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Monitoring the sea change: Preliminary assessment of the conservation value of nearshore reefs, and existing impacts, in a high-growth, coastal region of subtropical eastern Australia

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Abstract

In northern NSW, Australia, coastal populations are forecast to increase dramatically over the next 25 years (the "sea change"). However, management of the effects of development on marine communities is hampered by the lack of data on key habitats. Consequently, we developed a protocol to assess the biodiversity and current human impacts on nearshore reefs, habitats that will be readily affected by coastal development. We assessed four reefs adjacent to each of three population centres targeting fish, mollusc and sessile benthic communities, and debris loads. Community structure was highly variable over all spatial scales indicating that reefs should not be considered equivalent within the planning framework. While, debris loads were relatively low on most reefs, those with highest conservation value also had the highest debris loads suggesting potential conflict between human use and long-term sustainability of reefal communities. Without intervention, this situation will be exacerbated in the future.

Keywords: Human impact; Shallow reef; Molluscs; Fish; Marine debris; Sampling protocol

1. Introduction

Over the past 30 years, there has been a general trend for Australians to move from cities and inland areas to coastal environs (e.g. Burnley and Murphy, 2003; Smith and Doherty, 2006). Termed the "sea change" phenomenon, migration rates have accelerated substantially over recent years with population growth as high as 71% predicted for some coastal regions by 2022 (Smith and Doherty, 2006). On the NSW coast, the mid-northern and northern regions are forecast to be one of the focal points for high levels of population growth over the next 25 years (Department of Planning, 2006). This will undoubtedly place increasing pressure on coastal habitats. However, assessing the scale of impact and managing and mitigating impacts on the health and biodiversity of coastal ecosystems may prove to be particularly difficult as very little baseline data are currently available for many marine and estuarine habitats. The data that are available indicate that this section of the coast is of particular importance as an overlap zone between tropical and temperate biogeographic regions, with high species richness and levels of endemism (Veron et al., 1974; Harriott et al., 1994; Smith, 2000). There is, therefore, an urgent need to collect baseline information in order to objectively and effectively manage future impacts and to identify sites with particularly high conservation value which may need specific protection.

Nearshore reefs are the first diverse habitats likely to be affected by changed land-use in adjacent areas. Indeed, nearshore reefs are already under assault from a range of coastal management practices including, for example: dredge-based, beach nourishment programs (e.g. Smith and Rule, 2001) that have the potential to completely smother reef habitats (Peterson and Bishop, 2005); run-off which reduces water quality and affects sediment

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regimes (e.g. Thrush et al., 2004); and marine debris, listed as a Key Threatening Process in Australia (Department of the Environment and Heritage, 2003), which is readily transported and trapped on shallow reefs. Nearshore reefs are also important for the amenity of human populations, especially along this stretch of coast where tourism is the primary industry, providing important resources for a range of activities such as snorkelling, diving and fishing. There is little doubt then, that targeting these habitats is a useful approach, potentially providing early warning of major effects of urbanisation on coastal waters from both an ecological and economic perspective.

With such a large stretch of coast likely to be affected, monitoring and assessment methods need to be cost-effective, addressing both key ecological processes and critical public concerns. In this paper, we outline a protocol that provides linked data on an array of key variables, in a cost-effective manner, and provide an evaluation of results from three locations adjacent to population centres of different sizes within the region. Specifically, we use the diversity of key indicator groups to assess the relative conservation value of a range of sites and explore potential conflicts with current levels of human impacts as reflected by debris load at each site.

2. Methods

2.1. Study area

Three locations, spanning some 250 km of coastline, were selected for this preliminary study of reef condition across the region (Fig. 1). South West Rocks, the southernmost location, is a coastal town with a small permanent population (ca. 5000) but is an important tourist destination during holiday periods during which the population doubles. With a population of 60,000, Coffs Harbour is the largest centre within the study area. The economy of Coffs Harbour is also based primarily on tourism, with agriculture (bananas), commercial fishing and light industry also important. The multi-use Solitary Islands Marine Park, the oldest marine park in NSW (est. 1998), lies offshore from Coffs Harbour and three of the four reefs surveyed during this study were within its boundaries (but in the zone with the lowest level of protection). The final location spanned the entrance to the Clarence River. Yamba, the closest coastal town, has a resident population of 7000 but smaller, adjacent coastal/estuarine settlements support a combined population of approximately 15,000. Tourism and commercial fishing are key industries in this area. The populations of both Coffs Harbour and Yamba have grown considerably in recent years and have been forecast to be key centres for further, substantial growth in the future (Department of Planning, 2006).

