historically high, and when no-take zones are enacted and well-enforced (4-5 years minimum, but typically longer; Babcock et al. (2010), Coleman et al. (2015)). Consequently, detection of any management associated changes to reef communities will require monitoring over the longer-term.

Biodiversity change through time at Norfolk Island may be naturally low. For example, its geographic isolation probably increases the relative dependence on local recruitment for most reef species, rather than episodic recruitment events from elsewhere (Walsh, 1985). Extensive Reef Life Survey monitoring of the similar Lord Howe Island reefs has also shown high stability through time in many of the same fish metrics examined here (including CTI and B20) – more so than at mainland locations in similar sub-tropical environmental contexts (Stuart-Smith et al., 2019). The latter locations receive far more inter-annual variability in recruitment of warm-water fishes, and adult movement between adjacent locations is facilitated by habitat connectivity along the coastline. Together these likely lead to greater interannual changes in fish community structure.

Benthic communities at Norfolk may also potentially change less if local corals are more resilient to bleaching events due to high zooxanthellae diversity (Wicks et al., 2010). Another possibility is that due to distance from other larval sources, relative to other subtropical coral reefs, Norfolk

Island corals are largely self-recruiting and therefore unusually stable. Long-term studies of Norfolk coral communities are needed to test these hypotheses.

Despite the above potential explanations for the observations of limited biodiversity change at NMP reported here, it is probable that subtle change has occurred, but the survey design was not able to confirm this. The results indicate that NMP shallow reefs appear to be characterised by extreme patchiness in some metrics of reef ecological condition. These include total fish biomass and B20, which can be influenced by the presence of large schools of highly mobile sea chubs (*Kyphosus* spp.), sawtail surgeonfishes (*Prionurus maculatus*) and widely roaming individuals of Galapagos sharks (*Carcharhinus galapagensis*). These species collectively make up a large proportion of fish biomass presently observed on the more exposed reefs in the NMP.

Few large, site-attached reef fishes appear to occur on these reefs, at least across the 16 sites and timeframe of 12 years covered here. For example, the doubleheader (*Coris bulbifrons*) and Black Cod (*Epinephelus daemelii*) were not frequently observed on transects and decreased in frequency of observation from 2009 to 2021. It is possible such fishes have progressively been removed from Norfolk Island shallow reefs through fishing, or have been declining for other reasons, but with the result that patterns in biomass relate primarily to whether more mobile species are scored on transects or missed at the time of the surveys.

The high variation in trophic structure of fish communities observed is also of ecological interest, in terms of suggesting that communities are not strongly shaped by predictable patterns in food resources, varying considerably from site to site and time to time. This is likely related to the points above about the patchiness and mobility of large fishes. These observations, although of ecological interest, are also relevant for monitoring of biodiversity values and management effectiveness because they mean that greater survey effort is likely required to detect change unless the magnitude of change increases substantially, as may nevertheless occur with climate change. Thus, not only is greater survey effort needed than undertaken to date to detect subtle ecological change, but also more survey effort would be useful relative to other locations on the Australian mainland.

Accordingly, we recommend that survey effort be increased for future monitoring of NMP shallow reefs, either through the establishment and survey of more sites or increased temporal frequency of surveys. Given this report is based primarily on comparisons of two snapshots of reef biodiversity 12 years apart, a need for increased frequency is clear, and a resurvey of the same 16 sites every two years would greatly improve capacity to track change in reef biodiversity through time, as has been effective for similar reefs at Lord Howe Island. The Reef Life Survey team that surveyed the NMP in 2021 appeared to be well-received by the local island community, evidenced by a strong turnout to a public presentation by the visitors. Although no local divers are presently trained to undertake RLS surveys, the potential and interest exist for local divers to become involved through the future. Regardless of local capacity for undertaking the surveys, promising signs for supporting ongoing surveys exist.

