

Marine: quadrats for invertebrate and macroalgal communities

Version 1.0



This specification was prepared by Kath Blakemore in 2016.

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Disclaimer

This document contains supporting material for the Inventory and Monitoring Toolbox, which contains DOC's biodiversity inventory and monitoring standards. It is being made available to external groups and organisations to demonstrate current departmental best practice. DOC has used its best endeavours to ensure the accuracy of the information at the date of publication. As these standards have been prepared for the use of DOC staff, other users may require authorisation or caveats may apply. Any use by members of the public is at their own risk and DOC disclaims any liability that may arise from its use. For further information, please email biodiversitymonitoring@doc.govt.nz



Synopsis

This section gives a brief summary of the application, most common approaches, key considerations and requirements associated with this methodology. For full details of how to perform quadrat surveys please refer to the final section: [Full details of technique and best practice](#).

Quadrat sampling is a classic tool for ecological study allowing the systematic collection of quantitative data on species or habitats. In general, a series of quadrats of a set size (and shape) are placed within a habitat of interest and the species and/or habitats within the quadrats are identified and recorded by either direct diver observations *in situ* or photographs. Quadrats have most commonly been used in New Zealand marine reserve surveys to characterise sessile invertebrate communities or to quantify the density of mobile invertebrates (e.g. sea urchins and pāua) and their associated macroalgal communities. This methodology has proven amenable to application by school students, community groups and citizen scientists wanting to undertake surveys of the marine environment.

In a marine context, counting every specimen of the species of interest in an area is often not practical, and alternative methods need to be employed. Quadrats offer a relatively quick and cost-effective way to sample large areas and are a good method for rapidly assessing species abundance and community structure.

Data collection from quadrats can be made either directly *in situ* or via post-processing of photographic or video still images captured in the field. For both methods, observations can be made across the entire quadrat area, over a subsampled area of the quadrat, at defined grid points within the quadrat, or at randomly placed points within the quadrat. Furthermore, data can include presence/absence (or frequency), size, cover, or density of a single species (see '[Case study B](#)'), habitat, functional or taxonomic group (see '[Case study C](#)').

The arrangement of sites, number of quadrats per site, frequency of sampling, and quadrat shape and size will be determined by the objectives of the monitoring study. Typically, sampling is repeated annually and can be used in long-term monitoring. A robust sampling design should complement quadrat surveys with the collection of covariate data to describe variability within the sampling area and aid in the interpretation of sampling data.

Examples of questions that quadrat surveys can be applied to include:

- What is the density of sea urchins within and outside a marine reserve?
- How does the abundance of cockles within an estuary change over time?
- How does the density of grazing invertebrates influence subtidal algal assemblages?
- What is the structure of sessile invertebrate communities on subtidal rock walls?



Key considerations to take into account when considering applying quadrat survey methodologies include:

- Which variable(s) to observe and record
- Any covariate information to be recorded concurrently
- Skill level required of personnel
- Equipment and other resources required
- Size and shape of quadrat
- Number and placement of replicates
- Temporal replication

Assumptions

- The taxa of interest can be detected and identified with sufficient accuracy for the research or survey objectives.
- Observer effort and skills are similar across sites, locations and/or sampling occasions.
- Quadrats sampled represent the variability of the habitat, taxa or area of interest (if no additional information is to be collected as co-variables).
- Quadrats used are an appropriate size to capture the spatial variability in the taxa of interest.
- Sites and quadrats are statistically independent.

Advantages

- Usually non-destructive, except if the objective of the study requires sampling the biota (e.g. for identification or measurement).
- If the study is correctly designed, random sampling of an area is possible.
- Helps standardise search effort between individuals.
- A permanent record can be made if photographs are taken.
- No specialised equipment is necessary (unless photos are required).
- Can be used in long-term monitoring.
- Is well suited to Before–After–Control–Impact (BACI) studies.
- Sampling is easily repeatable over time.
- The method is amenable to the collection of covariate data regarding the physical environment, to assist with better understanding of the relationship between communities or populations and their environment.
- Reasonably quick and cost-effective to gather data from a high number of sampling units.
- Amenable to use for a wide range of taxa and habitat types.



- Subsampling within a quadrat is possible, making the technique amenable to concurrent sampling of a wider range of taxa, in a more efficient manner.

Disadvantages

- May require observers to have extended taxonomic knowledge depending on the taxa being observed.
- For subtidal areas, suitably qualified divers are required to carry out the work, which may make sourcing appropriate personnel difficult.
- Only provides data for the habitat that has been sampled, hence is very much dependant on site selection and size of quadrat used, relative to the spatial heterogeneity of the habitat or species being sampled.
- Can only be used to sample the density of organisms with limited mobility, such that there is no movement of individuals in or out of the quadrat frame while observations are being made.
- Observer bias can be introduced if different observers are used among times and places.
- For community analysis, visual or photographic methods will in most cases not allow a full inventory of the species in the quadrat due to some species being too small, cryptic or concealed by other species.
- Less useful for rare, uncommon or cryptic species (can be partially alleviated by increasing the quadrat or sample size).
- Particularly for permanently marked quadrats, or in intertidal areas, sampling disturbance may become evident over time due to the concentration of sampling effort in a small area.

Suitability for inventory

- For sites with high habitat heterogeneity, species inventories are difficult because taxa are likely to differ between microenvironments associated with depth, light environment, exposure, biotic habitats. In this instance, quadrats are not recommended as a method for inventory unless sources of spatial heterogeneity can be identified before sampling and incorporated into sampling design.
- One quadrat size will generally not be suitable for sampling all types of organisms in an area, therefore making inventory across a broad range of taxa groups difficult. If feasible, a quadrat that is large enough for the most heterogeneous taxa can be used, with subsequent subsampling for other taxa. However, where the taxa of interest can all be sufficiently detected using one quadrat size, quadrat sampling may be appropriate for conducting an inventory survey.
- Due to this method only being suitable for surveying species with limited mobility, it is unsuitable for inventory of mobile species.



Suitability for monitoring

- Quadrat sampling is well suited to monitoring of a wide range of variables and species due to the ability to replicate the same method over time and space with a high level of consistency, and often relatively quickly.
- Highly mobile species are not amenable to monitoring via this method due to the difficulty of them moving in or out of the quadrat frame while observations are being made.

Skills

Macroinvertebrate dive transects require a relatively high level of expertise.

Pre-survey:

- Survey design skills for determining the number of replicates, stratification (if any) and placement of replicates, and what variables are to be recorded
- GIS knowledge for the planning of field locations and sites
- Transfer of site coordinates to portable GPS
- Where relevant, appropriate dive-planning skills (e.g. max depth and times) and knowledge of relevant standard operating procedures

In the field:

- Appropriate SCUBA diving certification (if subtidal sampling is required)
- Expertise relevant to the level of taxonomic distinction required and type of organisms being recorded within quadrats
- The skills to record and securely manage data
- Use of portable GPS
- Good fitness level
- Digital SLR camera use and care (if photoquadrats are to be taken)

Processing of imagery (for photoquadrats):

- Expertise relevant to the level of taxonomic distinction required and type of organisms being recorded within quadrats
- Familiarity with image analysis software (if processing photoquadrats)

Data analysis:

- Familiarity with basic statistics
- Familiarity with statistical package (R recommended)



Resources

- Sunscreen, hat, insect repellent and plenty of snacks and water.
- Wet weather gear and warm items of clothing, as weather can change quickly.
- General field equipment, including pencils, slates, waterproof paper, data sheets.
- Data recording sheets, printed on waterproof paper. Figure 1 shows a generic quadrat sampling field data sheet; however, this may need to be adapted depending on the particular survey objectives and design.
- For sampling requiring the use of divers, all equipment and personnel necessary for the safety of divers will be required as outlined in the 'Scientific diving and snorkelling technical document' (doccm-237640).¹
- Where sampling requires the collection of organisms, sample jars containing 70% isopropyl alcohol for storage and preservation of animals, or ziplock bags for algae.
- Additional ziplock bags for samples of unknown species for lab identification.
- Quadrat frame.
- For photoquadrats, camera equipment and associated frame (see Figure 2).
- GPS unit for site location.
- Measuring tapes may be necessary for determining placement of quadrats (e.g. placement of quadrats at random distances along a transect).
- Calipers for recording the sizes of indicator species (e.g. width of cockles or kina).
- ID guides to aid in species identification.
- A survey vessel and associated personnel if sampling is boat-based.
- Personnel time for the adequate completion of all stages of the project, including planning, field work, data management and analysis, and write-up of the survey and results.

¹ <http://www.doc.govt.nz/documents/science-and-technical/inventory-monitoring/im-toolbox-marine-scientific-diving-and-snorkelling-technical-document.pdf>



Date:	Survey:	Recorder:	
QUADRAT # :	Site name:	Stratum:	Time:
		Depth:	Transect #:
Species/taxa group	<i>Parameter to be recorded (insert here prior to printing data sheets)</i>	Habitat general description:	
		NZMHCS Biotic:	
		NZMHCS Abiotic:	
		Other notes	
QUADRAT # :	Site name:	Stratum:	Time:
		Depth:	Transect #:
Species/taxa group	<i>Parameter to be recorded (insert here prior to printing data sheets)</i>	Habitat general description	
		NZMHCS Biotic:	
		NZMHCS Abiotic:	
		Other notes	
QUADRAT # :	Site name:	Stratum:	Time:
		Depth:	Transect #:
Species/taxa group	<i>Parameter to be recorded (insert here prior to printing data sheets)</i>	Habitat general description	
		NZMHCS Biotic:	
		NZMHCS Abiotic:	
		Other notes	

Figure 1. Generic quadrat sampling field data sheet ('Quadrats: field data sheet'—doccm-2785236)².