Nearshore reefs in this subtropical region are characterised by a mosaic of habitats ranging from kelp-dominated (*Ecklonia radiata*) to coral-dominated communities (Smith and Simpson, 1991; Harriott et al., 1994; Edwards and Smith, 2005). For the purposes of this study, nearshore reefs were generally classified as those being within 1 km of the coast; wherever possible, patch-reefs, rather than fringing reefs were targeted.

2.2. Selection of methods

In establishing a protocol for assessing and monitoring nearshore reefs, we were mindful of the large number of methods that have been applied to reefal habitats in the past. For this reason, and in order to facilitate comparison with other studies, we chose established methods wherever possible. Thus, the primary deliberation was on selecting a suite of variables that would best address the primary objectives of the study – to provide a rapid assessment of the health and relative conservation value of reefs. These variables also needed to be sensitive enough to detect shifts in community structure in a long-term monitoring program.

2.2.1. The sampling unit

Transects are one of the most common methods for obtaining quantitative data in subtidal environments. Because of their ease of deployment, and their historical use in similar studies, we adopted transect-based methods during the study. In order to provide links across all variables evaluated, each of the survey methods was performed, sequentially, along the same transects. We chose a 25×5 m transect as the most suitable unit size. This transect size has been used extensively for fish surveys in temperate and subtropical regions, especially where medium to large-sized fish are targeted (Holbrook et al., 1994; Willis et al., 2006); this size was also the most appropriate given the scale of habitats and reefs surveyed across the region (Edwards and Smith, 2005).

2.2.2. Selection of variables

A primary objective of conservation management is the maintenance of biodiversity; consequently, generation of representative biodiversity data was a critical component of the study. Clearly, given the high biodiversity of most subtidal regions, it was impractical to sample all species. For this reason, survey methods targeted taxa that were either of specific interest to those charged with managing coastal resources, and to the wider community (fish), or taxa that have been suggested as reliable indicators of wider biodiversity (molluscs) (Gladstone, 2002; Gladstone and Alexander, 2005; Smith, 2005). A specific objective of this study was also to assess habitat condition. For this reason, we chose to include assessments of sessile biota and densities of debris. Anthropogenic debris, and its interaction with marine biota, has been identified as one of the Key Threatening Processes to marine habitats and organisms in Australia (Department of the Environment and Heritage, 2003), especially to threatened and/or endangered species. As much of the debris present in marine habitats originates from adjacent coasts (e.g. Edyvane et al.,