The lagoon habitat in the south of Norfolk Island, comprising Slaughter Bay and Emily Bay, is of particular importance within the NMP, in terms of the locally distinct community structure, biomass, and richness of reef fauna and benthic habitats, as well as its importance for tourism and as an area accessible for people to interact with marine life in an Australian Marine Park (e.g. through snorkelling and glass-bottom boat tours). The lagoon sites had an order of magnitude less fish biomass than the other localities in 2009, which declined a further 58% to 2021, making the observed biomass of reef fishes in the lagoon in 2021 the lowest observed across RLS surveys at any location on Norfolk in any year. This lagoon decline in fish biomass was coupled with a replacement of short turfs on the seabed with larger macroalgae. With only two sites and two years (2009 and 2021), such changes were difficult to confirm as statistically significant, however, and continued monitoring is required to be able to provide more formal confirmation. **A tentative management recommendation relates to these changes, in that further investigation and consideration be given to levels of fishing pressure and nutrients in the lagoon**, which may potentially contribute to declining fish biomass and habitat shifts to large macroalgae, respectively. An increased number of sites surveyed in the lagoon would also increase the power of analyses.

Our surveys at Emily and Slaughter Bay also suggest that the bleaching and rainfall events in 2020 (Ainsworth et al., 2021) did not result in significant coral mortality (reduced coral cover), at least based on comparison of values in March 2021 to observations from 2009 (a period which also spans other potential bleaching events in 2011 and 2017). A recent study by SIMS showed coral disease to be increasing in the lagoon over the same time period (Ainsworth et al., 2021), and while coral disease was not recorded by the current study, we did not observe any potential impact of this increase in disease on the total cover of living corals. Changes in the cover of individual coral taxa in the lagoon (Figure 16) more likely relate to fine-scale patchiness of coral composition, transect placement, and the dynamic nature of sand movement, than to impacts of bleaching events or disease outbreaks.

The last notable, albeit non-significant, trend observed was a large decrease in fish biomass at Phillip Island sites. This was predominantly driven by highly variable observations of Galapagos sharks (*Carcharhinus galapagenesis*) and sea chub (*Kyphosus* spp.). Galapagos shark observations on shallow reefs are rather sporadic, especially using the visual census methods applied here, and so care should be placed on the interpretation of this result. More survey effort and future monitoring will help in determining whether this is a real and persistent trend over the long-term, but alternative methods such as BRUVS can provide a more targeted assessment of species such as sharks and should be supported if this trend is of particular management interest. As of great conservation and ecological interest, we **recommend that transect-based reef surveys are complemented with additional methods that particularly target the sharks and deeper water reef species not well covered by the RLS methods**. Anecdotal observations passed on in 2021 by local Norfolk Island fishers of large catches of emperor (*Lethrinus miniatus*) from deeper reefs provides further impetus to this recommendation, with potential that fishing effort has progressively moved from shallower reefs to deeper reefs and may be having unnoticed impacts.