² <http://www.doc.govt.nz/documents/science-and-technical/inventory-monitoring/im-toolbox-marine-quadrats-field-data-sheet.pdf>



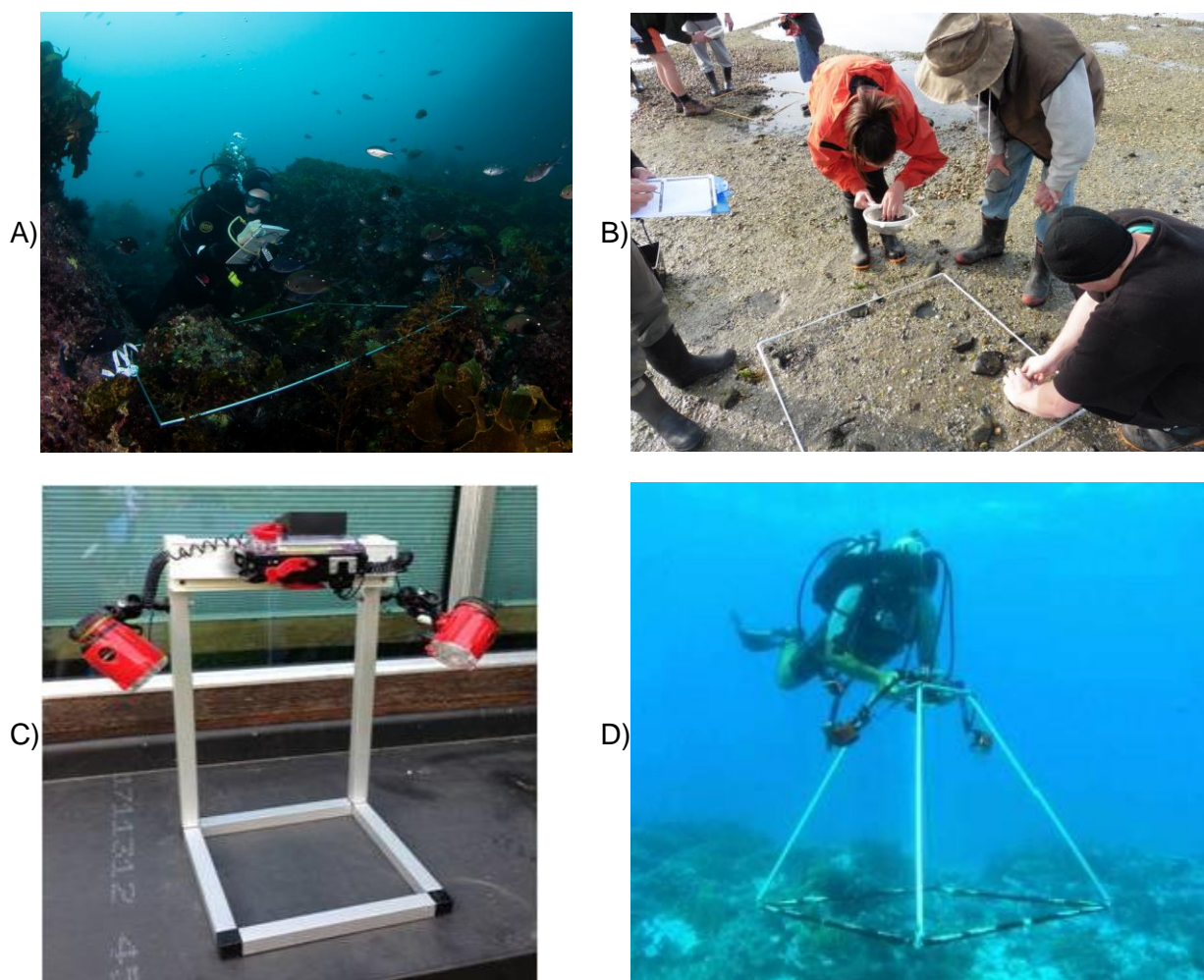


Figure 2. A) A diver conducting quadrat observations on subtidal rocky reef habitat (photo: Vincent Zintzen); B) intertidal area quadrat surveys (photo: Patti Vanderburg); C) an example of a photoquadrat setup (photo: <http://jncc.defra.gov.uk/>); D) photoquadrat sampling subtidally (photo: <http://www.marinespatialecologylab.org>).

Minimum attributes

Consistent measurement and recording of the following attributes is critical for the implementation of the method. Depending on the research question(s), other attributes may be required.

DOC staff must complete a 'Standard inventory and monitoring project plan' (doccm-146272)³.

Survey metadata

- Survey name
- Survey objectives

³ <http://www.doc.govt.nz/Documents/science-and-technical/inventory-monitoring/im-toolbox-standard-inventory-and-monitoring-project-plan.doc>



- Survey period (dates)
- Site name and coordinates
- Observer and recorder's names
- Vessel name
- Date and time
- Tide
- Weather
- Quadrat size and shape
- How sampling sites were spatially arranged (e.g. random, random within stratified areas, fixed)

Quadrat data

- Location of quadrat within the site (e.g. position down the shore, depth, distance along a transect tape)
- Quadrat (replicate) number
- Data of the variables of interest to the survey objectives (e.g. species counts, size measurements, percent cover)
- Information on any subsampling within the quadrat

Optional attributes

- Whether any images were taken (e.g. for species identification purposes), and reference numbers for images for linking with the quadrat number
- Information on associated covariates (e.g. water temperature, sea state), or any other covariate data of interest, such as a broader habitat characterisation
- If permanent quadrats are established, photographs and detailed notes to allow future researchers to re-find the quadrats
- Any additional notes that may be useful for future surveys or for interpretation of the results
- Details of any physical samples collected

Data storage

DOC is currently developing a national database to hold and provide access to data collected from marine reserve monitoring in New Zealand. The aims of the database are to:

- Support consistent standards in national marine reserve monitoring programmes for marine environmental quality
- Coordinate and optimise marine reserve monitoring in New Zealand
- Provide a high quality monitoring dataset for New Zealand's marine reserves



Once operational, this methodology will be updated with a description of how to lodge data within the national database. In the interim, data should be recorded within the spreadsheets associated with this methodology. It is essential that all raw data sheets are completed, digitised and backed up on external hard drives. Raw data and associated metadata should be entered into databases/spreadsheets in a standardised format. This should include metadata stored in a separate sheet, and a sheet containing sampling data collected during the monitoring programme stored in one 'brick' of data that can be continually updated as more surveys in that monitoring programme are carried out.

For internal DOC monitoring, information pertaining to each survey within a marine reserve and resultant data/reports should be entered into the Marine Protected Area Monitoring and Research (MPAMAR) datasheet ('MPAMAR metadata—National'—doccm-1163829) so there is an easily accessible account of the survey.

Analysis, interpretation and reporting

Seek advice from a statistician or suitably experienced person prior to undertaking any analysis. Ideally, statistical advice should be sought prior to any data collection to ensure that the design of the data collection is robust and suitable for answering the question at hand. For quality control the data should be checked for unlikely abundances of organisms, and errors in data entry.

Data analysis

The type of analysis most applicable to the data will largely be determined by the research question, and whether additional supporting information has been collected or is available. Table 1 provides a brief description of the more common metrics derived from quadrat data.

Table 1. Common metrics that can be calculated from quadrat data, a description of their data requirements, and how to calculate/present them.

Metric	Required data	Calculation/Presentation
Density	<ul style="list-style-type: none"> Number of individuals per quadrat Area of quadrat sampled 	Convert the number of individuals observed per quadrat to the number per unit area (typically per m ²) by dividing the number of individuals by the area of the quadrat sampled. For example, if 10 individuals are counted within a 2 m ² quadrat, the density of those individuals within that quadrat is 5 per m ² . Means (and associated variance) can then be calculated from these values across all measured quadrats.
Relative abundance	<ul style="list-style-type: none"> Number of individuals of each species present 	How common or rare a species is relative to other species, calculated by dividing the number of individuals from one species by the total number of individuals from all species.



Biomass	<ul style="list-style-type: none"> Total weight of the taxa of interest for each quadrat sampled Area of quadrat sampled 	Mean biomass per site; change in biomass through time; relationship of biomass to other variables.
Presence/absence	<ul style="list-style-type: none"> Which species are present, or which of selected taxa are present and absent 	The presence or absence of a species or attribute in a quadrat.
Frequency	<ul style="list-style-type: none"> Record of which species are present, or which of selected taxa are present and absent 	The proportion (%) of quadrats occupied by each species.
Species richness	<ul style="list-style-type: none"> Number of species present 	Species richness is simply a count of the number of species observed.
Species diversity	<ul style="list-style-type: none"> Number of individuals of each species present 	Species diversity incorporates both species richness (the number of species in a community) and the evenness of species' abundances (how similar the abundance of each species in a community is).
Size structure	<ul style="list-style-type: none"> Size or size class of each individual observed 	Population size structure may be presented simply as a mean of the parameter measured, or the full set of data may be presented as size frequency histograms.
Cover	<ul style="list-style-type: none"> Either directly measure (if possible) or estimate the proportion of quadrat area occupied by different taxa, identified to the required level (e.g. species, family, functional group) 	Calculate the mean (and variance) of cover scores across all quadrats sampled.