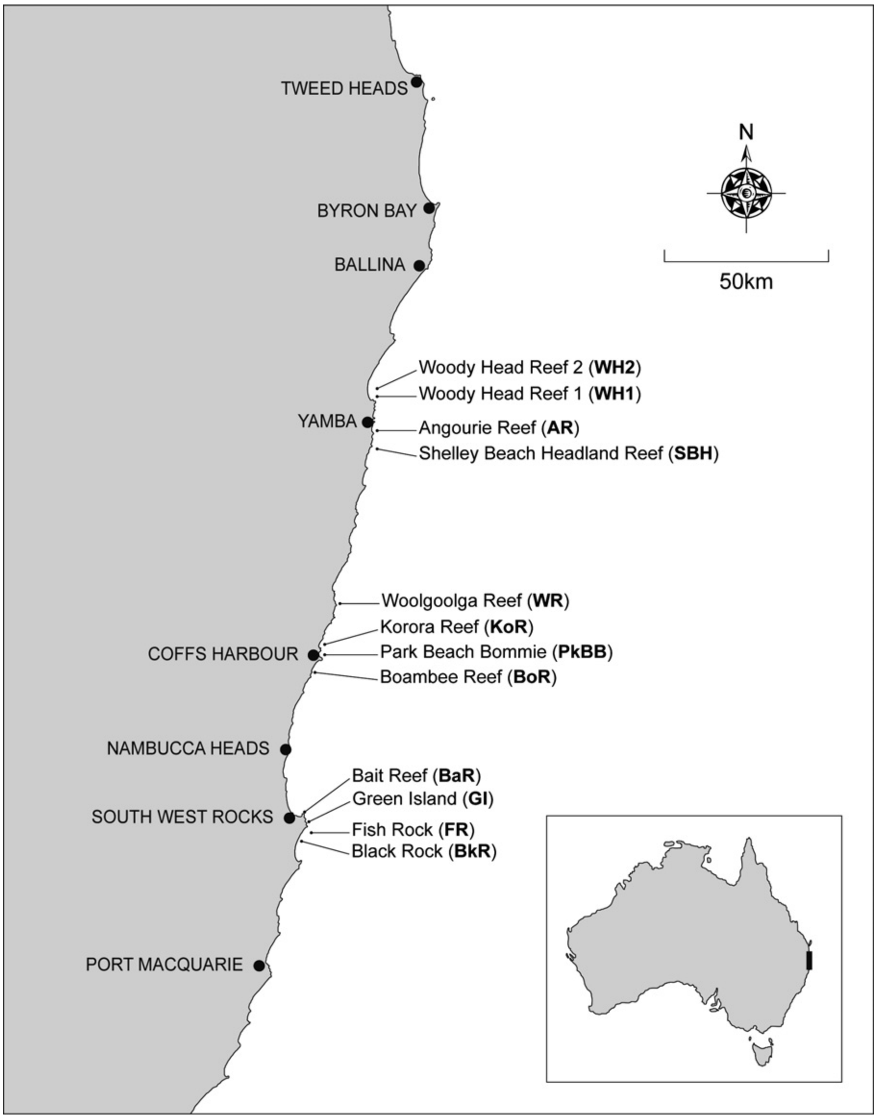

Fig. 1. Map of the NSW mid-north coast showing the location of the nearshore reefs evaluated in the study.

2004), nearshore reefs are likely to come into early contact with a range of debris types. In addition, due to ease of access, nearshore reefs are targeted by fishers; fishing debris is therefore commonly seen on many of these reefs where it is often entangled around sessile biota (pers. obs.).

2.3. Study design and field methods

Four reefs were chosen at each location. These were selected haphazardly from a list of sites that fulfilled the criteria of: distance from shore (<1 km); depth (workable reef areas in a range of 8–12 m); size (large enough to assess with four independent transects in the nominated depth range – analysis of preliminary data on fish and mollusc richness indicated that 4 replicates provided adequate precision – ratio of standard error:mean $\leqslant$ 0.20); and type (isolated patch-reefs targeted in preference to those contiguous with intertidal areas). However, as there are few reefs offshore from South West Rocks, and most of these are associated with islets (i.e. fringing reefs), not all of the selection criteria could be standardised across the study.

Four transects were established, in random positions, upon each reef. To maximise independence, each transect was at least 10 m away from any other transect. After a 10-min. acclimation period (allowing fish to re-establish their positions across transects after diver disturbance), visual censuses were conducted for fish using standard methods (Halford and Thompson, 1994). Because of the inherent biases of this method in under-estimating the densities of small, cryptic reef fish (e.g. Lincoln-Smith, 1989; Ackerman and Bellwood, 2000; Willis, 2001) only the non-cryptic, larger species (>50 mm) were assessed (i.e. families such as the Gobiidae, Blennidae and Trypterygiidae were omitted). In addition, the inclusion of schools of pelagic species in visual censuses of reef fish introduces high levels of variation into the data as the abundance of these species can vary dramatically over very small spatial and temporal scales (Willis et al., 2006; McClanahan et al., 2007). For this reason, pelagic species, although recorded, were omitted from subsequent analyses. Searches were performed for a maximum of 30 min. per transect and the abundance of each species present was recorded on an underwater slate.

Mollusc assemblages were assessed semi-quantitatively. A thorough search of the 25 × 5 m transect area was performed for a period of 30 min. during which all prosobranchs and bivalves ⩾5 mm were recorded and each species was given an abundance score based on a log base three scale (1 = 1–3 individuals; 2 = 4–10; 3 = 11–30; 4 = 31–100; 5 = 101–300; 6 > 300). This scoring system was adopted because it was appropriate for the abundance ranges encountered on these nearshore reefs and because counts of total abundance were impractical for many of the common or abundant species.

Benthic community structure was evaluated using video transects. The camera was held at an angle of 45°, approximately 0.5 m above the substratum and just to the side of the tape-measure, while a diver slowly swam the length of the transect (Page et al., 2001). The presence and percentage cover of the different substratum types and biotic groups was subsequently determined in the laboratory by pausing the tape at predetermined intervals and identifying the categories lying below five points placed on the monitor. Habitat-forming taxa were identified to the highest level of taxonomic resolution possible (species targeted) and data summaries at lower levels of resolution (e.g. broad taxon and growth-form) were also produced. Benthic categories were based on those listed in English et al. (1997) for reefal communities on the Great Barrier Reef with modifications for subtropical reefs as listed in Smith and Edgar (1999). A total of 300 data points were assessed for each transect and data summaries were facilitated by the use of Coral Point Count with Excel Extension (CPCe) software (Kohler and Gill, 2006).

Debris, which was defined as any anthropogenic item, was documented and removed (where possible or appropriate[1]) in a corridor 2.5 m either side of the tape-measure. Items were counted and classified into broad categories. In order to provide a more complete picture of debris load, additional, roaming searches were conducted for a further 30 min. at each site. This approach was taken because our initial observations indicated that debris can be patchily distributed and is often concentrated in specific areas by the combined effects of water movement and benthic topography. Such sites are often on the margins of reefs and so are unlikely to fall within transects.