Acknowledgements

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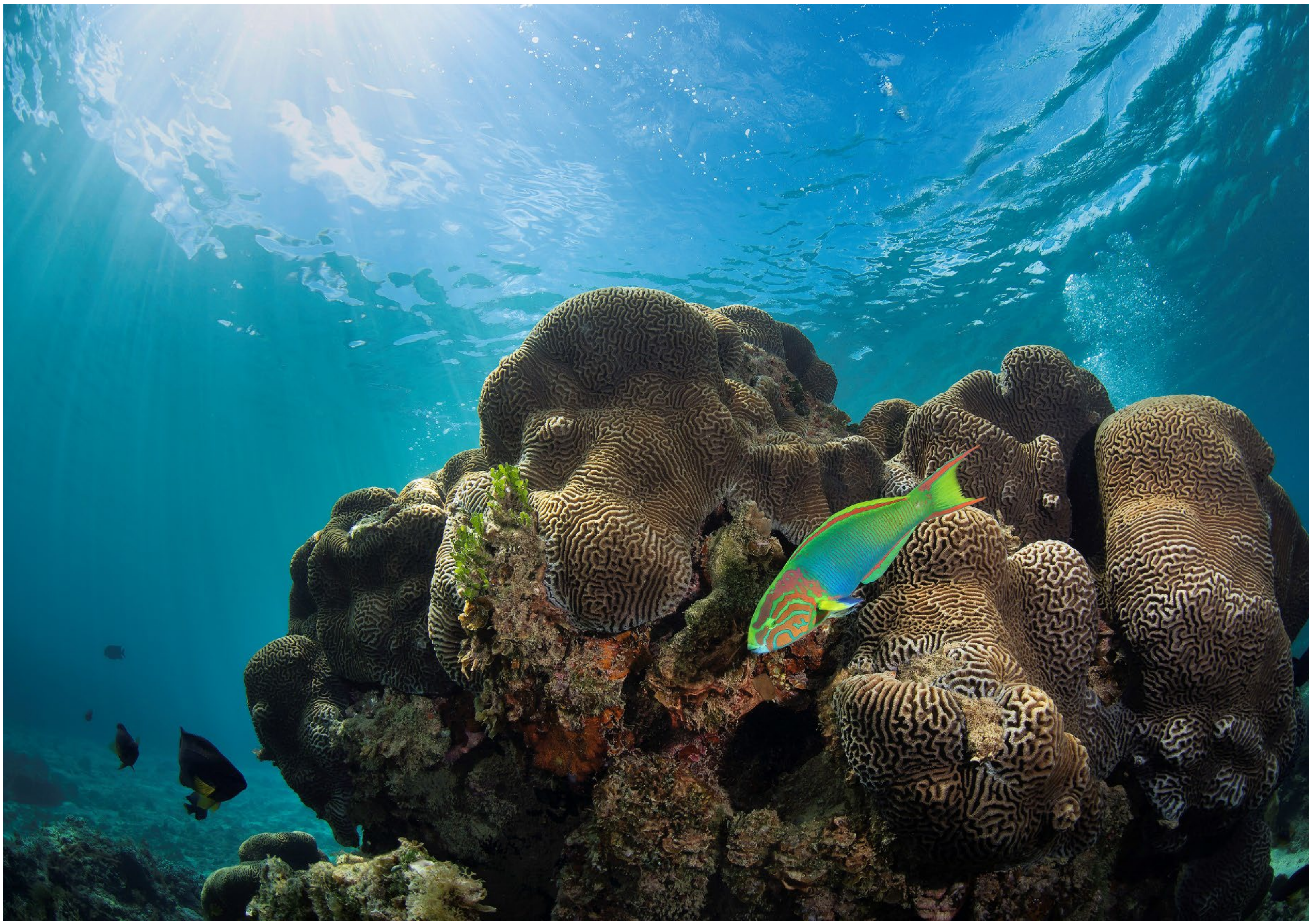

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Appendices

Survey sites

Table 1. Survey site details and the number of surveys perform at each site each year.

Site code	Site locality	Latitude	Longitude	2009	2013	2021
NI10	Lagoon	-29.05875	167.95792	6	-	2
NI12	Lagoon	-29.06139	167.96269	1	-	2
NI13	Lagoon	-29.06008	167.96166	1	-	2
NI9	Lagoon	-29.06141	167.96094	2	-	2
NI15	North-west	-29.00681	167.91665	-	-	4
NI3	North-west	-28.99960	167.91903	3	-	2
NI4	North-west	-28.99774	167.92000	3	-	2
NI5	North-west	-28.9995	167.93832	3	-	2
NI6	North-west	-29.01054	167.91784	3	-	3
NI16	Phillip	-29.12785	167.946683	-	-	1
NI7	Phillip	-29.11731	167.94171	2	2	2
NI8	Phillip	-29.11641	167.96309	3	2	-
NI1	South	-29.07193	167.96139	2	3	2
NI14	South	-29.06172	167.95021	-	2	2
NI17	South	-29.047977	167.98779	-	-	2
NI2	South	-29.05856	167.95106	2	2	2

Fish community

Table 2. PERMANOVA of fish community structure between the years 2009 and 2021, and the locality of the site.

Factor	Df	Sum Sq	Mean Sq	F value	p value
Locality	3	1.706	0.569	5.036	<0.001***
Year	1	0.392	0.392	3.473	0.008**
Locality*Year	3	0.305	0.102	0.901	0.56
Residuals	19	2.145	0.113		
Total	26	4.548			

Fish biomass and richness

Table 3. ANOVA of fish biomass and species richness by survey year and site locality.

Variable	Factor	Df	Sum Sq	F value	p value
Biomass	Locality	3	17.521	8.348	<0.001***
	Year	2	2.922	2.089	0.132
	Locality*Year	4	4.353	1.555	0.197
	Residuals	64	44.776		
Richness	Locality	3	201.677	3.23	0.028*
	Year	2	21.941	0.527	0.593
	Locality*Year	4	26.00	0.312	0.869
	Residuals	64	1332.2		

Fish biomass by trophic group

Table 4. ANOVA of fish biomass per trophic level by survey year.

