Southern Cross University
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A long-term program to monitor the health of nearshore reefs

Report cards for 2012/13

Stephen D. A. Smith, Matthew A. Harrison, Steven J. Dalton, Robert J. Edgar and Ian V. Shaw

NSW GOVERNMENT | Catchment Management Authority Northern Rivers

Report prepared for the Northern Rivers Catchment Management Authority, August 2013

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Cover photographs by Steve Smith (left to right): *Bennett's nudibranch (*Hypselodoris bennetti*) at Nambucca Reef; A small hawkfish (*Cirrhitichthys falco*) at Cook Island; soft plastic lures are becoming more common in debris surveys*

Executive Summary

This study follows previous investigations of the health and biodiversity of nearshore reefs in the Northern Rivers region of NSW. In earlier reports, we provided descriptions of the marine biodiversity of 25 nearshore reefs at representative locations along the coastline of the NRCMA region (Smith et al., 2006; 2009), and summaries of changes in the values of key indicators in follow-up surveys at key sites (Smith et al., 2010, 2011, 2012). This report provides data on the condition of 7 sites surveyed between September 2012 and June 2013, and adopts the previously established “report card” format.

A suite of methods was used to provide as wide an assessment of reef condition as practicable. Thus, measures of biodiversity (fish and molluscs) and benthic community structure were combined with assessments of anthropogenic debris load (as an indicator of existing human impact). In 2012/13, we re-surveyed 4 nearshore reefs (Cook Island, Park Beach Bommie, Nambucca Reef and Black Rock - South West Rocks), 1 mid-shelf reef (Split Solitary Island) and included 2 offshore reefs (North Solitary Island and South Solitary Island) as part of the adaptive management of the project.

Reef condition was generally good at all sites with most biodiversity measures being within the range of previous surveys. The exceptions were at Cook Island South where mollusc diversity was substantially higher than recorded in 2012, and Split Solitary and South Solitary islands where mollusc and fish diversity, respectively, were lower than in previous surveys. However, these lower diversity values were not associated with obvious loss of habitat condition and most likely reflect natural variation.

Of concern was the fact that 4 of the 5 sites for which this was repeated sampling, recorded their highest marine debris loads during 2012/13. Most of the debris items were fishing-related, and mostly comprised monofilament fishing line entangled around corals. The highest loads were at the 2 sites at Cook Island, both of which are within the Cook Island Aquatic Reserve from which fishing is prohibited. This is a recurrent observation and one which requires management intervention to mitigate.

Further investigation into the apparent loss of mollusc biodiversity at Cook Island South in 2012 suggested that some of the decline in species richness may simply be related to habitat heterogeneity, and the consequent variability associated with the distribution of mollusc taxa. However, extensive searches in 2013 failed to find any specimens of *Cerithium novaehollandiae* which was one of the more common

species in historical sampling. Benthic conditions had improved at this site in 2013, with little evidence of the fine silt that coated most surfaces in the previous 2 years. This site clearly shows considerable variation in conditions, and is one of the most diverse for both fish and molluscs, and should consequently receive continued, and preferably intensified, monitoring effort into the future.

The extension of the program to include more offshore sites is consistent with the broadening of the objectives to assess potential impacts of climate change as well as the effects of change in land-use practices within the region. Subsequent iterations of the program should continue this approach by adding a mid-shelf site with high coral cover (South West Solitary Island) whilst also gaining temporal data on the nearshore locations previously identified as core monitoring sites.

Contents

Introduction

Nearshore reefs, which we broadly define as being within 1.5 km of the coastline (e.g. Malcolm et al. 2010b), are the first diverse habitats likely to be affected by changed land-use in adjacent areas. Indeed, nearshore reefs are already under threat from a range of coastal management practices including, for example: dredge-based, beach nourishment programs (e.g. Smith & Rule, 2001) that have the potential to completely smother reef habitats (Peterson & Bishop, 2005); run-off which reduces water quality and affects sediment regimes (e.g. Thrush et al., 2004); and marine debris, listed as a Key Threatening Process in Australia (Department of the Environment & Heritage, 2003; Smith et al., 2008; Smith, 2010), which is readily transported and trapped on shallow reefs. Nearshore reefs are also important for the amenity of human populations, especially along the north coast of New South Wales (NSW) where tourism is one of the primary industries, providing important resources for a range of activities such as snorkelling, diving and fishing (e.g. Hammerton et al., 2012). There is little doubt then, that monitoring of 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. This is the context underpinning this long-term monitoring (LTM) of reef health.

In previous reports (Smith et al., 2006, 2009) we provided detailed analysis of the biodiversity and debris load on 25 reefs across the Northern Rivers region of NSW (Tweed River to South West Rocks) and the rationale for targeting a reduced set of 12 reefs for long-term monitoring (Smith et al., 2009). In our most recent reports (Smith et al., 2010, 2011, 2012) we provided data from repeated sampling of some of these reefs and summarised the trends in biodiversity and human impact (as represented by marine debris) in simple Report Cards. Here, we continue the examination of temporal trends across reefs by providing additional data from 5 previously surveyed reefs, and expand data collection to 2 offshore reefs within the Solitary Islands Marine Park (South Solitary and North Solitary islands).

With any long-term program, it is important to consider how sampling may be expanded to address issues not initially factored into the study, or to complement more recent initiatives. The primary objective of the project is to monitor the conditions on reefs with a view to evaluating changes related to the predicted high rate of population growth and consequent changes in land-use patterns (Smith et al., 2006). Since the commencement of this project, however, it has become increasingly apparent that the region is a critical area to monitor with respect to climate-change driven effects. It has been suggested that subtropical eastern Australia, and especially the north coast of NSW, may become a refuge for tropical species unable to cope with increasing sea temperatures (Beger et al., 2011). At the same time, a change in water temperatures may further threaten endemic species with limited distributions, forcing them southward and/or making them locally extinct (Malcolm et al., 2011). Each of these effects could potentially be detected by long-term programs such as this.