Habitat complexity or rugosity can have a strong effect on community structure, especially for fish (e.g. Gratwicke and Speight, 2005a; Carraro and Gladstone, 2006; Lingo and Szedlmayer, 2006). Thus, assessments of complexity are important in the interpretation of studies of community patterns among reefs. Habitat complexity at each reef was determined using the 'rope-and-chain' method (Luckhurst and Luckhurst, 1978). Other physical measurements determined for each transect and/or reef included: distance from shore; depth; latitude; reef size (categorical – small, medium or large); and reef type (categorical – patch or island-associated).

2.4. Statistical methods

Data resulting from the study were analysed using univariate methods to determine differences between the species richness of molluscs and fish and the density of debris, and multivariate methods to compare the structure of fish, mollusc and benthic communities. The design of the study was nested in that four reefs were sampled within each of the three locations; analyses were therefore performed using a balanced, two-way design.

2.4.1. Univariate methods

Univariate methods involved two-way nested analysis-of-variance (ANOVA) with *post-hoc* contrasts (SNK tests) to compare across the levels of factors found to differ significantly in the main analysis. Where necessary, data were transformed prior to analysis to improve homoscedasticity. The relationship between species richness of fish and molluscs and the range of physical measurements taken for each transect and/or reef were explored using stepwise regression analysis. This analysis evaluates the relationships between the biotic data and the full set of predictors (physical variables) providing a final list that most closely explains the variation in the biotic data set.

2.4.2. Multivariate methods

Multivariate methods followed a standard protocol (Clarke, 1993) which involved: determining the similarity of community structure across all transects using the Bray–Curtis similarity measure; displaying this relationship between transects from each site using non-metric multidimensional scaling (nMDS) ordinations (for specific transformations, see below); determining the significance of apparent differences between sites and locations using PERMANOVA (this included pairwise contrasts of locations, and reefs within each of the locations) (Anderson, 2005). Although this protocol also uses the similarity percentages (SIMPER) analysis to determine which taxa are primarily responsible for differences in community patterns, these analyses have not been included here as our objective was to demonstrate the management application of the protocol rather than provide an exhaustive analysis of biotic patterns (presented in Smith et al., 2006).

The relationship between the different biotic variables measured across the transects was assessed using the RELATE procedure. This analysis was used to determine the strength of the correlation between fish, mollusc and benthic communities. The BIOENV procedure was also used to determine the association between physical mea-

[1] Larger pieces of debris may become habitat for marine biota – these were noted but left *in situ*.

sures and the structure of fish, mollusc and benthic communities. Unless otherwise specified, all multivariate methods were performed using the PRIMER package (Clarke and Gorley, 2001).

3. Results

3.1. Fish assemblages

There was considerable variation in the species richness of fish assemblages across the study (Fig. 2). However, this was mostly associated with differences between reefs within a location and there was no significant difference overall between locations (Table 1). Significant differences were evident between at least some of the reefs at the Coffs Harbour and South West Rocks, but not at Yamba (Fig. 2).

Data were fourth-root transformed prior to multivariate analysis to reduce the influence of the abundant species on the relationship between samples (Clarke, 1993). There were strong patterns of fish assemblage structure across the study. Thus, the nMDS analysis (Fig. 3) shows that sites at South West Rocks were very different to those from

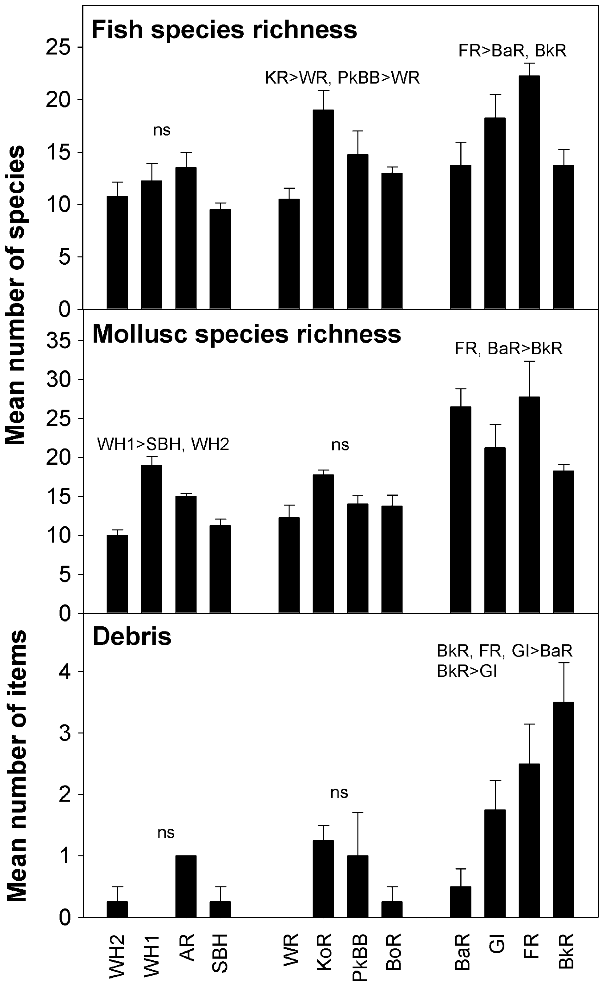

Fig. 2. Mean (±SE) values per transect for: species richness (S) of fish and molluscs, and the number of debris items (site abbreviations as in Fig. 1).

