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Using community-based monitoring with GIS to create habitat maps for a marine protected area in Australia

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In recent years there has been an increase in community-based monitoring programmes developed and implemented worldwide. This paper describes how the data collected from such a programme could be integrated into a Geographic Information System (GIS) to create temperate subtidal marine habitat maps. A differential Global Positioning System was utilized to accurately record the location of the trained community-based SCUBA diver data. These georeferenced data sets were then used to classify benthic habitats using an aerial photograph and digitizing techniques. This study demonstrated that trained community-based volunteers can collect data that can be utilized within a GIS to create reliable and cost-effective maps of shallow temperate subtidal rocky reef systems.

Keywords: community-based monitoring, GIS, habitat maps, marine protected area, Australia

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INTRODUCTION

In recent years, there has been increased interest in the creation of marine reserves, and their potential use for both conservation and fisheries management. This has generated considerable debate on the possible effects of marine reserves on the assemblages contained within them (Allinson *et al.*, 1998; Pauly *et al.*, 2002). In particular, environmental managers may wish to know whether reserves protect the species most affected by human activity, whether the integrity of habitats can be maintained, and what trophic cascade or other ecological flow-on effects may arise from increases in the density of organisms that are elsewhere depleted (Babcock *et al.*, 1999).

Globally, discussions on placement of marine protected areas (MPAs) are often made in the absence of adequate marine habitat information (Williamson *et al.*, 2004). In highly dynamic marine environments, such as those found on Australia's southern coastline, major obstacles are often encountered in providing detailed information to decision makers. This is in large part due to constraints imposed by budgets, time and limited weather windows for data collection. Field surveys, by their nature, are labour intensive and expensive, especially in temperate marine environments (Stevens, 2002). As such, there is a need for alternative cost-effective mapping programmes to be established and implemented.

It is widely regarded that public participation in environmental monitoring may contribute to increasing the knowledge on the state of the environment. At the same time, this can promote involvement in environmental protection, and ultimately can dictate the success of a protected area (Kelleher & Kenchington, 1992; Darwall & Dulvy, 1996; Lunney & Matthews, 2002; Foster-Smith & Evans, 2003; Walmsley & White, 2003). Indeed, volunteers and community groups have already made significant contributions to scientific knowledge through participation in a range of studies, including involvement in sea grass monitoring through Seagrass-Watch (McKenzie *et al.*, 2000), and fish and invertebrate monitoring through various programmes such as Reef Check (Hodgson *et al.*, 2003), Reef Watch (Reef Watch, 2006), Locally-Managed Marine Area Networks operating in the Pacific and south-east Asia (LMMA Network, 2006), and other community-based initiatives in the Philippines (Pomeroy & Carlos, 1997; Pollnac *et al.*, 2001).

Unfortunately, the use of volunteer-collected data is often viewed as limited due to a lack of confidence in data collection procedures (Underwood & Chapman, 2002). Additionally, data quality is often unknown and data sampling usually dispersed and non-structured. As such, adequate training and guidance is essential to maintain the creditability and usefulness of community-based monitoring programmes (Underwood & Chapman, 2002; Koss *et al.*, 2005b). Following the success of community monitoring initiatives and the above mentioned concerns, a subtidal community-based monitoring programme that could be implemented for Victoria's, Australia, network of Marine National Parks and Marine Sanctuaries was developed. This programme, entitled 'Sea Search', was specifically designed to complement professionally collected data. The programme utilizes trained underwater community-based SCUBA divers to collect information on temperate subtidal marine assemblages using georeferenced belt transects and quadrats (see Koss *et al.*, 2005a).

It is also viewed that access to data is crucial to initiate public support and participation during environmental decision-making processes. However, these data are not always available to the broader public and are not usually

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available in a format that can be understood by the variety of stakeholders often present. Morgan & Gramman (1988) found that the technique most effective in producing attitude change was modelling through the use of visual technologies such as GIS.

Previous studies have shown that the use of validation information combined with remotely sensed data (i.e. aerial photography or satellite images) and the analytical capabilities of a GIS provides a cost-effective approach to rapidly map subtidal coastal habitats (Dahdough-Guebas *et al.*, 2002; Ierodiaconou & Laurenson, 2002; Stevens & Connolly, 2005). It has also been identified by management that mapping marine habitats is essential to establish information concerning how habitat sizes or distributions change over time within the network of MPAs (Parks Victoria, 2007). Parks Victoria, the management agency responsible for Victoria's MPAs has since formed an extensive partnership with universities, government agencies and private enterprises to map marine habitats within five of the largest Marine National Parks in Victoria (Holmes *et al.*, 2007). However, the vessel-based mapping methods used are often not practical for smaller MPAs. The aim of this study was to assess whether subtidal information from a community-based monitoring programme (Koss *et al.*, 2005a) could be integrated with remotely sensed data in a GIS to create reliable habitat maps of one of the smaller MPAs, the Merri Marine Sanctuary in south-west Victoria, Australia.

MATERIALS AND METHODS

Description of study area

The Merri Marine Sanctuary (628,346E 5,748,352N) covers 32 hectares on the coast of Warrnambool, south-west Victoria, Australia, offshore from the mouth of the Merri River. The seabed at the river mouth is a mixture of rocky sandstone reef and sand, providing a range of habitats and diverse marine life. Deep canyons support a variety of fish. Little penguin (*Eudyptula minor* Forster) colonies are also found on Merri and Middle Islands within the Sanctuary (Overeem & Wallis, 2003). The Sanctuary supports various recreational activities (boating, snorkelling, SCUBA diving and swimming), as well as providing protection for fish, invertebrate and algal species. It has a maximum depth of 17 m, but in general, subtidal rocky reefs occur in depths $<$10 m.