For this reason, from 2011, we included additional reefs in the program, focusing initially on quantitative evaluation of condition at 2 mid-shelf islands in the Solitary Islands Marine Park (Split Solitary and North West Solitary islands). In 2012, to complement the catchment-based Ecohealth program (coordinated by the NRCMA) we also expanded the list of sites to include Muttonbird Island, a diverse reef (e.g. Smith & Simpson, 1991; Harriott et al., 1994) immediately offshore from Coffs Creek, which was the target of Ecohealth monitoring in 2012 (Ryder et al., 2012). Data on fish communities have been collected at this site since 2007 as part of a separate program (Smith, unpublished). Sampling was extended to all of the key LTM variables in 2012. In the 2013 iteration of the program, we continued the site expansion by including 2 offshore locations with the SIMP, South Solitary and North Solitary islands. These offshore sites are known to support assemblages of coral (Harriott et al., 1994), fish (Malcolm et al., 2010a) and molluscs (Harrison & Smith, 2012) that are different to those found closer to shore, primarily because of more frequent contact with the East Australian Current (Malcolm et al., 2011).

In 2012, we recorded the first unambiguous decline in the biological condition of one of our core monitoring sites at Cook Island (Smith et al., 2012). There was a clear reduction in the diversity of molluscan assemblages with the loss of 2 species of gastropod that had been common in previous surveys. This decline was associated with an anecdotal increase in the cover of fine silt on most benthic surfaces. Given this alarming trend, we re-surveyed the site in 2013 and conducted more comprehensive assessments of changes in molluscan assemblages to shed more light on the trends.

Methods

The study locations of each of the 7 reefs surveyed for this report are shown in Fig. 1. The coordinates for each site are provided in the *Results* section in the Report Cards for each reef.

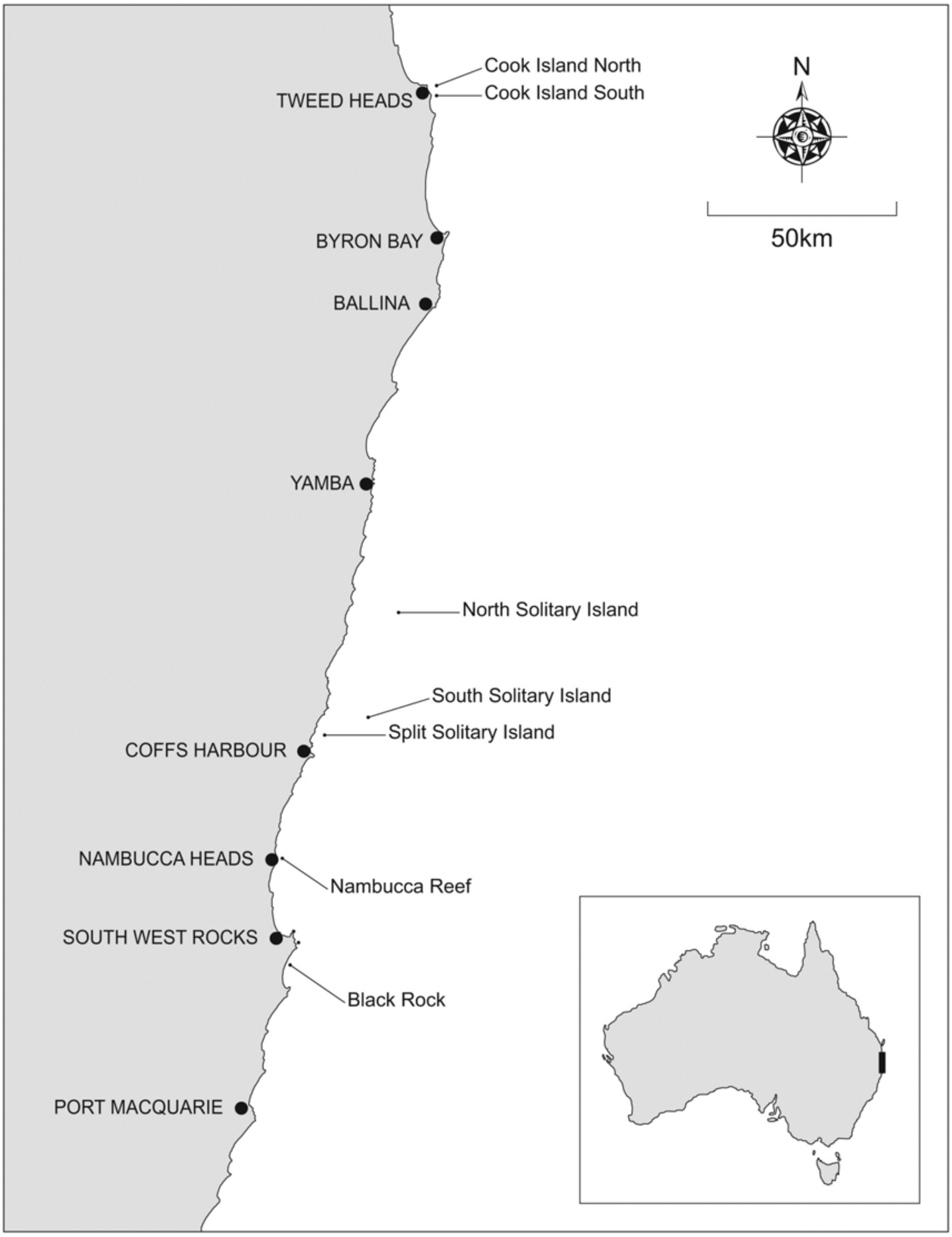

Fig. 1. Map of the NRCMA region showing the location of the 7 reefs surveyed for this report.

Field and laboratory methods

General study design

The suite of methods used in this study was chosen to provide as wide an assessment of reef condition as practicable. Thus, measures of biodiversity were combined with assessments of anthropogenic debris load as well as surveys of coral health and condition. The reasons for choosing each of the variables, as well as the specific methods used to assess them, are outlined below.

The overall approach (methods and design) for the surveys was based on initial work conducted in nearshore reef habitats in south-eastern Queensland and northern NSW in the past (Edwards & Smith, 2005, Smith et al., 2005, 2006, 2008, 2009, 2010). The extensive surveys conducted in 2006 further refined the methods and resulted in the recommendation of a standard protocol for such studies (Rule & Smith, 2007). A brief description of the methods appears below; full details are provided in Rule & Smith (2007) and Smith et al. (2008).

The main sampling unit for data collection was a 25-m transect across which the majority of the quantitative data were collected. Thus, at each reef, four 25-m transects were randomly placed within a depth-range of 8-12 m and each of the main sampling methods was performed sequentially across these transects (Fig. 2). For the most part, and to reduce confounding associated with differences in depth, transects were deployed in a narrower depth range (8-10 m) wherever possible. Experience from previous surveys using the same methods indicated that 4 replicate transects provide data that are both precise and cost-effective for descriptions of biotic patterns on nearshore reefs (Edwards & Smith, 2005, Smith et al., 2006, 2008).