Table 1
Summary of the results (*P*-values) of two-way nested ANOVA for the species richness of fish and molluscs and the density of debris

	Loc	Site (Loc)	SNK (Loc)
Fish	0.115	**<0.001**	ns
Molluscs	**0.009**	**0.002**	SWR > CH = Y
Debris	**0.041**	**<0.001**	SWR > CH = Y

Significant values appear in bold font. ns = not significant.

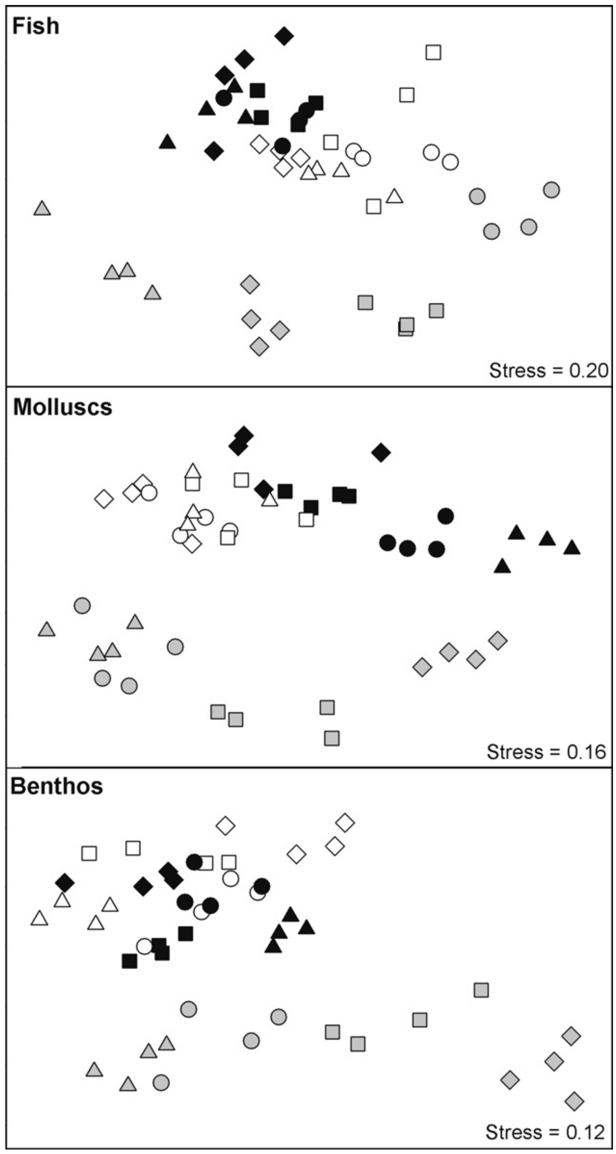

Fig. 3. Non-metric MDS plots of biotic assemblages across the 12 reefs evaluated in the study. Yamba – ▲ = WH2, ● = WH1, ■ = AR, ◆ = SBH; Coffs Harbour – △ = WR, ○ = KoR, □ = PkBB, ◇ = BoR; South West Rocks – ▲ = BaR, ● = GI, ■ = FR, ◆ = BkR (site abbreviations as in Fig. 1).

the other two locations and formed discrete groups of points, clustered by reef, across the lower half of the plot. This pattern indicates not only that fish assemblages at South West Rocks were very different to the other locations, but also that assemblages showed strong site fidelity.

Table 2
Summary of the results of two-way nested PERMANOVA (*P-perm* values) for fish, mollusc and benthic assemblages

	Loc	Site (Loc)	Sig. pairwise
Fish	**0.001**	**0.001**	CH vs SWR
Molluscs	**0.001**	**0.001**	All contrasts
Benthos	**0.006**	**0.001**	Y, CH vs SWR

Significant values appear in bold font.

The results of PERMANOVA (Table 2) indicated significant effects for location, and sites nested within locations, and for all pairwise contrasts between locations. With the exception of Angourie Reef vs Shelley Beach Headland Reef at Yamba ($P\text{-}perm = 0.053$), all comparisons between reefs within locations were significant ($P\text{-}perm < 0.029$ for all).