Interpretation

Interpretation of results should be performed with the assistance of a statistician as well as consideration of the major driving forces operating within the system. At this stage, it should be determined whether the objectives of the original data collection have been achieved and whether the data is sufficient to answer those questions outlined prior to the initial surveys.

Reporting

Reporting will largely be governed by the duration of the monitoring and data collection. If data collection is ongoing, regular reports should be submitted at 3–5-year intervals, whereas for short-term (< 2 years in duration) data collection, reports should be submitted within a year of the final data collection.



Case study A

Case study A: Te Whanganui-A-Hei Marine Reserve Benthic Monitoring Programme (Haggitt et al. 2014)

Synopsis

Biological monitoring of Te Whanganui-A-Hei Marine Reserve (hereafter referred to as MR) started in 1993. Part of this programme has been focused on monitoring the benthic communities for detecting differences between the MR and adjacent non-marine reserve areas, and to detect changes over time. This part of the programme was initiated in 2006 with permanent 100 m² plots established, which have subsequently been resurveyed in 2009, 2011, 2013 and 2015. Within these 100 m² plots, replicate 1 m² quadrats are sampled by divers on SCUBA to quantify, *in situ*, the abundance and percent cover of selected benthic species. This study provides an illustration of a common marine reserve monitoring approach using quadrats to survey shallow subtidal rocky reef habitat.

Objectives

- To determine natural levels of temporal and spatial variation in reserve biota and habitats
- To assess biodiversity within reserve and non-reserve areas
- To detect changes that differ significantly from natural variation

Sampling design and methods

- Permanent 100 m² plots were established by fixing stainless steel bolts to the substrate, to which subsurface marker buoys could be attached. Eight (initially 10) such plots were established within the MR, and 8 (initially 10) were established adjacent to the MR. For each group of 8 plots, 4 plots were classified as 'shallow' and 4 classified as 'deep', i.e. in a depth-stratified survey design.
- Within each plot, 10 haphazardly placed 1 m² quadrats were sampled *in situ* by divers on SCUBA (following the methodology of Shears & Babcock 2003).
- Within each 1 m² quadrat, all large brown macroalgae and turfing algal species were counted and their percent cover estimated. Lengths of brown macroalgae were also taken, and later converted to biomass based on previous calculations for the relationship between length and dry weight.
- Also within each 1 m² quadrat, the primary percent cover of foliose algae, turfing algae, encrusting algal species and encrusting invertebrates, as well as sediment and sand cover, was visually estimated.
- Additionally, urchins within each quadrat were counted, their test diameter measured (if > 10 mm), and their behaviour and health was recorded based on pre-determined categories.



- All gastropods within each quadrat were also quantified, with shell dimensions recorded for selected species.

Results

The results discussed here are a brief summary from the 2013 survey, as well as patterns emerging from all prior surveys.

- Differences in the pattern of macroalgal assemblages within and outside the reserve are evident at shallow sites (Figure 3). Non-reserve sites have shown a transition from urchin barrens to *Carpophyllum flexuosum* and articulated coralline turf dominated reef, while MR sites have featured mixed algal communities more consistently. In both areas, deeper sites are characterised by *Ecklonia radiata*.
- The community structure and diversity of sessile invertebrates has remained stable across time both within and outside the MR (Figure 4), but higher diversity has been observed at the deeper sites.
- Sea urchin abundance was higher outside the reserve compared to inside, and was also the highest of all survey years to date. Differences in the behavioural characteristics of sea urchins in the two areas were also observed—a higher percentage of individuals displayed cryptic behaviour within the reserve than outside (Figure 5).
- Long-term monitoring of key gastropod species has shown that gastropod diversity has remained relatively stable across time in both reserve and non-reserve sites (Figure 6).



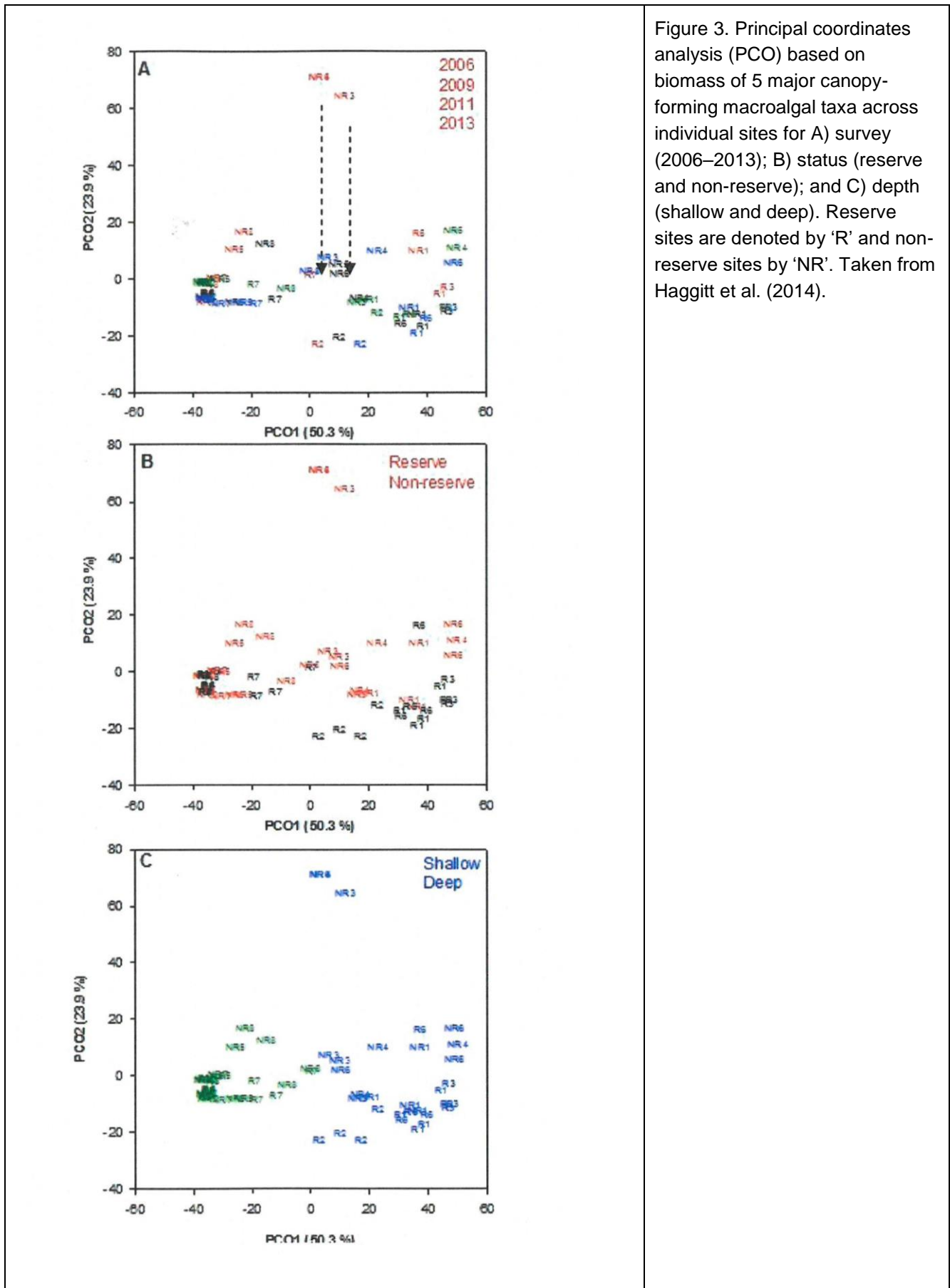


Figure 3. Principal coordinates analysis (PCO) based on biomass of 5 major canopy-forming macroalgal taxa across individual sites for A) survey (2006–2013); B) status (reserve and non-reserve); and C) depth (shallow and deep). Reserve sites are denoted by 'R' and non-reserve sites by 'NR'. Taken from Haggitt et al. (2014).

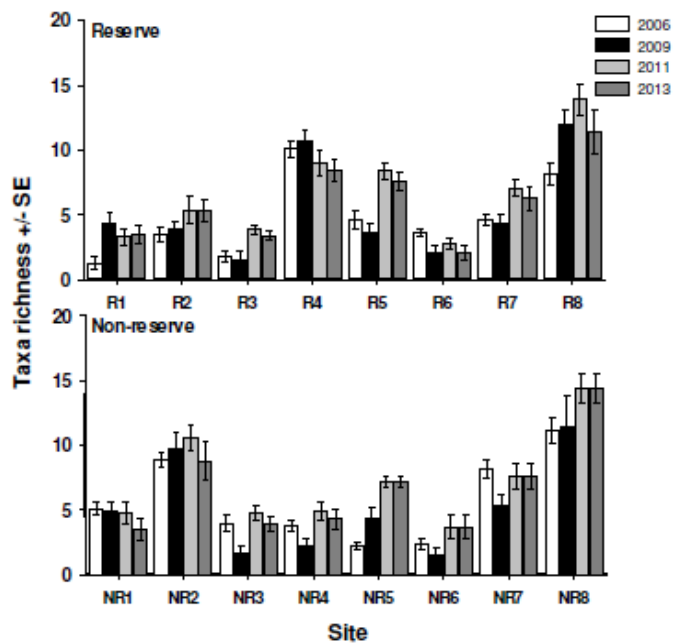


Figure 4. Sessile invertebrate taxa richness within Te Whanganui-A-Hei Marine Reserve and non-reserve sites for 2006, 2009, 2011 and 2013 surveys. Taken from Haggitt et al. (2014) (SE = standard error).