Where possible, transects were deployed from a random point in the middle of the reef, at radial intervals of 90^o. Thus, viewed from above, transects radiated out from a central point and formed a cross. On some smaller reefs, or on fragmented reefs, this pattern could not always be achieved and so, in such cases, transects were allocated randomly across the available reef habitat. In all cases, transects were deployed so that they were spaced by at least 10 m to maximise the likelihood that each was independent of all others.

Fish community structure

Fish are one of the most visible components of reef communities and fish assemblages are known to respond to a variety of human impacts. Fish also represent an important commercial and recreational resource and so there is considerable public interest in the composition of assemblages and, in particular, how these might be affected by human impacts.

Fish communities were compared using quantitative counts within a corridor measuring 2.5 m either side of the tape-measure and to a height of 5 m above the substratum (Fig. 2A).

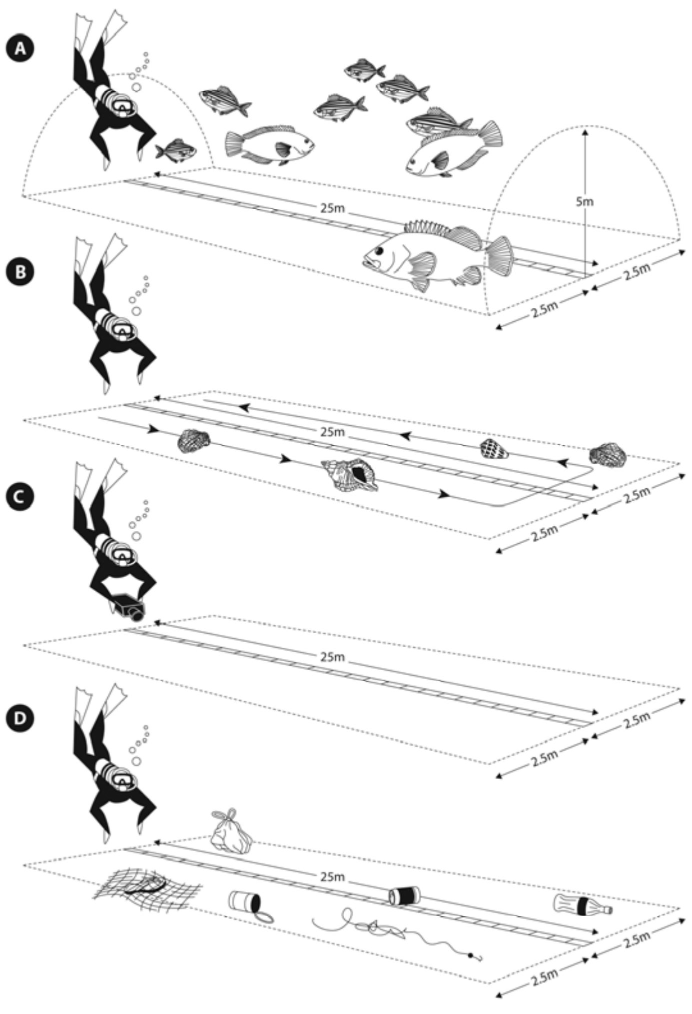

Fig. 2. Diagrammatic representation of the methods used to assess the four primary variables targeted along the replicated 25-m transects. A) Fish assemblages; B) Molluscs (bivalves and shelled gastropods); C) Benthic communities (video); D) Debris (reproduced from Smith et al., 2006).

Using this method, the identity and number of pelagic fish (i.e. those associated with the water column) are assessed during the first passage of the transect and benthic and demersal fish are documented during the return swim within the same corridor. The number of individuals of all species was recorded. Juveniles (young-of-the-year) were listed but excluded from subsequent analysis. The time taken to complete each transect is dependent on the abundance and diversity of the fish assemblage; an upper limit of 30 min per transect was applied in all cases. Pelagic fish are known to be highly variable over space and time (most aggregate in schools and move through areas quickly) and are generally removed from data sets prior to assemblage-level analyses as they can over-influence patterns (e.g. Smith et al., 2009). However, in this Report Card format, which reports overall species richness, both pelagic and demersal species are included.

Mollusc biodiversity

Molluscs are one of the most abundant groups of invertebrates in the marine environment, occupying the full range of available habitats. Recent work on rocky shores has indicated that molluscs have exceptional promise as surrogates for other invertebrate taxa both for reflecting gradients of community structure and in predicting total species richness for a site (Smith 2005). Subtidal habitats generally support many more invertebrate species, from a wide range of taxa, than adjacent intertidal areas. Many of these species are in groups which are difficult to identify *in situ* or for which taxonomic data are currently poor or inaccessible. For this reason, the reef condition assessment protocol targets molluscs as an indicator of wider invertebrate biodiversity.

Mollusc biodiversity was assessed by examining a strip of reef 2.5 m either side of each transect (i.e. a total of 125 m^2 per transect) (Fig. 2B). As some species are highly abundant, it was not practicable to count all individuals and a semi-quantitative scoring system was adopted. The scoring is based on a log_3 system which provides the most relevant abundance categories for the densities encountered (Table 2). Only the shelled gastropods and bivalves, which comprised by far the majority of species, were documented (Smith, 2005) and survey time was restricted to 30 min per transect.

Table 2. Semi-quantitative scoring system used to assess mollusc abundance.

Abundance	Score
1-3	1
4-10	2
11-30	3
31-100	4
101-300	5
>300	6

Benthic community structure

The structure of sessile, benthic communities is a fundamental biological property of a reef that has a large influence on the other types of organisms that might be found there. Benthic community structure is a product of a large number of biological and physical factors (and their interactions); patterns are often predictable given knowledge of the physico-chemical parameters at a specific site (e.g. depth, salinity, latitude, wave exposure, surrounding habitat type). For these reasons, amongst others, assessments of benthic community structure are important components of reef studies.

Benthic community structure at each reef was assessed using standard video-transect methods (Fig. 2C). The camera was held pointing vertically downwards, 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 (biological) groups was subsequently determined in the laboratory by pausing the tape at predetermined intervals and identifying the categories lying below 5 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. A total of 300 data points were assessed for each transect and data summaries were facilitated by the use of CPCe software (Kohler & Gill, 2006). Where present, hard corals were also enumerated and examined to determine the presence of stressors such as disease, bleaching and aggregations of predators. While benthic communities were assessed during the field work in 2012/2013, the results are not presented in this report.