3.2. Mollusc assemblages

High levels of variation within a location were also apparent for mollusc species richness (Fig. 2) but this did not mask the differences between locations (Table 1) with South West Rocks supporting a significantly higher richness than Coffs Harbour or Yamba. Between-reef differences were evident at both Yamba and South West Rocks but not at Coffs Harbour (Fig. 2).

The nMDS, using untransformed abundance scores, shows a very obvious separation by location (Fig. 3) with most reefs at each location also showing distinct differences. The results of PERMANOVA confirmed that these differences were significant (Table 2). At South West Rocks and Yamba, individual reefs supported discrete mollusc assemblages ($P\text{-}perm < 0.043$ for all contrasts). However, at Coffs Harbour, there were no significant differences between Boambee and Korora reefs ($P\text{-}perm = 0.073$).

3.3. Benthic assemblages

Patterns of benthic community structure showed similarities to those for fish and molluscs with strong separation of reefs at South West Rocks from those at other locations and also from each other, and overlap between samples from Yamba and Coffs Harbour (Fig. 3). The results of PERMANOVA confirmed significant effects for both location and reefs nested within locations and also revealed significant differences between South West Rocks and the northern locations. Pairwise contrasts within locations indicated that all reefs were different ($P\text{-}perm < 0.040$ for all comparisons).

3.4. Debris

Debris loads were generally low at most sites (<2 items 125 m^{-2}). However, there was a strong difference between South West Rocks and the other locations (Table 1, Fig. 2) with the three highest densities (in transects) occurring on reefs at this location. These patterns were even more evident when the data from roaming surveys were included. Thus, using total debris items at each reef as replicate data in a one-way ANOVA, there were significant differences between locations ($F = 6.65$, $P = 0.018$) with South West Rocks supporting greater debris loads ($\bar{X} = 15.8$ per reef) than Coffs Harbour ($\bar{X} = 7.5$) and Yamba ($\bar{X} = 4.3$), which were not significantly different from each other. Fishing-related debris was by far the most prevalent at all locations (35–61% – Fig. 4) while non-fishing-related plastics were also found at all locations and contributed a consistent proportion (15–18%) to the total debris load.

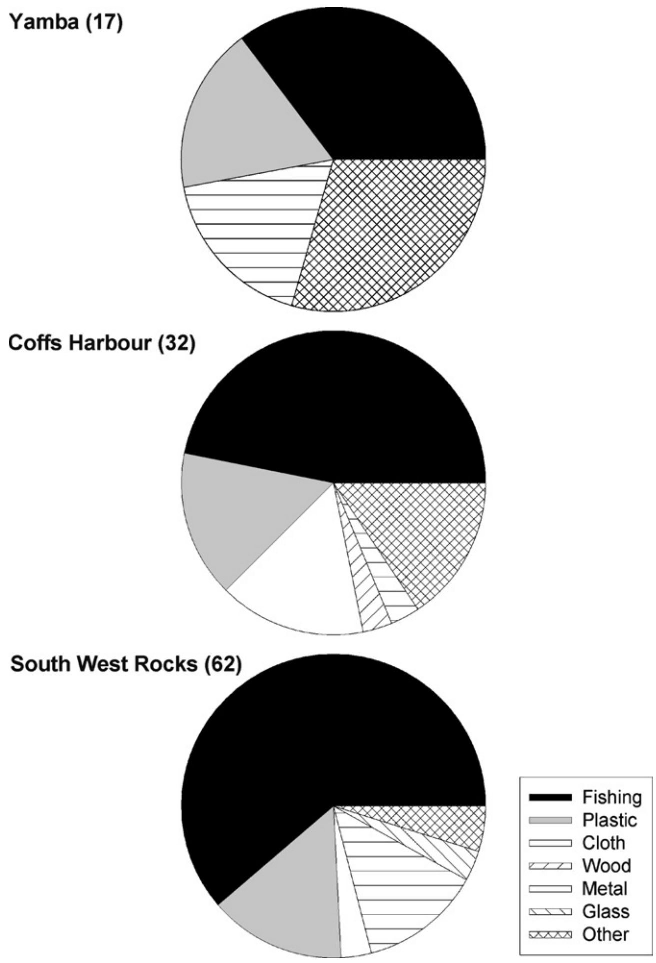

Fig. 4. Pie-charts showing the relative contribution of different types of debris to the total (transects plus roaming searches) found at each location. The number in brackets after each location name is the total number of debris items found during surveys at that location. Categories follow the order in the legend in an anticlockwise direction.