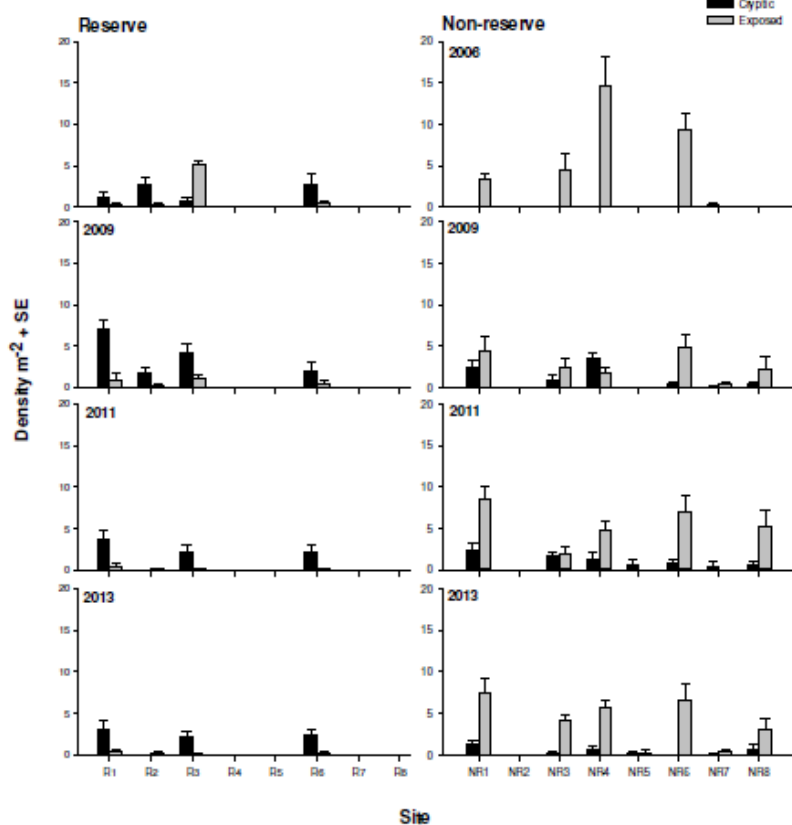
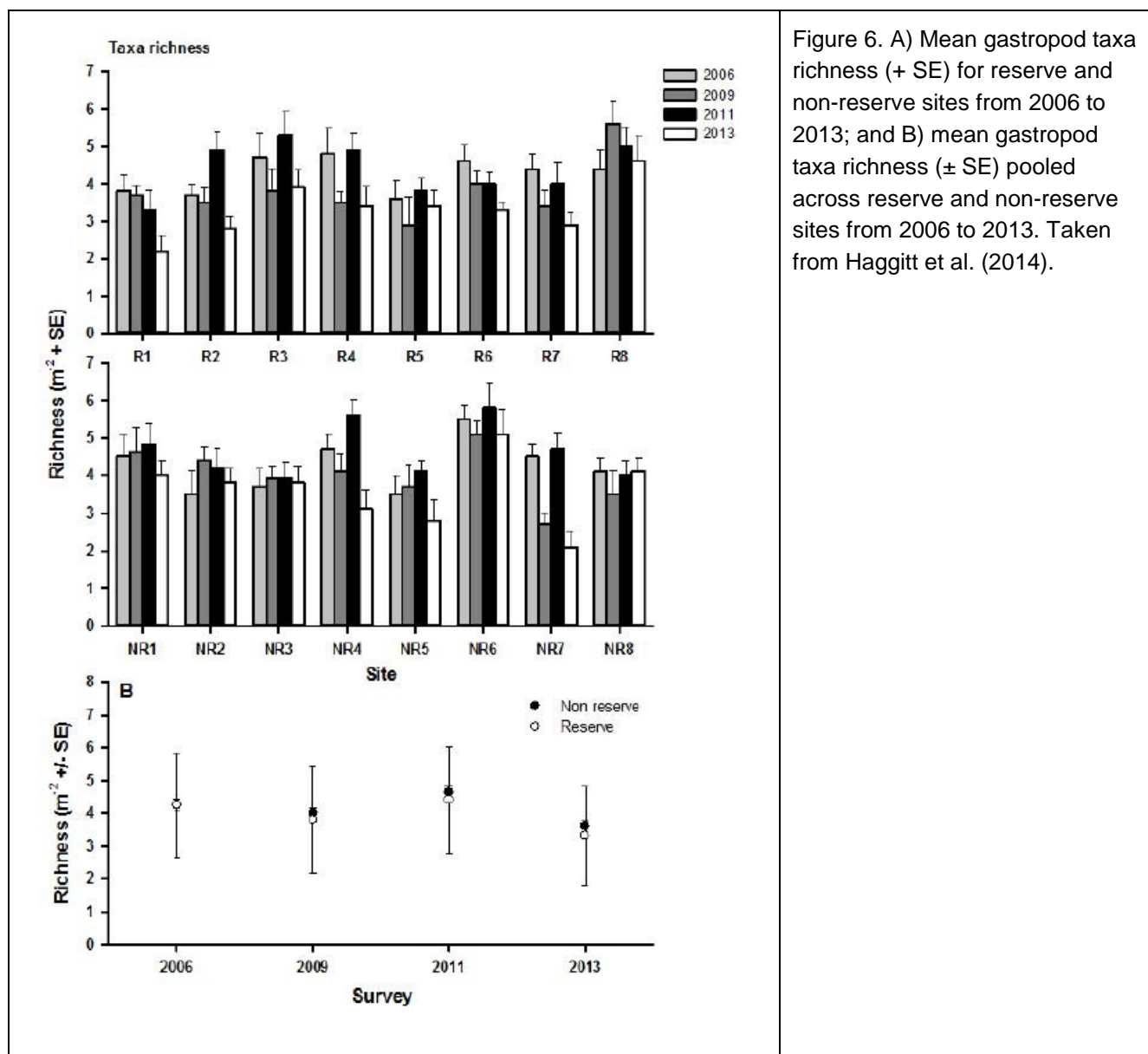


Figure 5. Abundance of exposed and cryptic *Evechinus chloroticus* within Te Whanganui-A-Hei Marine Reserve and non-reserve sampling sites for 2006, 2009, 2011 and 2013. Taken from Haggitt et al. (2014).





Limitations and points to consider

Data quality and consistent implementation of methods over time are likely to be high as the methods have stayed the same throughout the survey period, and key personnel leading the surveys have also remained consistent.

This methodology illustrates how quadrat sampling can be used efficiently to collect data for a number of different variables of interest within replicate quadrats. Similarly, one quadrat size was able to be used for all variables measured, thus making for a simpler and quicker operation by divers underwater.



References for case study A

Haggitt, T.; Mead, S.; Smith, H.; Hillock, K. 2014: Whanganui-a-Hei Marine Reserve Benthic and Lobster Monitoring Programme: 2013 survey. Report prepared for the Department of Conservation. 86 p.

Shears, N.T.; Babcock, R.C. 2003: Continuing trophic cascade effects after 25 years of no-take marine reserve protection. *Marine Ecology Progress Series* 246: 1–16.

Case study B

Case study B: Guardians of Pāuatahanui Inlet cockle monitoring programme, Porirua (Michael 2011)

Synopsis

A community volunteer group, the Guardians of Pāuatahanui Inlet, has carried out surveys of cockle populations at the inlet every 3 years since 1992, providing a long-term time series for assessing the ecological health of Pāuatahanui Inlet. This study provides an example of how to use quadrat sampling techniques to deliver long-term intertidal monitoring data to inform an ecological health assessment in an intertidal setting.

Objectives

- To monitor changes over time in the abundance and size structure of cockles (*Austrovenus stutchburyi*) as an indicator for assessing the ecological health of Pāuatahanui Inlet.

Sampling design and methods

- The frequency of sampling for the long-term monitoring programme is once every 3 years.
- The sampling location (the inlet) is divided into 10 different areas. There are 31 ‘permanent’ transects located across the sampling location.
- The position of each of the 31 transects is determined on each sampling occasion by following previously detailed notes on their location and instructions to survey volunteers about how to locate and orientate each transect, and how to locate the appropriate area for each tide level.
- At each transect, sampling occurs at four tide-levels (high, upper-mid, lower-mid, and low). At each of these tidal levels, three 0.1 m² quadrats are haphazardly placed on or within approximately 5 m of the transect.
- Within each quadrat, the sediment down to a depth of 7 cm is collected with a spade and sieved through a colander using seawater, retaining cockles of 2 mm length or greater.
- All live cockles were measured for length (along the posterior-anterior axis) to the nearest millimetre using rulers, then returned to the substrate.



- Cockle population size is estimated using the mean density from all quadrats, and scaled to the size of the intertidal area of the inlet.
- Shell length measurements are combined to produce estimates of the population size structure for investigating spatial and temporal differences across life-stage (juvenile versus adult), tidal height, transect, site and survey.