Debris

Debris has been identified as one of the Key Threatening Processes to marine habitats and organisms in Australia (Department of the Environment & Heritage, 2003), especially to threatened and/or endangered species. As much of the debris present in marine habitats originates from adjacent coasts, 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 (Smith et al., 2006, 2008, Smith, 2010). An assessment of debris load will thus provide an indication of risk to nearshore reefal habitats and biota.

Debris was documented and removed (where possible or appropriate[1]) in a corridor 2.5 m either side of the tape-measure (Fig. 2D). Items were subsequently counted and classified into broad categories based on material and use. An additional 30-min, timed survey was conducted outside the transects to document other debris within the site.

Habitat complexity

Habitat complexity (or rugosity) can have a strong effect on community structure, especially for fish (Gratwicke & Speight, 2005; Carraro & Gladstone, 2006; Lingo & Szedlmayer, 2006). Thus, assessments of complexity are important in the interpretation of studies of community patterns among reefs.

Substratum heterogeneity at each reef was determined using the ‘rope-and-chain’ method (Luckhurst & Luckhurst, 1978). This technique consisted of contouring a second tape measure to the substratum under the already established, horizontal, 25-m transect to provide an outline length for the substratum. The ratio of the contoured measurement to the horizontal measurement can then be used as a simple indication of habitat complexity. These data are expected to be relatively invariant between surveys as the same sites are targeted each time. Thus, while these data were collected in 2012/2013, they are not presented in this report.

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

Analytical methods

Report Cards

Following the template established in the first report of follow-up surveys (Smith et al., 2010), this report summarises the data into Report Cards that document how key variables have changed over the duration of the study. This not only provides a summary of broad trends in the key variables at a glance, but also fits with the current practice of the many management agencies (through various monitoring, evaluation and reporting and improvement (MERI) programs). In the Report Cards presented below, we provide information on biodiversity (mean species richness from the four transects conducted at each site) and total debris load at each site. We also provide brief observational notes about the condition of the habitat at the most recent time of sampling. Data from Cook Island South are available from related studies conducted prior to the implementation of the LTM (Edwards & Smith, 2005; Smith et al., 2005) - these have been included to provide additional insight into temporal patterns. Data are also available for surveys of fish communities at the same sites at Split Solitary and South Solitary islands in 2007, 2008, 2011 and 2012 (and from Split Solitary Island in 2010): these data are also included.

Analyses of molluscan patterns at Cook Island South

As identified in the Introduction, there was a noticeable shift in mollusc assemblage patterns in 2012 with both a reduced species richness, and the loss of 2 species that were previously common. For this reason, the assemblage-level patterns are explored in more detail in this report. Data exploration comprised multivariate analysis of assemblage-level data including: non-metric Multidimensional Scaling (nMDS); permutational analysis of variance (PERMANOVA); and similarity percentage (SIMPER). As molluscs are assessed using a scoring system rather than actual abundance, untransformed data were used to construct a Bray-Curtis similarity matrix which was then used as the basis for nMDS and PERMANOVA. Univariate analyses of differences in species richness were assessed based on a matrix of Euclidean distances. SIMPER analyses were used to provide a list of taxa that primarily drove differences in assemblage patterns between sampling times, and vectors (based on Spearman rank correlation) for the highest ranked species were superimposed on the nMDS to give a graphical representation of the way in which they contributed to overall patterns. All analyses were performed in the PRIMER 6 + PERMANOVA package (Clarke & Gorley, 2006; Anderson, 2008).

Results

Report Cards

The following pages present brief Report Cards for the 7 reefs surveyed in 2012/2013. The report cards are mostly self-explanatory and provide brief background information on the reef, including GPS coordinates and distance from the nearest point on the mainland shore. The survey data are summarised as averages for the biodiversity measures and as totals for the marine debris (combined data from four transects and the 30-min searches). Colour codes are used to signify trends for the most recent sample: red signifies a deterioration of the measure (a reduction by ≥25% of the species richness recorded in the previous study); green indicates an improvement in the measure (≥25% increase in the species richness recorded in the previous study); orange indicates that the measure has remained similar to the previous value (<25% change in either direction). The colour-coding system was also applied to data for marine debris. However, where there was a substantial reduction in debris load, but accumulation rates were still moderate to high, an orange coding is used rather than a green coding.

Cook Island North

Latitude:	-28.19450
Longitude:	153.57613
Distance from shore (m):	590

Description:	Island-associated reef on the north-western corner of Cook Island. Transects run the length of a wall comprising medium-sized (~1 m diameter) boulders. The site is within the Cook Island Aquatic Reserve.

Dates of surveys	June 2008	Aug 2009	Aug 2012	June 2013
BIODIVERSITY MEASURES				
Mollusc richness	18.0	25.5	18.3	28.8
Fish richness	26.8	23.5	42.3	44.5
IMPACT MEASURE				
Total debris load	19	7	15	37

Comments:	Visibility was good in 2013 (~12-15 m). However, swell was moderate which meant that surveys of molluscs and video transects were difficult on the most seaward transects.

Trends:	All metrics were the highest yet recorded for the site. Mollusc richness was substantially higher than in 2012 and similar to the values recorded in 2009. Debris loads were more than twice those recorded in 2012 with most (29) items comprising fishing line. Fish richness was similar to the values recorded in 2012.

Cook Island South

Latitude:	-28.19620
Longitude:	153.57626
Distance from shore (m):	560

Description:	Island-associated reef on the south-western corner of Cook Island. Transects were placed on a southward-directed, gently sloping, section of reef that included the "pan handle" at its western edge. The site is within the Cook Island Aquatic Reserve.

Dates of surveys	June 2003	Nov 2004	June 2008	Sept 2009	June 2011	Aug 2012	June 2013
BIODIVERSITY MEASURES							
Mollusc richness	no data	16.0	22.3	19.3	21.3	14.3	27.3
Fish richness	31.0	27.8	22.8	19.8	31.8	32.3	37.0
IMPACT MEASURE							
Total debris load	no data	no data	17	11	13	1	29

Comments:	Visibility was good in 2013 (~15 m) which, combined with a low swell, provided ideal conditions for the surveys. The fine silty sediment apparent in the last 3 surveys was no longer evident. The temperature data logger deployed in 2011, and changed in 2012, was successfully recovered and a new logger was deployed.

Trends:	Mollusc richness recovered from the low of 2012 to be the highest recorded from this site to date. Similarly, fish richness was the highest yet recorded from the site. However, while the biodiversity metrics showed positive trends, this was not the case for marine debris which was the highest on record. Most of the debris comprised monofilament fishing line which was found entangling corals.