3.5. Relationships between biotic variables and physical data

Stepwise regression indicated that depth and reef size were the best predictors of molluscs species richness ($P < 0.001$, $P = 0.005$, respectively) which, together explained 41.9% of the variation between biotic and physical data. Mollusc species richness increased with depth but decreased with increasing reef size. The relationships for species richness of fish were more complex with four physical variables included in the final subset which explained 58.7% of the variation. Thus, depth ($P < 0.001$), reef size ($P = 0.002$), latitude ($P = 0.031$) and distance offshore ($P = 0.041$) all showed significant relationships with fish species richness, which increased with depth, latitude and distance offshore but decreased with increasing reef-size.

Correlations between benthic, mollusc and fish assemblages using the RELATE procedure were significant. The strongest correlation (Spearman rank correlation – ρ) was between mollusc and benthic assemblages ($\rho = 0.724$, $P = 0.001$) with slightly lower values for fish and benthos ($\rho = 0.627$, $P = 0.005$) and molluscs and fish ($\rho = 0.575$, $P = 0.001$). Correlations were also performed (BIOENV) between the three sets of biotic data and the suite of physical measures determined for each transect at each reef. The best correlations for each set of biota were: molluscs – latitude and reef type ($\rho = 0.650$); fish – habitat complexity and reef type ($\rho = 0.602$); and benthos – latitude and reef type ($\rho = 0.569$).

3.6. Relative conservation value vs debris load

While many factors contribute to the conservation value of a reef (e.g. Regan et al., 2007), and this study addressed only some of these, we nevertheless attempted to distil a summary conservation value (SCV) based on the biodiversity recorded at each reef. To do this, we summed the mean richness (across transects) of fish and molluscs for each site. Benthic data were not used within this metric as categories included physical habitats (e.g. sand, rubble and free-space). By comparing the SCV scores with debris load at each site, it was possible to determine potential conflicts that may need to be addressed if high value sites are to be sustainably managed. The data clearly show that the sites with the highest SCVs also had the highest debris loads (Table 3) and further correlation analysis indicated that this relationship was significant ($r = 0.622$, $P = 0.031$).

Table 3
Summary conservation value (SCV – sum of mean species richness of molluscs and fish across transects) and total debris load (from transects and roaming surveys) for the 12 reefs assessed during the study (listed by SCV rank)

Reef	SCV	Total debris load
Fish rock (SWR)	50.00	15
Green Island (SWR)	39.50	18
Korora reef (CH)	36.75	14
Black rock (SWR)	32.00	24
Woody Head reef 1 (Y)	31.25	2
Bait reef (SWR)	30.25	6
Park Beach Bommie (CH)	28.75	11
Angourie reef (Y)	28.50	7
Boambee reef (CH)	26.75	3
Woolgoolga reef (CH)	22.75	4
Shelley Beach Headland reef (Y)	20.75	6
Woody Head reef 2 (Y)	20.75	2

Y = Yamba, CH = Coffs Harbour, SWR = South West Rocks.

4. Discussion

This preliminary, multifaceted investigation of nearshore reefs on the mid-north coast of NSW revealed some important insights into: spatial variability in community patterns over scales ranging from hundreds of metres to hundreds of kilometres; current levels of human impact as exemplified by debris load; and challenges for mangers in balancing the amenity and human use of reefs with their long-term sustainability. Each of these is discussed below.

4.1. Spatial variation in biotic assemblages

Marine communities on nearshore reefs in this region are highly variable over the spatial scales examined in the study. Thus, both the richness of communities, and the relative abundance and identity of their component species, differed between most reefs within a location as well as between locations. Analyses of variation in species richness clearly identified depth and reef size as important contributors to variation for both molluscs and fish, while latitude and distance from shore were also important predictors for fish. Interestingly, despite the widely accepted paradigm that marine species richness decreases with increasing latitude, the southernmost locality in this study, South West Rocks, supported the highest diversity of molluscs. However, this is likely to be a local anomaly caused by the influence of the East Australian Current which regularly bathes this easterly projection of the NSW coast and is a recruitment source of tropical species with pelagic larvae (Harriott et al., 1994, 1999). Indeed, water temperature recorded by fixed loggers over the last few years indicate that Green Island and Fish Rock generally experience water temperatures higher than nearshore reefs offshore from Coffs Harbour to the north (H. Malcolm, unpublished data). Observations made during this study lead very easily to the hypothesis that South West Rocks is an important sink area for a range of tropically-affiliated taxa.

Multivariate analyses of the relationship between the different assemblages indicated a strong and significant association between mollusc, fish and benthic assemblages. This is consistent with many other studies that have demonstrated specific habitat associations of motile taxa with biologically and physically structured habitats (Kohn, 1968; McClanahan, 1990; Curley et al., 2002; Gratwicke and Speight, 2005b; Pante et al., 2006; Grober-Dunsmore et al., 2007). The strongest correlation was between molluscs and the benthos which reflects the feeding association of many molluscs with specific sessile taxa (e.g. ovulids with soft corals, coralliophilids with hard corals). The strength of this relationship also suggests that human impacts that affect the composition of benthic communities (such as altered sediment regimes and nutrient loads – McCook, 1999) would be reflected in changes in mollusc communities, supporting intertidal studies that advocate their use as biodiversity surrogates in conservation planning (Gladstone, 2002; Gladstone and Alexander, 2005; Smith, 2005).