Results

From the 2013 survey:

- The maximum density of cockles (153 per 0.1 m²) recorded in quadrats, as well as the mean cockle density (33.6 per 0.1 m², 99% confidence interval (CI) 27.1–40.1), was higher than in all previous surveys since 1992 (27.7 per 0.1 m²).
- Estimates of total cockle population size showed a continued upward trend, and was 87% higher than the lowest estimate in the time series (Figure 7).
- The distributions of size frequencies in the population have shown little change over the last three surveying periods (Figure 8). The proportion of juveniles (≤ 10 mm) in the population increased markedly from 1992 to 2004, and then stabilised from 2004 to 2013 (Figure 9).

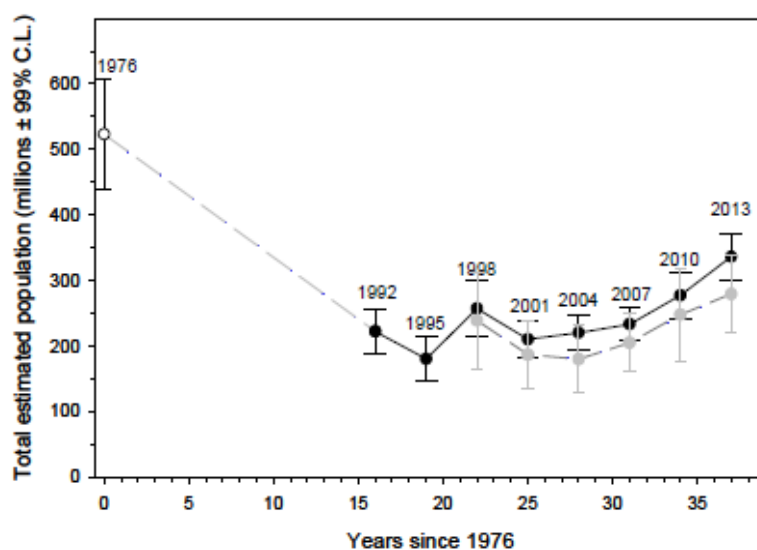


Figure 7. Estimates of total cockle population size and 99% confidence limits for Pāuatahanui Inlet, 1976–2013. The initial survey in 1976 (Richardson et al. 1979) used a different survey design. Surveys since 1992 carried out by the Guardians of Pāuatahanui Inlet have used the same survey design and methods. Estimates using the previous method are shown in black and estimated using weighting factors for transect length in grey. Taken from Michael & Wells (2014) (C.L. = confidence limits).



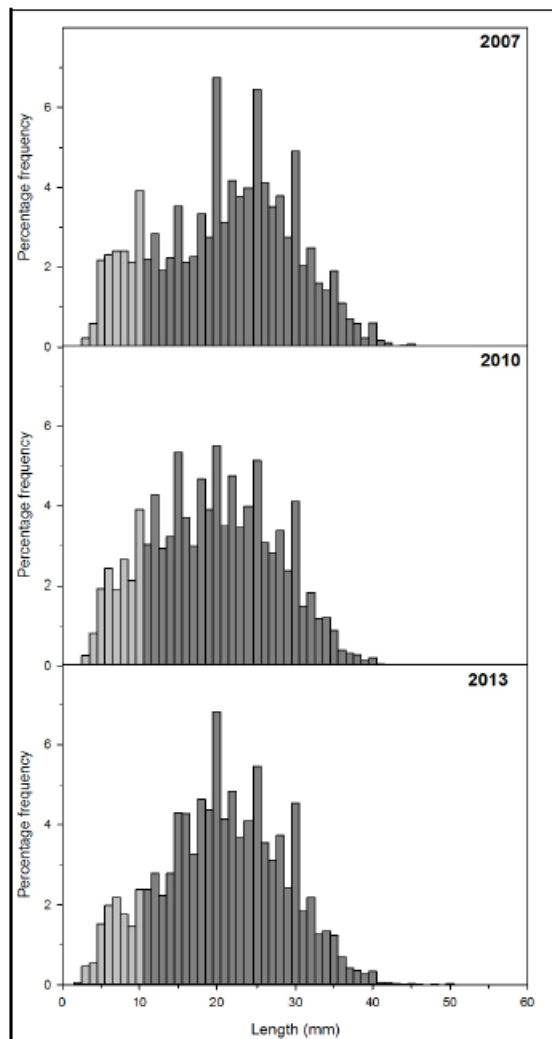


Figure 8. Percentage length frequencies of cockles sampled in the intertidal zone of Pāuatahanui Inlet in 2007, 2010 and 2013. Juvenile cockles classified as those 10 mm in length and smaller are shown in grey. Adults greater than 10 mm length are shown in dark grey. Taken from Michael & Wells (2014).

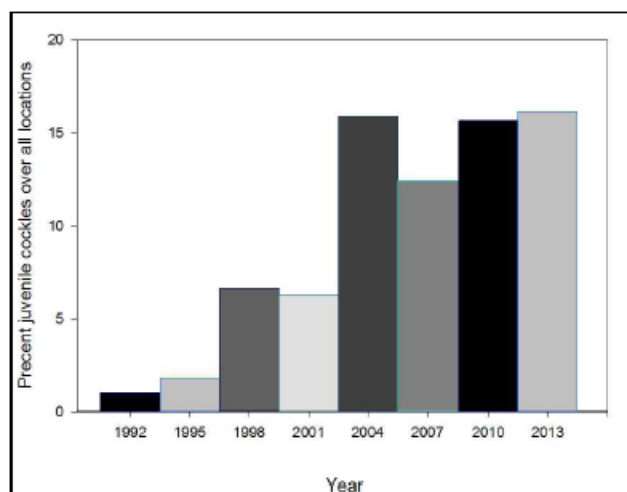


Figure 9. Juveniles (10 mm or smaller in length) as a percentage of total cockle population, 1992–2013. Taken from Michael & Wells (2014).



Limitations and points to consider

- Data quality may be affected by the use of volunteers, the inconsistency in personnel used over time, and their experience level from year to year and from transect to transect. However, the activity is reasonably straightforward and systems are in place to ensure this is minimised as far as is practical.
- When surveying repeatedly over long time, it is important to maintain consistency in the time of year that sampling occurs to minimise the effects of confounding factors such as season or recruitment events.
- Due to the sampling methodology requiring physical disturbance to the cockles and their habitat, consideration should be given to the possibility that the survey affects the results of current or future sampling events.
- Dividing the survey area into different sections may be useful in a survey such as this, where the focal species is predominantly sessile, and where there may be interest in the effect of localised sources of disturbance or impact on cockle density (e.g. sedimentation from adjacent terrestrial activities).

References for case study B

Michael, K.; Wells, J. 2014: Community survey of cockles (*Austrovenus stutchburyi*) in Pauatahanui Inlet, Wellington, December 2013. Prepared for Guardians of Pauatahanui Inlet by NIWA.

Case study C

Case study C: Nearshore benthic community structure at the Bounty and Antipodes Islands, Subantarctic New Zealand (Freeman et al. 2011)

Synopsis

Photoquadrat surveying by divers was used to describe the general structure of the shallow rocky reef benthic communities at the Antipodes and Bounty Islands. This survey illustrates the use of photoquadrat surveying that can serve both to characterise a particular habitat or community type, and to provide baseline information for assessing change.

Objectives

- To describe the structure of nearshore marine habitats, focusing on benthic rocky reef communities of the Antipodes and Bounty Islands.

Sampling design and methods

- Sampling at each location occurred over two consecutive weeks in March 2009.
- Benthic assemblages on rock walls between 10 m and 20 m depth were surveyed using haphazardly placed 0.5 × 0.5 m (0.25 m²) photoquadrats.



- Photoquadrats were taken at 7 and 8 sites at the Antipodes and Bounty Islands respectively, with between 4 and 43 replicate photoquadrats per site.
- Photos were taken by divers on SCUBA using a Nikon D70 camera mounted on a 50 × 50 cm frame.
- Photos were later analysed using the point intercept method in the software PhotoGrid (Bird 2003). Fifty randomly placed points were overlaid onto each photo and the organism or substrate beneath each point recorded to the lowest possible taxonomic level.
- Data from the random points were used to quantify the proportion of macroalgal canopy cover, the percent covers of functional groups (algae, suspension feeders, deposit feeders and filter feeders), and density of all visible mobile invertebrates.
- Specimen collections were also made to aid identification of species where necessary.

Results

- Distinct differences were found in assemblage composition and potential functional role of the encrusting communities between the two island groups, with hierarchical cluster analysis identifying 4 groups of similar sites (2 from each island group) (Figure 10).
- The Antipodes Island rock walls were dominated by layered nongeniculate coralline algae, while encrusting invertebrates, particularly sponges, were the dominant sessile organisms at the Bounty Islands (Figure 11). Large canopy-forming brown macroalgae were more common at Antipodes Island than the Bounty Islands.
- A comparison of functional groups showed algae to be the predominant organisms at all Antipodes Island sites, while at the Bounty Islands, algae and filter- and suspension-feeding organisms were present in more equal proportions (Figure 12).
- While the density of mobile invertebrates was low at both sites, the composition differed between the island groups, with herbivorous gastropods and holothurians being common at Antipodes Island, and predatory gastropods, crabs and shrimps being common at the Bounty Islands sites (Table 2).