North Solitary Island

Latitude:	-29.92766
Longitude:	153.38947
Distance from shore (m):	11235

Description:	Island-associated reef on the north-western side of the island. The site is adjacent to a permanent mooring and is the site of a number of previous projects focusing on benthic community structure (e.g. Harriott et al., 1994). The site is primarily coral dominated and contains considerable quantities of old debris resulting from the sinking of the Monterey (this was not assessed as part of debris load). It is also the site for the underwater trail established by the Solitary Islands Underwater Research Group. This site has been a sanctuary (no take) zone since 1991.

Dates of surveys	Apr 2013
BIODIVERSITY MEASURES	
Mollusc richness	28.0
Fish richness	35.0
IMPACT MEASURE	
Total debris load	2

Comments:	The surveys were conducted in good conditions with clear water and little surge. Transects ran parallel to the island. Diversity outside the transects was high, and a range of tropically affiliated cryptic fish species were observed although these were not included in the data (as per the protocol). Corals were healthy and very little marine debris was present.

Trends:	Not applicable.

Split Solitary Island

Latitude:	-30.242457
Longitude:	153.177260
Distance from shore (m):	2340

Description:	Island-associated reef on the south-western corner of Split Solitary Island in the Solitary Islands Marine Park. This site has been zoned as a sanctuary (no take) zone since 1991.

Dates of surveys	May 2007	May 2008	May 2010	June 2011	May 2012	May 2013
BIODIVERSITY MEASURES						
Mollusc richness	no data	no data	no data	22.0	no data	14.8
Fish richness	19.0	21.3	14.0	13.8	23.0	16.5
IMPACT MEASURE						
Total debris load	no data	no data	no data	1	no data	13

Comments:	This site has been included as part of a nearshore-offshore gradient to facilitate modelling of the effects of a range of different parameters on the biodiversity and community structure of shallow reefs in the region. In 2013, we sampled the same site as in 2011 for which extensive historical fish data are available (inc. 2012). Underwater visibility was poor at this site in 2013 (~7 m) and only just within the allowable limits under the sampling protocol (min. 6 m).

Trends:	Fish richness was substantially lower than in 2012 but within the range of results recorded since 2007. Mollusc richness was substantially lower than in 2011. All of the marine debris was monofilament found entangled around corals.

South Solitary Island

Latitude:	-30.20169
Longitude:	153.26665
Distance from shore (m):	7585

Description:	The site is adjacent to the North Boulder Wall mooring on the north-western side of the island. Transects were set perpendicular to the island shore across a shelf comprise boulders of various sizes between depths of 8-12 m. There is high coral cover at this site.

Dates of surveys	May 2007	May 2008	May 2011	May 2012	April 2013
BIODIVERSITY MEASURES					
Mollusc richness					30.7
Fish richness	27.3	24.8	30.5	39.5	26.7
IMPACT MEASURE					
Total debris load					2

Comments:	Sampling conditions were comfortable in 2013 with low swell and underwater visibility of 20 m. Problems with the boat meant that one mollusc transect was only partially completed (this transect was omitted from the summary data).

Trends:	Fish species richness was lower than recorded in surveys conducted in the past 2 years but within the historical range for this site. The 2 items of debris were monofilament fishing line.

Nambucca Reef

Latitude:	-30.64053
Longitude:	153.02339
Distance from shore (m):	600

Description:	Part of a large area of reef north-east of Shelly Beach. This area is easily accessible from the Shelly Beach boat ramp and is a popular fishing location. The reef lies approx. 1 km NNE of the entrance to the Nambucca River.

Dates of surveys	Mar 2008	Jan 2010	Oct 2011	Sept 2012
BIODIVERSITY MEASURES				
Mollusc richness	18.8	14.8	19.0	17.3
Fish richness	9.0	17.5	15.5	15.5
IMPACT MEASURE				
Total debris load	5	4	2	6

Comments:	Surface conditions were good in 2012, but visibility was only marginally above the minimum workable level (6 m).

Trends:	All biodiversity metrics were within the values previously recorded for the site. Abundances of most species were low, especially for molluscan taxa. Although more debris was found than in other survey periods, loads were still quite low in comparison to many other reefs.

Black Rock

Latitude:	-30.94834
Longitude:	153.07611
Distance from shore (m):	800

Description:	Island-associated reef on the north-western side of Black Rock which lies south of Smoky Cape. The habitat in this area is dominated by hard corals.

Dates of surveys	Aug 2006	Mar 2010	May 2012	May 2013
BIODIVERSITY MEASURES				
Mollusc richness	18.3	26.5	30.5	27.8
Fish richness	14.5	17.3	30.3	34.8
IMPACT MEASURE				
Total debris load	25	14	44	19

Comments:	Sampling in 2013 was conducted in moderate southerly winds with underwater visibility of 12-15 m. Swell was low (<1 m).

Trends:	There was a continuation in the trend of increasing fish richness while mollusc richness was within the values recorded in all but the first surveys in 2006. Debris loads were less than half those recorded in 2012, but still primarily comprised monofilament entangling corals.

Analyses of molluscan patterns at Cook Island South

Molluscan assemblages show complex patterns of change over time (Fig. 3). In this plot, data points represent separate transects and they are labelled by year and replicate number. The blue-dotted lines enclose samples that are ≥40% similar. Thus, samples from 2004 group to the top right of the plot, those from 2011 to the bottom left and those from 2012 to the top left: the other years, including 2013, are intermediate in structure (lying between these 3 year clusters). The black circle with radiating vector lines is a superimposition of the contribution of key species (identified by SIMPER as primarily driving patterns) to the overall assemblage patterns. The direction of the line indicates increasing abundance and the length of the line represents the strength of the correlation (using Spearman rank correlation as the metric).