Correlations with physical variables highlighted latitude (benthos and molluscs), reef type (fish, molluscs and benthos), and reef complexity (fish), as key predictors of patterns, although much of the variation remained unexplained by these analyses. It is clear from this that biotic patterns are complex and affected by a suite of both measured and unmeasured factors that result in the observed, high levels of variation across all scales of the study.

The high levels of spatial heterogeneity demonstrated by this study have ramifications for management of nearshore reefs. In marine park zoning schemes, for example, arbitrary measures (i.e. a percentage of a broad habitat type) may be used to allocate conservation effort when qualitative information on community types and quantitative data on their comparative diversity is lacking (e.g. Breen et al., 2004). This approach makes the unavoidable assumption that reefs of a similar type support similar communities – which is not supported by this study. Thus, despite recent success in the use of physical data or broad, qualitative, habitat data as surrogates for community composition (O'Hara, 2001; Banks and Skilleter, 2002; Shears et al., 2004; Stevens and Connolly, 2004; Kuffner et al., 2007), this study reasserts the need for biotic data, at appropriate scales, for conservation planning (Gladstone, 2007). While the generation of these types of data requires effort, this study clearly demonstrates that such effort is essential in order to identify reefs with high conservation value and to ensure that representative habitats and communities are adequately conserved.

4.2. Debris on reefs

Debris, from both marine and terrestrial sources, was present on all reefs surveyed. This is despite the fact that many of these reefs are remote from centres of high population density. Fishing activities contributed by far the majority of debris across all sites and plastics were also a consistent component of debris loads. Of particular concern was the observation that debris load was highest on reefs that also had high conservation value. There are a number of possible explanations for this. Despite South West Rocks having a substantially lower population than the other locations, more debris was found on reefs in this locality than at most other sites. This may well be associated with the fact that there are very few reefs within the region and fishing is, therefore, more concentrated on these reefs than on those at locations where reefal habitats are more prevalent. A further possibility is that the general amenity of diverse reefs is higher and so activities such as fishing and diving are more likely to occur at these sites. Whatever the reason, conflict between human use, and fishing in particular, and marine communities at these sites is highly evident. While the higher debris load reduces the visual appeal of a site for divers and snorkellers, the nature of debris interactions with the benthos is of more concern. For example, corals are a dominant feature of benthic communities at Black Rock (e.g. Harriott et al., 1999; Smith et al., 2006) and over half of the fishing-related debris at this site was found entangled around coral (especially on colonies of the branching species *Pocillopora damicornis*). Monofilament is highly persistent in the marine environment and has been documented as a major source of coral mortality in heavily-fished localities elsewhere (Asoh et al., 2004; Yoshikawa and Asoh, 2004). As South West Rocks is the most southerly location on the Australian east coast to support well-developed, albeit localised, coral communities (Harriott et al., 1999) the demonstrated levels of impact are clearly a cause for concern.

4.3. Long-term sustainability

This preliminary study provided a one-off evaluation of the condition of just 12 reefs in subtropical eastern Australia. The reality of the situation is that, with the predicted rates of growth for the population centres adjacent to these reefs, their condition is likely to deteriorate unless they are carefully and holistically managed (i.e. linked terrestrial–marine management). The study has highlighted the existing conflicts between sites with high conservation value and human impact in the form of debris. This represents only a very small sample of nearshore reefs along this coast and it is highly likely that similar conflicts are not uncommon. Clearly then, there is a need for wider information about the conservation value of such reefs, determinations of existing levels of impact, and the establishment of long-term monitoring to establish measures of natural temporal variation within these systems. Without the latter, in particular, it will be difficult to detect the effects of increasing anthropogenic pressure, obviating the possibility of these habitats being optimally managed into the future.

The protocol developed for use in these surveys of nearshore reefs has proven to be cost-effective, providing linked data that facilitate a holistic assessment of reef health. Although more time-consuming to collect than simple measures of physical complexity and habitat type, the data provided by this suite of methods are sufficiently detailed to provide good descriptors of communities and are sensitive enough to determine differences in community structure across spatial scales of only a few hundred metres. Thus, we strongly advocate a similar approach in studies of reef condition elsewhere and will be further refining these methods (e.g. using data loggers to monitor salinity and sediment traps to evaluate changes in sediment regime) during the establishment of a long-term monitoring program for nearshore reefs on this, the sea change coast.

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