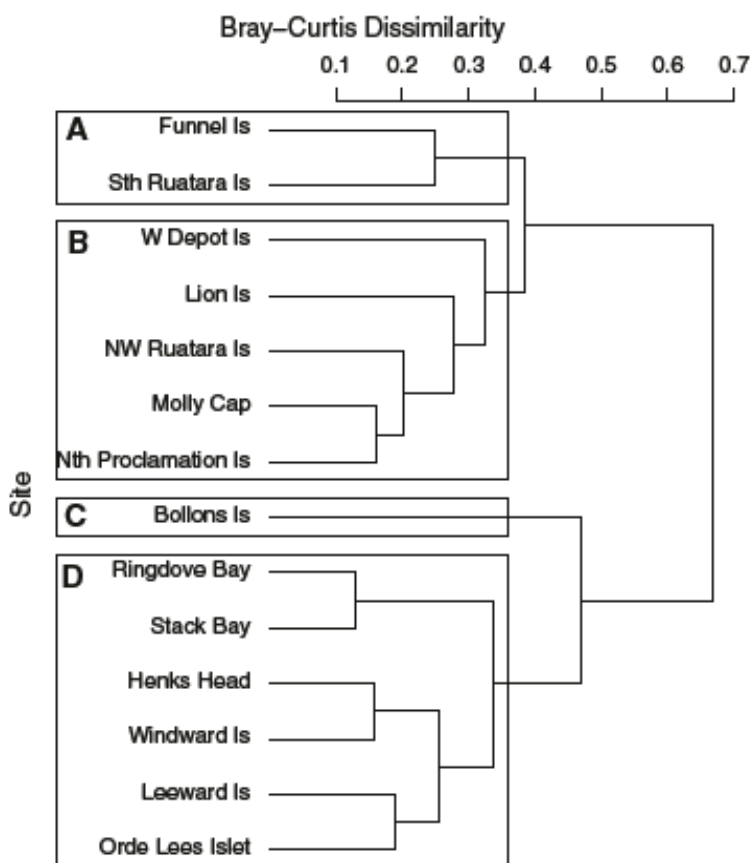


Figure 10. Hierarchical cluster analysis (based on Bray-Curtis Dissimilarities) of percent covers of encrusting phyla in photoquadrats taken at the Bounty and Antipodes Islands. Four distinct clusters have been arbitrarily defined: A) Bounty Islands sites: Funnel Island and South Ruatara Island; B) the remaining Bounty Islands sites; C) Bollons Island, at Antipodes Island; D) the remaining Antipodes Island sites. Taken from Freeman et al. (2011).

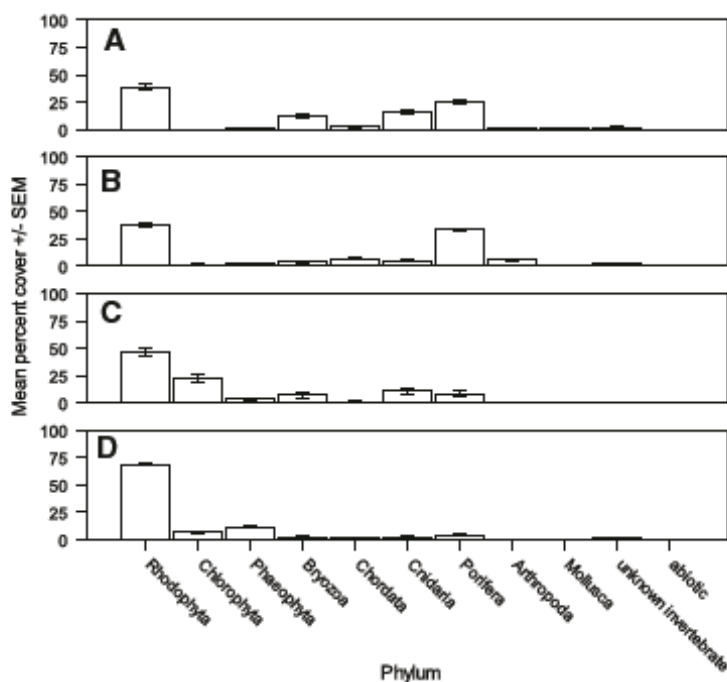


Figure 11. Mean percent covers of encrusting phyla at sites sampled using photoquadrats at the Bounty and Antipodes Islands. Data are split into the four clusters of sites from Figure 10 above. Taken from Freeman et al. (2011) (SEM = standard error of mean).



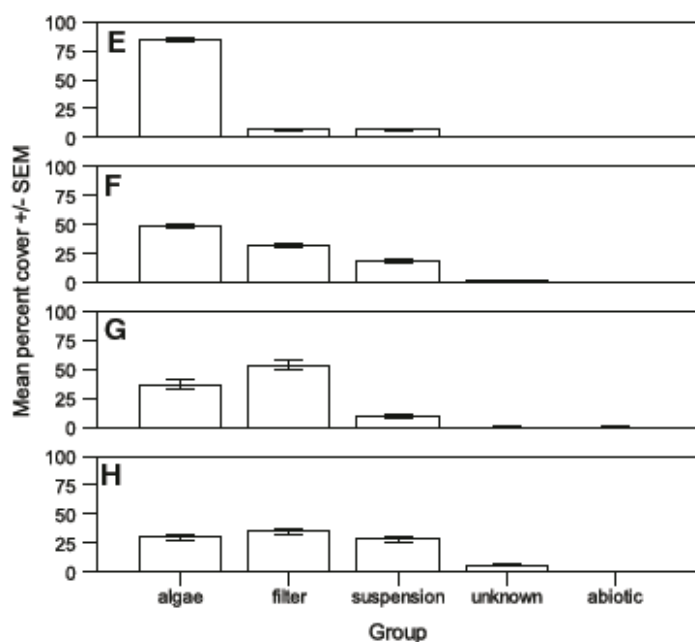


Figure 12. Mean percent covers of encrusting species (based on feeding method) at sites sampled using photoquadrats at the Bounty and Antipodes Islands. Data are split into four clusters of sites: E) all Antipodes Island sites; F–H) Bounty Islands sites. Taken from Freeman et al. (2011).

Taxon	Antipodes Island	Bounty Islands
Mollusca		
<i>Cantharidus capillaceus</i>	4.89 (0.69), 24.6%	
<i>Eudoxochiton nobilis</i>	0.11 (0.04), 2.7%	0.54 (0.12), 8.7%
<i>Onithochiton neglectus</i>	0.02 (0.02), 0.6%	0.21 (0.10), 2.4%
<i>Buccinum</i> sp.	0.04 (0.02), 0.9%	0.03 (0.02), 0.7%
<i>Calliostoma eminens</i>	0.08 (0.03), 2.1%	
<i>Haliotis virginea huttoni</i>	0.44 (0.13), 5.1%	0.66 (0.64), 0.7%
<i>Cellana strigilis bollonsi</i>	0.07 (0.03), 1.2%	
<i>Cellana strigilis oliveri</i>		0.24 (0.17), 1.4%
<i>Octopus huttoni</i>		0.01 (0.01), 0.3%
Unidentified large octopus*	0.02 (0.01), 0.6%	
<i>Fusitriton laudandus</i>	0.05 (0.03), 0.6%	
<i>Haustrum lacunosum</i>		0.67 (0.14), 10.8%
Echinodermata		
<i>Henricia</i> spp	1.02 (0.15), 18%	0.88 (0.16), 12.2%
Unidentified ophiuroid*	0.04 (0.02), 0.9%	
<i>Anasterias suteri</i>	0.02 (0.02), 0.6%	
<i>Paranepanthis aucklandensis</i>	0.41 (0.09), 7.2%	
<i>Anasterias laevigata</i>	0.19 (0.06), 3.9%	
Unidentified seastar 1*	0.02 (0.02), 0.6%	
Unidentified seastar 2*		0.01 (0.01), 0.3%
<i>Anasterias</i> sp.	0.01 (0.01), 0.3%	
White reefstar*	0.01 (0.01), 0.3%	
<i>Psolidiella nigra</i>	0.04 (0.02), 0.9%	
<i>Squamocnus brevidentis</i>	1.98 (0.47), 11.1%	
<i>Pseudechinus novaezealandiae</i>	0.01 (0.01), 0.3%	
Arthropoda		
Unidentified brachyuran crab*		0.01 (0.01), 0.3%
Unidentified isopod*		0.01 (0.01), 0.3%
Unidentified hermit crab*		0.01 (0.01), 0.3%
<i>Jacquinitia edwardsii</i>		0.01 (0.01), 0.3%
<i>Leptomithrax australis</i>		0.52 (0.11), 9.4%
<i>Palenopsis obliqua</i>	0.01 (0.01), 0.3%	
Unidentified shrimp 1*	0.01 (0.01), 0.3%	
Unidentified shrimp 2*		1.67 (0.34), 18.5%
Annelida		
<i>Micrura pleuropolia</i>		0.03 (0.02), 0.7%

Table 2. Mean density (number per m²; SE in brackets) and percent occurrence (percentage of quadrats in which this species occurred) of mobile invertebrates (> 5 mm) in photoquadrats taken at Antipodes Island ($n = 334$) and the Bounty Islands ($n = 287$). Taken from Freeman et al. (2011).



Limitations and points to consider

- This study recognised the limitations of the photoquadrat technique in accounting for very small or cryptic species.
- This study highlights the effectiveness of this technique in detecting community-scale differences in composition between sites (in this case, geographically distinct sites).

References for case study C

Bird, C.E. 2003: PhotoGrid version 1.0. Honolulu, Hawaii.