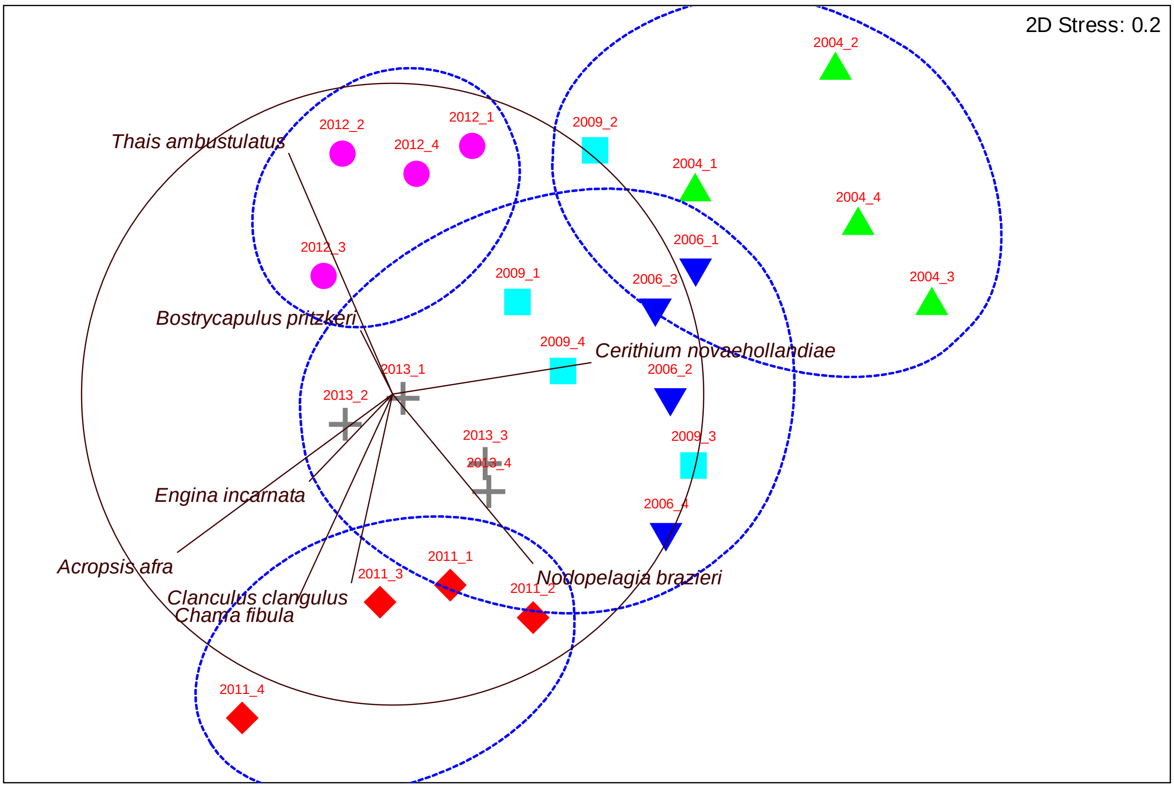

Fig. 3. Non-metric multidimensional scaling plot of the mollusc assemblage data from Cook Island South from 2004-2013. Blue-dotted contours enclose samples that are ≥40% similar, and the black vectors show the species highly correlated with over patterns in the plot.

Examining 2012, specifically, it can be seen that samples were typified by greater representation of taxa that are mainly found in areas with urchin grazing (*Bostrycapulus pritzkeri*) and rocky substrate (*Thais ambustulatus*), and by low absence of 2 species, *Nodopelagia brazieri* and *Cerithium novaehollandiae*, that had been recorded in all earlier studies. The latter species shows a high correlation through the main distribution of sample points, indicating a primary role in separating earlier samples from more recent ones. This reflects the decline in abundance since the initial samples in 2004. *Nodopelagia brazieri* was recorded in 2013, but in low abundances. The trends in scores for these 2 species over the study period are shown in Fig. 4.

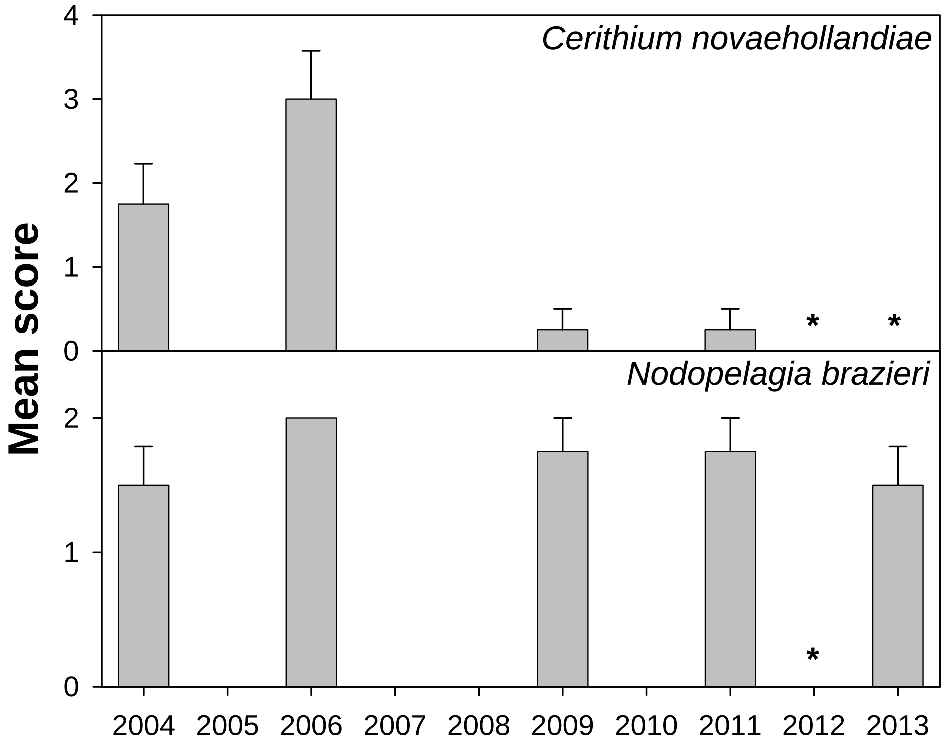

Fig. 4. Mean scores (± SE) for the 2 gastropod species that were absent in 2012. While *N. brazieri* was recorded in 2013, *C. novaehollandiae* was not found within any transects or in broader searches (* = none recorded in transects).

The results of PERMANOVA showed a significant difference among years overall (P = 0.001), and subsequent pairwise analyses indicated that all years were different from each other with the exception of 2006 vs 2009 and 2009 vs 2013 (samples from these year form the central group of data points in Fig. 3).

Univariate analyses of species richness (means and standard errors displayed in Fig. 5), also revealed significant differences among years (P = 0.01). Subsequent pairwise contrasts (Table 2) primarily confirmed the lower relative richness in 2004 and 2012, and the high values recorded in 2013.