Factor	Df	Sum	Mean Sq	F value	p value
Trophic group	3	50.262	16.754	20.632	<0.001***
Year	2	0.872	0.436	0.537	0.585
Trophic	6	4.109	0.685	0.843	0.538
Residuals	251	203.82	0.812		

Fish B20 and CTI

Table 5. ANOVA of fish biomass of individuals 20 cm or larger (B20) and the community temperature index (CTI) by survey year and site locality.

Variable	Factor	Df	Sum Sq	F value	p value
B20	Locality	3	26.492	8.997	<0.001***
	Year	2	2.467	1.257	0.292
	Locality*Year	4	5.196	1.323	0.271
	Residuals	64	62.818		
CTI	Locality	3	12.734	31.723	<0.001***
	Year	2	0.012	0.044	0.957
	Locality*Year	4	0.143	0.267	0.898
	Residuals	64	8.563		

Invertebrate community

Table 6. PERMANOVA of macroinvertebrate community structure between the years 2009 and 2021, and the locality of the site.

Factor	Df	Sum Sq	Mean Sq	F value	p value
Locality	3	2.304	0.768	5.939	<0.001***
Year	1	0.348	0.348	2.691	0.021*
Locality*Year	3	0.57	0.19	1.47	0.107
Residuals	19	2.457	0.129		
Total	26	5.68			

Invertebrate density and richness

Table 7. ANOVA of macroinvertebrate density and richness by survey year and site locality.

Variable	Factor	Df	Sum Sq	F value	p value
Density	Locality	3	103.755	50.419	<0.001***
	Year	2	6.375	4.647	0.013*
	Locality*Year	4	5.719	2.084	0.093
	Residuals	63	43.214		
Richness	Locality	3	72.039	7.52	<0.001***
	Year	2	128.021	20.047	<0.001***
	Locality*Year	4	6.935	0.543	0.705
	Residuals	63	201.161		

Cryptic fish community

Table 8. PERMANOVA of cryptic fish community structure between the years 2009 and 2021, and the locality of the site.

Factor	Sum Sq	Mean Sq	F value	p value
Locality	1.126	0.375	3.164	<0.001***
Year	0.468	0.468	3.942	<0.001***
Locality*Year	0.432	0.144	1.213	0.237
Residuals	2.254	0.119		
Total	4.278			

Cryptic fish density

Table 9. ANOVA of cryptic fish density and richness by survey year and site locality.

Variable	Factor	Df	Sum Sq	F value	p value
Density	Locality	3	22.784	10.849	<0.001***
	Year	2	0.673	0.481	0.62
	Locality*Year	4	1.879	0.671	0.615
	Residuals	64	44.803		
Richness	Locality	3	403.292	4.064	0.01*
	Year	2	723.242	10.932	<0.001***
	Locality*Year	4	157.022	1.187	0.325
	Residuals	64	2117.138		

Benthic community

Table 10. PERMANOVA of benthic community structure between the years 2009 and 2021, and the locality of the site.

Factor	Sum Sq	Mean Sq	F value	p value
Locality	0.477	0.159	2.555	<0.001***
Year	0.149	0.149	2.387	0.009**
Locality*Year	0.199	0.066	1.064	0.379
Residuals	1.058	0.062		
Total	1.882			

Benthos percent cover

Table 11. ANOVA of benthic community percent cover by survey year and site locality.

Variable	Factor	Df	Sum Sq	F value	p value
CCA	Locality	3	178.553	4.055	0.011*
	Year	2	40.573	1.382	0.258
	Locality*Year	4	14.749	0.251	0.908
	Residuals	64	939.452		
Live coral	Locality	3	935.136	1.074	0.366
	Year	2	414.884	0.715	0.493
	Locality*Year	4	1287.2	1.109	0.36
	Residuals	64	18570.92		
Macroalgae	Locality	3	3460.513	4.325	0.008**
	Year	2	54.87	0.103	0.902
	Locality*Year	4	1107.21	1.038	0.395
	Residuals	64	17069.71		
Turf	Locality	3	610.154	0.773	0.514
	Year	2	3279.427	6.229	0.003**
	Locality*Year	4	1716.787	1.631	0.177
	Residuals	64	16846.42		