Freeman, D.; Cooper, S.; Funnell, G.; Neale, D. 2011: Nearshore benthic community structure at the Bounty and Antipodes Islands, Subantarctic New Zealand. *Polar Biology* 34: 1485–1499.

Full details of technique and best practice

The description of quadrat surveys below provides generic information for applying this methodology and is not specific to one type of quadrat surveying. If more detail is required on a specific application (e.g. rocky reef photoquadrat surveying), please refer to relevant publications in the scientific literature or consult with a member of DOC's Marine Ecosystem Team. The description below is structured around the key steps that should be followed when planning and carrying out a survey using quadrat sampling methodology.

Survey design

Monitoring preparation includes developing a robust survey design, including prior consultation with experts/statisticians, to ensure the design meets the requirements to answer the research question. The following aspects need to be incorporated:

- Identification of monitoring objectives
- Statement of clear outcomes of the surveys and how they relate to the original monitoring objectives
- Determining which variables are of interest for measurement, how they are to be measured, and how the data are to be recorded (see Box 1)
- Determining the number of sites to be surveyed within the survey location, and where they are to be situated (Box 2)
- Determining the number of quadrats to be sampled within each site and their spatial arrangement (Box 2)
- Determining a survey schedule to ensure that data are collected as required over the lifetime of the study



Box 1: What to measure

Which taxa are of interest?

- Single species (e.g. for a density measure of sea urchins)
- Multiple species (e.g. for determining the relationship between sea urchins and macroalgae)
- Single functional group (e.g. for an inventory of mobile grazers)
- All visible species (e.g. for a species richness measure)

Which variable(s) are to be measured and how are the data derived?

Presence/absence and frequency: Simple observations of whether a particular species or multiple species can be observed within the quadrat. Data are recorded as '1' for present or '0' for absent. This can be determined across the entire quadrat or by using an overlaid grid and recording what species occurs under each grid point (or a random set of these points).

Relative abundance: How common or rare a species is relative to other species, calculated by dividing the number of individuals from one species by the total number of individuals from all species.

Density: For some taxa, individuals can be easily counted and a density estimate recorded. A tally of the number of individuals of each species of interest within each quadrat is recorded, and later used to derive a measure of density/m² by multiplying by a factor relevant to the size of the quadrat used (e.g. 6 whelks recorded in a 0.25 m² quadrat equates to a density of 24 whelks/m²).

Cover: For some taxa, it is not possible or feasible to count individuals (e.g. colonial ascidians, bryozoans) and a percent cover estimate provides a better alternative. Data recorded will be a percentage and will be the area that species/taxon occupies as a proportion of the total area. The percent cover can be estimated visually within the entire quadrat, or the quadrat can be divided into subquadrats and observations made within each of these (later summing to give the value for the entire quadrat). An alternative technique is to overlay a grid and record the species present under each point. The grid method can be done directly *in situ* or in the post-processing stage of photos if these have been taken. Meese & Tomich (1992) provide a comparison of various cover estimate methods.

Biomass: Where a measure of biomass of a species or taxa is important for the survey objectives, it will be necessary to physically sample the quadrat to collect the organisms of interest for weighing.

Size: Size distribution(s) of a species or multiple species can be determined by measuring species-specific size parameters (e.g. shell width, carapace length) either *in situ* or from photos, provided a scale is included in the image. Specific sizes of each individual may be recorded, or alternatively, the frequency of individuals that fall into predetermined size classes may be appropriate.

Species richness or species diversity: Species richness is a measure of the number of species present in a defined area, while species diversity is a measure of the number of species combined with the evenness of the spread of individuals within these species. Within each quadrat, record the abundance of each species present.



Box 2: How and where to measure

How are the observations to be made?

The method used for making the observations will depend largely on the taxa and variables of interest. Foster et al. (1991), Preskitt et al. (2004) and Parravicini et al. (2009) compare quadrat techniques and may be useful for determining the most relevant technique for a given objective.

***In situ* observation:** The observer directly records data during sampling, which requires a high taxonomic knowledge of the local biota.

Photography: The observer takes a digital photograph of the quadrat for later processing. When the unit of sampling is flat, and when the ratio of organism size to sampling unit is not so small as to make identification difficult, photographs are the most time-efficient method to obtain data underwater. They offer a permanent record that can subsequently be analysed by the method of choice. They can also be re-analysed later using other techniques or with other objectives. It should be noted, however, that it may be more difficult to correctly identify species from photos compared with directly in the field, especially in situations where the three-dimensional structure of the areas photographed is high.

Video: Similar to photography, but frame grabs will be extracted from the video files during post-processing.

What size quadrat should be used?

Quadrat size is principally related to the characteristics of the habitat(s) or organisms(s) of interest, including their size, density and spatial arrangement. If too small a quadrat is used, many taxa or individuals will not be sampled, and if too large, the abundances of some species may be too large to count.

If monitoring is an extension of a previous survey, or similar surveys occur at other locations, quadrat size should be standardised to allow cross-study comparisons to be made.

The most common applications of quadrat surveying in DOC's marine reserves are for characterising sessile benthic communities, or for assessing the relationship between grazing macroinvertebrates and algal composition, using 0.25 m² and 1 m² sized quadrats, respectively.

How many sites and quadrats are needed, and how should they be positioned?

The study site should be clearly defined so that decisions about how many quadrats and how to position them can be made in an informed manner. Information to inform delineation of the study site will include the survey objectives, local knowledge, previous research in the area, a pilot study, or from physical or habitat information existing about the area.

In general, it is better to sample from more than one site at a location, or more than one location, as



differences in the composition and abundances of organisms increase as spatial scale increases. Consideration should be given to having fewer replicates per site, and more sites, except if small-scale variation is high (Kingsford & Battershill 1998). A pilot study could help determine this.

Quadrat placement can be made in a number of ways: random within site, random within stratifications within site, haphazard, or fixed. Again, a pilot study may help determine the most appropriate approach for the location and study objectives.

Determining the number of quadrats needed should be done in consultation with a statistician and, if available, pilot data describing spatio-temporal variation in the variables of interest. In general, the more replicates the better, but there is a trade-off with time and cost associated with fieldwork and post-processing.

Sampling procedure

Following the formulation of a clear and robust survey design, a typical process for conducting a quadrat survey includes:

- Ensuring all personnel involved in sampling are clear about the protocol for the particular survey they are conducting. This should include any rules relating to placement of quadrats, what to do in the event a quadrat is placed on unsuitable habitat for the variable of interest, and decisions around inclusion or exclusion of organisms on the quadrat boundary.
- Navigating to the site where sampling is to begin, using either pre-determined GPS coordinates, previous site descriptions, or permanent markers.
- Recording metadata for the survey and site as per the fields in the 'Quadrats: survey field data sheet' (doccm-2786717)⁴ (see Table 3 for field explanations). If sampling is via photoquadrats, record this information on a whiteboard or pad, and take a photo of this prior to beginning the photoquadrats, which will make later sorting of photoquadrat files easier.
- Placing quadrats. This step will be dependent on the method being used for quadrat placement (e.g. stratified random, haphazard, systematic etc.).
 - A common approach is to lay out transects across the study site, and place quadrats at pre-determined random numbers along each transect. For example, for 10 replicate quadrats across a 50 m transect, 15 random numbers between 1 and 50 would be generated for each transect prior to the survey, and would dictate the position of quadrats along each transect. If a quadrat is placed at an unsuitable location in terms of the study question (e.g. on a sand patch where pāua is the taxa of interest), move to the next random number. For this reason, it is usually useful to generate more random numbers than may be required before the field activity begins.
 - An alternative technique is to place the quadrats systematically along a transect, rather than randomly as above, e.g. placing quadrats every 5 metres along the

⁴ <http://www.doc.govt.nz/documents/science-and-technical/inventory-monitoring/im-toolbox-marine-quadrats-survey-field-data-sheet.pdf>



- transect, thus ensuring even spacing of the quadrats across the habitat. However, it is statistically more robust to undertake random sampling, and a statistician should be consulted before undertaking uniform sampling.
- A third approach is to place quadrats haphazardly without the use of a transect. In this case, the observer haphazardly places the quadrat on the substrate (within the defined depth or habitat strata if this is required by the survey design). Subsequent quadrat placements can be made by moving a pre-determined number of paces or fin kicks.
 - Once the quadrat is in place, begin recording data for the primary variables of interest in the 'Quadrats: field data sheet' (doccm-2785236)⁵ (see Table 4 for field explanations). The exact fields to be filled in will vary depending on what variables are being observed, but in all cases, applying a systematic technique to searching, counting or measuring will give the most accurate information. For surveys of a range of taxa, those species with some mobility should be observed first where possible, minimising the possibility of them exiting the quadrat frame. Data can be derived using one or more of the following techniques (which apply to both direct observation quadrats and photoquadrats):
 - **Search the entire quadrat:** Make observations across the entire quadrat area. In some cases (e.g. for estimating percent cover of taxa) it may prove more efficient and accurate to first divide the quadrat into sections, either physically or visually, and make observations in each subsection consecutively.
 - **Subsample the quadrat:** Make observations from a sub-sample of the quadrat. This can be a useful and efficient technique if the abundance or size of one of the taxa of interest means that sampling on a smaller spatial scale is appropriate. Quadrat frames with a built-in sub-frame can be used, or a ruler or other device can be used for consistently delineating the subsampled area. It is essential to be able to derive the area of the subsampled area, and that this remains constant over the course of the survey. Data derived from the subsampled area must then be scaled up to be comparable with data collected at the full quadrat level. For example, a count of brachiopods within a subsampled area of 0.25 m² would be multiplied by 4 to be comparable with data derived from the full area of a 1 m² quadrat.
 - **Point intercept method:** Use a quadrat divided into a grid (or overlay a grid on photos during post-processing) and make observations at each intersection of the lines of the grid.
 - **Random point method:** Make observations at random points throughout the quadrat (using generated random numbers for the x- and y-axes of the quadrats to locate the points). For photoquadrats, this can be done using computer programs to generate random points which can be overlaid on photos.
 - For photoquadrat surveying, the only actions required *in situ* are to take the photo (ensuring it is of sufficient quality for later analysis) and record metadata for the quadrat and a

⁵ <http://www.doc.govt.nz/documents/science-and-technical/inventory-monitoring/im-toolbox-marine-quadrats-field-data-sheet.pdf>



reference for the photo to relate it back to the quadrat metadata. The other data from the quadrat are recorded during post-processing of the photos.