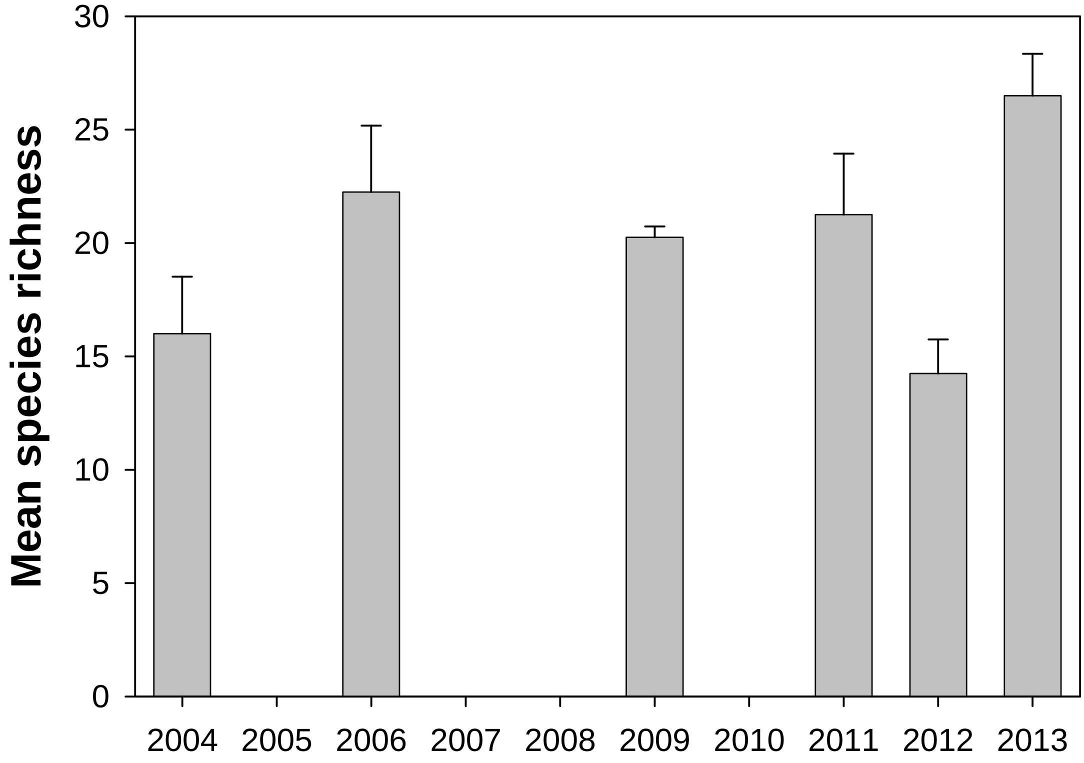

Fig. 5. Mean species richness of molluscs (± SE) at Cook Island South over all sampling periods.

Table 2. Summary of pairwise contrasts for species richness using univariate PERMANOVA of Euclidean distance. Significant comparisons are show in bold font.

Comparisons	t	P(perm)
2004 vs 2006	1.6181	0.202
2004 vs 2009	1.6581	0.122
2004 vs 2011	1.4254	0.252
2004 vs 2012	0.5978	0.567
2004 vs 2013	3.3599	**0.030**
2006 vs 2009	0.6737	0.628
2006 vs 2011	0.2514	0.862
2006 vs 2012	2.4342	0.054
2006 vs 2013	1.2281	0.313
2009 vs 2011	0.3660	0.683
2009 vs 2012	3.8224	**0.027**
2009 vs 2013	3.2725	**0.031**
2011 vs 2012	2.2765	0.057
2011 vs 2013	1.6086	0.175
2012 vs 2013	5.1524	**0.025**

Discussion

General

The 2012/13 program continued to both provide data on long-term change at key sites, and data from additional sites for which information was not previously available. This work extends the spatial coverage of the program to a total of 31 sites from Cook Island in the north, to South West Rocks in the south, and out to North Solitary Island in the east (see summary of site coverage in Appendix 1).

Trends and condition by site

Cook Island North

Mollusc richness was the highest yet recorded at Cook Island North, although most species were recorded in low abundance. The availability of different habitats (rock wall and boulders, coral, soft-coral, sand and shell grit), as well as the relative shelter, makes this site very suitable for the development of diverse assemblages. This was also reflected in the fish with mean species richness that is one of the highest yet recorded in the LTM program.

Marine debris continues to be a primary concern, especially as most items were fishing-related. Monofilament was the most prevalent item and almost all of this was found entangling coral, often with algal overgrowth and clear evidence of at least partial mortality of the coral colony. Given that the waters of Cook Island are gazetted as an Aquatic Reserve, with a fishing exclusion zone covering all waters within a 500-m radius of the island, this is a clear and critical, ongoing management issue (which has been highlighted in every previous LTM report).

Cook Island South

There are 3 primary discussion points with respect to this site: the loss of a once-abundant species; the decline in mollusc diversity in 2012; and the huge increase in marine debris since 2012. The 2013 surveys confirmed the loss of a once abundant species which first disappeared from the site in 2012. Dead shells were present in 2013 but, despite extensive searching inside and outside transects, no living specimens were found. Benthic conditions at the site were much improved compared to the 2 previous sampling periods with little of the fine sediment remaining. Diversity across the site appeared to be high, not only for molluscs and fish but also for taxa that do not form part of the sampling protocol (e.g. flatworms, nudibranchs). This apparent recovery is encouraging but the loss of a common species still raises concerns that warrant further investigation.

The lower species richness of molluscs in 2012 may simply be associated with the sampling procedure. Thus, while we visit the same site each year, the 4 replicate transects are not placed in exactly the same position each time. The benthic topography and habitat distribution within the site is quite heterogeneous and it is thus possible that at least some of the 2012 transects were established in areas with naturally low diversity. The fact that the primary drivers of differences in assemblage structure in 2012 were species that prefer urchin-grazed barrens, supports this idea. Thus, the apparent decline may, at least in part, be related to habitat heterogeneity. This can be tested in more exhaustive analyses of correlations between the mollusc data and the cover of different benthic taxa (i.e. from the video transects), but this is outside the scope of this report.

The final point is that fishing-related marine debris proliferated at the site between 2012 and 2013 and it is clearly having an impact on benthic communities, and especially coral. Illegal fishing is a significant problem at this site and mechanisms need to the implemented to manage and mitigate this issue. Cook Island supports important ecological communities in northern NSW and it is important to foster their sustainability by promoting resilience in the face of a changing environment (i.e. increased urbanisation and population growth, climate change - e.g. Beger et al., 2011). The best way to promote resilience is through reducing impacts known to reduce ecosystem health – we argue that fishing is one such impact that should be much better managed in this Aquatic Reserve.