- When sampling a quadrat is complete, take a moment to check over the data sheet to ensure all necessary fields have been filled in, before moving the quadrat.
- Move the quadrat to the next sampling location, using the same method as for the initial quadrat placement, and repeat the recording of information on the data sheet.

Table 3. Minimum metadata attributes to be recorded for quadrat sampling.

Database field	Description	Value
Location	General locality where the sampling occurred (e.g. Ulva Island).	Short text
SurveyName	A name for this survey. Allows to differentiate surveys achieved at different dates at similar location (e.g. Poor Knights Feb 2015).	Short text
SurveyLeaderName	Name (first name + surname) of the person in charge of this survey.	Short text
ContractorName	Name of person/company contracted out to carry out the survey, if applicable.	Short text
OfficeContact	Name (first name + surname) of the key contact in DOC office who was related to this survey.	Short text
Vessel	Vessel used to deploy the diver, if appropriate.	Unlimited text
EventDate	Date of sampling.	Date (dd/mm/yyyy)
EventTime	Time at which the quadrat was sampled.	Time in 24 h format (hh:mm)
SiteName	Site within <i>Location</i> where the sampling occurred.	Short text
Latitude	Decimal degree latitude for the site (WGS84) (e.g. latitude for Wellington Conservation House is -41.289904).	Number with up to 6 digits after decimal. Values are between -90 to 90, but typically negative for New Zealand.
Longitude	Decimal degree longitude for the site (WGS84) (e.g. longitude for Wellington Conservation House is 174.775043).	Number with up to 6 digits after decimal. Values are between 0 and 360.
ProtectionStatus	Indicates the protection status of the area sampled.	One of the six values: <ul style="list-style-type: none"> • Marine reserve (type 1 MPA) • Type 2 MPA • Mātaitai • Taiāpure • Other protection • No protection
Recorder	Name of the person who recorded the transect data.	Unlimited text



NoQuadrats	The number of quadrats sampled at <i>SiteName</i> .	Integer
QuadratDimensions	Width × length of the quadrat used (cm).	Integer
Weather	Description of the atmospheric conditions (wind, sea state, swell, etc.).	Unlimited text
Tide	Simplified tidal level at the time of sampling.	One of the four values: <ul style="list-style-type: none"> • Low • Medium • High • Undetermined
SiteNotes	Any general notes relating to <i>SiteName</i> .	Unlimited text

Table 4. Site and quadrat data fields to be recorded for quadrat sampling.

Database field	Description	Value
SurveyName	A name for this survey. Allows to differentiate surveys achieved at different dates at similar location (e.g. Poor Knights Feb 2015).	Short text
SiteName	Site within <i>Location</i> where the sampling occurred.	Short text
QuadratID	A unique identifier during this survey for this specific quadrat.	Unique number
Stratum	Depth stratum within which the quadrat is placed (if sampling is stratified). The investigator might not have designed different depth strata for the study. In this case, a general value encompassing the depth range at which the survey occurred should be entered (e.g. 5–25 m).	e.g. 5–15 m or 16–25 m
ReplicateWithinSite (‘Quadrat #’ on data sheet)	Number of replicate within the site, starting at 1 and up to the number of deployments achieved at that particular site. Note that if only one deployment was achieved per site, then this field takes the value 1 throughout.	Integer
Abiotic	A description of the physical component of the benthos (silt, mud, gravel, shell hash, boulder, etc.).	Short text
Biotic	A description of the dominant habitat-creating organisms associated with the benthos (<i>Ecklonia</i> , red algae, Crustose Corraline Algae, Mytilidae, Pinnidae, etc.).	Short text
Recorder	Name of the person who recorded the quadrat data.	Unlimited text
EventDate	Date of sampling.	Date (dd/mm/yyyy)
Depth	Depth of the quadrat, in metres.	Number



EventTime	Time at which the quadrat was sampled.	Time in 24 h format (hh:mm)
ScientificNameSpecies	Scientific name of the species observed, if observations are made to the species level.	Short text
TaxaName	Name for the taxa observed if observations are not made to species level.	Short text
Count	Number of individuals of <i>ScientificName</i> observed. Note that if specimens of the same species have different sizes, a line per size group needs to be created.	Integer
Size	Size of the specimen(s) observed in cm within the quadrat.	Integer
Biomass	Biomass of the specimens observed in grams within the quadrat.	Integer
Cover	Percent cover of the specimens observed within the quadrat.	Integer
PresenceAbsence	A record of which species/taxa are present and absent within.	'1' for present, '0' for absent

Processing of samples

Direct observation quadrat surveying generally will not require the collection of any samples (the exception to this being when a voucher specimen is collected to aid or verify identification). Where length or biomass measurements of organisms are required, and cannot be made without physically sampling the individuals, samples may need to be taken and processed in a manner relevant to the organism and variable in question.

For photoquadrat surveying, post-processing of images will be required to extract the data of interest, either directly by an individual analyst or using image analysis software.

Timing

Consideration of timing of the surveying activity should include:

- Any diurnal, seasonal or lunar characteristics of the taxa of interest and how this may affect surveying (including whether previous surveys have occurred at a certain time of year/day etc.)
- For intertidal sampling, the level of the tide will be paramount for survey timing
- What are deemed 'safe' hours of operation for the surveying activity (e.g. for allowing enough time for personnel involved to return safely home/back to base within daylight hours).

Safety

Safety is paramount during any survey activity. The safety recommendations below are provided as general guidance, but it is imperative that the survey leader understands all risks associated with



the activity, always uses caution, and develops a Safety Plan for the survey activity and location (DOC staff should use RiskManager, and non-Departmental staff should consult WorkSafe New Zealand's 4-step risk management⁶ or their own organisation's safety plans. Safety Plans should include resources (e.g. equipment, boats, communication, support, personal protective equipment), environmental hazards or considerations (e.g. remoteness, surf zones), personnel (experience, training, physical and mental fitness), weather and mission complexity. Following a thorough safety briefing, all team members should read and then sign the Safety Plan.

Specifically, it is recommended that:

- A minimum of two people make up the survey team (or a minimum of three people for diving operations)
- All personnel should operate within the limits of their training and experience
- The magnitude and complexity of the survey are relevant for the planned duration of the survey

Quality assurance

Quality control measures should be used to ensure that data quality is consistent with previous surveys. A measure of observer accuracy or bias in quadrat surveying will provide an assessment of the confidence that can be had in the results. Some form of quality assurance should be integrated into the survey protocol at one or more stages.

Quality control measures should be employed to ensure that the organisms recorded in each quadrat are accurately identified to the correct taxonomic group and counted correctly. To aid identification, samples can be taken and later checked against identification guides, or checked with other observers involved in the same survey.

A quality control measure for counting errors involves reassessment of a portion of the quadrats by a different observer and estimating the variability in the two sets of observations. For photoquadrats this can easily be done in the post-processing stage, while for direct observation quadrats this will need to be done in the field by another observer before the quadrat is moved to the next location. It is recommended that 5% of quadrats sampled are reassessed to give a measure of the counting error or counting efficiency. Singleton (2010) provides a description of a quality control method used for a different sampling technique, but it can be applied to quadrat sampling. For more detail, see Singleton (2010), but in brief, the identification and enumeration efficiency is calculated as:

$$\frac{\text{\# organisms in recount} - \text{number of errors}}{\text{\# organisms in recount}} \times 100$$

where the 'number of errors' is the difference between the original count and the recount.

If possible, it may be useful to carry out a quality control exercise during a pilot study, and if the counting efficiency is less than 90% (or another level as determined by the survey objectives), steps can be taken to try to improve this when the full study is undertaken (e.g. via observer training).

⁶ <http://www.worksafe.govt.nz/worksafe/hswa/health-safety/how-to-manage-work-risks>



For photoquadrats, it is simpler to reassess photos if the counting efficiency is found to be below the acceptable level. For direct observation quadrats, it is more difficult to calculate the counting efficiency in the field and adjust the programme as necessary; however, it is still useful to have a measure of this error for reporting purposes.

References and further reading

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Appendix A

The following Department of Conservation documents are referred to in this method:

doccm-1163829	MPAMAR metadata—National
doccm-2785236	Quadrats: field data sheet
doccm-2786717	Quadrats: survey field data sheet
doccm-237640	Scientific diving and snorkelling technical document
doccm-146272	Standard inventory and monitoring project plan