The Solitary Islands

The extension of data collection to the 2 most offshore islands in the Solitary Islands Marine Park (SIMP) represents an important extension of the previous spatial scope, and objectives, of the LTM. While the initial focus of the program was on the detection of impacts of urbanisation within the region, the issue of climate change, and the range of possible impacts this may have, has increasingly taken centre stage in ecological investigation and monitoring over recent years. Climate change is likely to have a wide range of impacts, especially in south-eastern Australia (e.g.

Poloczanska et al., 2007) and this may affect the distribution of habitats and species within the region (e.g. Beger et al., 2011). A change in the strength of the East Australian Current (EAC) is predicted to have a number of possible effects including a more frequent flooding of mid-shelf and nearshore sites with warmer water (Malcolm et al., 2011). At the same time, a stronger EAC may force more frequent episodes of upwelling, bringing cool, nutrient-rich water into nearshore habitats (Roughan & Middleton, 2002). The establishment of monitoring sites across the shelf is clearly highly strategic for monitoring the impacts that such changes may have on biotic communities.

The LTM program has now collected data from 4 of the Solitary Islands as well as from a large range of nearshore sites. We recommend that the remaining island, South West Solitary (Groper) Island is included in the next iteration of the program to gain full coverage, and to include the site with the highest coral cover within the SIMP (Harriott et al., 1994).

Nambucca Reef

Nambucca Reef is an important component of the LTM and, as such, is a core reef within the program. Lying close to a large river system, and at the boundary of 2 marine bioregions, monitoring of this site fulfils the dual objectives of monitoring impacts associated with altered land-use (though river plumes) and climate change (as species distribution patterns may be most noticeable at bioregional boundaries). Given the dominance of complex reef in the study location, it is surprising that diversity across each of the biodiversity categories is not higher. Molluscs are less abundant than at many nearshore sites, although species richness is comparable. Fish richness is quite low in comparison to other complex reef sites, and is consistently so over the 4 periods of sampling to date. The reef is relatively sheltered, close to a popular boat ramp, and lacks fishing restrictions: thus, it is unsurprising that debris is mostly fishing-related. However, debris loads continue to be relatively low despite the tripling that occurred between 2012 and 2013 (from 2 to 6 items).

Black Rock

The primary change that was evident at Black Rock was the substantial reduction in debris load (although this is still high in comparison to many other nearshore reefs).

It is highly likely that this occurred simply because the mooring that was in place since the inception of sampling at this site, was lost in early 2013. There are no fishing restrictions at this site and moorings often focus boating-related activities through the convenience of their use. Indeed, in surveys of subtidal debris distribution elsewhere, highest loads are often associated with popular anchorages or mooring sites (Backhurst & Cole, 2000), an observation which has also been made from clean-up activities by volunteer divers in the Solitary Islands Underwater Research Group (SURG) (Smith, 2010). Consistent with previous surveys, most debris items were fishing-related and mostly comprised monofilament entangling branching corals. Both biodiversity indicators were within the range of previous surveys and the site appeared to be in good condition otherwise.

Future directions

With very poor underwater conditions for the first half of 2013, many of the reefs that were to be targeted in 2013 could not be assessed (e.g. Bait Reef -Byron Bay, sites adjacent to the Clarence River, Park Beach Bommie). These sites should be priorities in 2013/14 along with the other core sites for which consistent data have been collected (Cook Island South, Nambucca Reef, Black Rock). Given the change in assemblage composition of molluscs at Cook Island, consideration should be given to more frequent sampling at this location and sourcing additional funds to facilitate this. In addition, consideration should be given to including South West Solitary Island so that baseline data are available for all of the main islands in the Solitary Islands group.

A comprehensive analysis of all existing LTM data, as well as those derived from other programs, is currently under way (supported by additional funding from NSW Department of Primary Industries (Fisheries)). The results of that modelling exercise will provide data to generate additional questions that can be incorporated into the LTM program and to direct future sampling emphasis across the range of survey sites. This will be a critical step in future iterations of the program.

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Appendix 1

List of sites from which data have been collected under the Long Term Monitoring (LTM) program. The number of times the site has been surveyed for the LTM program is shown in brackets (i.e. this excludes data collected under other projects). Reefs nominated as core sites are show in bold font.

Location	**Site**	**Lat.**	**Long.**
Tweed Coast	Cook Island North (4)	-28.19450	153.57613
	Cook Island South (5)	-28.19620	153.57626
	Local Reef (Kingscliff) (1)	-28.25017	153.59632
	Outer Bommie (Kingscliff) (1)	-28.25367	153.59402
Byron Bay	**Bait Reef (2)**	-28.62810	153.61610
	Middle Reef (1)	-28.63178	153.62705
Yamba	Woody Head Reef 2 (1)	-29.35425	153.35517
	Woody Head Reef 1 (1)	-29.35560	153.37745
	Angourie Reef (1)	-29.47706	153.36555
	Shelley Beach Headland Reef (1)	-29.53043	153.36239
Northern SIMP	Wilson's Reef (1)	-29.82916	153.29484
	Barcoongere Reef (2)	-29.92057	153.28000
	North Solitary Island (1)	-29.92766	153.38947
	Doherty's Wash (1)	-29.94448	153.27949
	North Solitary West Island (1)	-30.01775	153.26837
	Woolgoolga Reef (2)	-30.09331	153.20770
Southern SIMP	South Solitary Island (1)	-30.20169	153.26665
	Split Solitary Island (2)	-30.24246	153.17726
	Korora Reef (2)	-30.26188	153.14587
	Park Beach Bommie (4)	-30.29552	153.15273
	Muttonbird Island (1)	-30.30322	153.15145
Sawtell	Boambee Reef (1)	-30.36060	153.11100
	Sawtell Reef (2)	-30.37429	153.11192
Nambucca	Wenonah Reef (1)	-30.54417	153.03479
	Valla Reef (1)	-30.59316	153.01906
	Nambucca Reef (4)	-30.64053	153.02339
South West Rocks	Ladies Reef (1)	30.88047	153.04381
	Bait Reef (2)	-30.87550	153.07100
	Green Island (1)	-30.90995	153.09066
	Fish Rock (1)	-30.94005	153.09673
	Black Rock (4)	-30.94834	153.07611

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