With no major land masses between the Southern Ocean and Australia's southern coast, the Sanctuary is exposed to frequent large swells. Strong (mean annual wind strength 14 knots) south-west winds are also common (Bureau of Meteorology, 2007). Despite the Sanctuary being only 32 hectares, these environmental restrictions make gathering reliable habitat and biodiversity data very time consuming and expensive using traditional means.

Collection of validation information

Over a three year period (2002–2005) community-based research divers undertook 20 underwater transects within the Merri Marine Sanctuary. Divers were required to complete an internationally accredited research diver course (PADI Research Diver Course: 453231) to develop skills in the collection of floral and faunal information. The course was developed through extensive consultation between community and industry partners. This resulted in the formation of a community-based subtidal monitoring programme entitled 'Sea Search'. It was specifically developed to complement commercially collected data using traditional belt and quadrat survey methods for mobile and cryptic fish, algae and invertebrate assemblages. The ability of divers to collect accurate data was assessed in a controlled environment using representative quadrat tests. Further assessment protocols involved the pairing with a dive leader (qualified marine biologist) for initial ocean dives to ensure data integrity (Koss *et al.*, 2005a). In addition to this, supplementary species identification practical training was also provided through university specialists and underwater identification packs. Habitat information (dominant algal coverage) and abiotic attributes were collected using 0.25 m^2 quadrats positioned every 10 m over a 100 m haphazardly positioned transect. Additional information on invertebrate distribution and mobile and cryptic fish diversity was also collected but is not included in this paper. Transect start points were plotted using a differential GPS. A compass bearing was taken to enable transect line direction to be integrated into the GIS software. Data from fourteen, randomly selected, transects were used to derive benthic habitat maps. The remaining six transects provided reference data for error assessment of the final map products.

Habitat classification

A digitized aerial photograph (2002) was obtained from United Photo and Graphic Services Pty Ltd, Melbourne, Australia. The photograph was rectified (GDA '94 MGA Zone 54, 1st order polynomial with nearest neighbour re-sampling) (ERMapper^{TM} version 6.4) using 10 differentially corrected ground control points. Ground control points were selected based on ease of identification in the photograph and field (e.g. road intersections, walking tracks, breakwater, etc). Enhancement techniques were applied to the aerial photograph to increase contrast among subtidal features. Habitat classification was undertaken in ArcView version 3.3 (ESRI Inc) using data from 14 community diver transects and manual delineation techniques, digitizing contrasting zones in the aerial photograph. The classification system used in this study was based upon the Victoria Marine National Park habitat classification schematic (Ball *et al.*, 2006). Ten algal habitat categories and four abiotic categories were used in the study (Table 1).

A quantitative accuracy assessment was undertaken of the final map products using an independent set of validation data (reference data) and presented using an error matrix. Two measures of error (overall accuracy and Kappa coefficient of agreement (K_{hat})) were used to assess the classification accuracy (Congalton & Green, 1999).

RESULTS

Subtidal habitat data collected by community-based divers were successfully integrated with remotely sensed data into GIS. Two habitat maps of the Merri Marine Sanctuary were created: one based on algal habitat (Figure 1) and the other on abiotic habitat features (Figure 2). Approximately 72% (13.1 ha) of the subtidal zone within the Merri Marine Sanctuary was categorized by algal habitats, while the remaining 28% was

Table 1. Biotic and abiotic classification categories used for mapping the Merri Marine Sanctuary, south-west Victoria, Australia.

Description	Subtidal attributes	
Algal habitat classes	*Phyllospora comosa* dominated algal assemblage	Mixed small red and brown algae
	Small mixed brown algae	*Caulerpa* spp. dominated algal assemblage
	Macrocystis angustifolia dominated algal assemblage	Coralline algae dominated algae assemblage
	Mixed foliose red algae	*Ecklonia radiata* dominated algae assemblage
	Sand (no visible biota)	Reef (no visible biota)
Abiotic classes	High (>1 m) relief reef	Fine sand
	Low (<1 m) relief reef	Cobble

fine sand (5.2 ha) and reef (0.2 ha) with no visible biota present (Figure 1). Kelp, *Phyllospora comosa* (Labillardière), was the most abundant habitat-forming alga, occupying 53% (9.9 ha) of the subtidal zone. The remaining 19% was covered by small mixed brown algae (1.3 ha), mixed red and brown algae (1.2 ha), *Caulerpa* spp. assemblages (0.7 ha), *Macrocystis angustifolia* (Bory) dominated assemblages (0.2 ha), encrusting (non-geniculate) and branching (geniculate) coralline algae-dominated assemblages (0.08 ha), foliose red algal mix (0.04 ha) and *Ecklonia radiata* (Agardh) dominated algal assemblages (0.01 ha).

Abiotic classification (Figure 2) revealed high (>1 m) relief sandstone reef dominating the Sanctuary, making up 47% (8.7 ha) of the subtidal area (Figure 2). Fine sand and low (<1 m) relief sandstone reef contributed 28% (5.2 ha) and 25% (4.6 ha), respectively. Cobble contributed just 0.3% (0.05 ha) of the total subtidal area (Figure 2).

Habitat maps for algal habitat and abiotic features both achieved an accuracy of 76% with a Kappa coefficient of agreement (K_{hat}) of 0.66 and 0.75, respectively (Table 2).

DISCUSSION

This study demonstrated that subtidal survey information collected by trained, community-based volunteers can be integrated with other spatial datasets in a GIS to accurately map the subtidal zones of shallow temperate reef systems. While previous attempts to generate habitat maps for the Merri Marine Sanctuary have been limited by budgets, time and weather constraints, the collection of information by community-based volunteers is primarily restricted by weather alone. Involvement of community-based volunteers in monitoring programmes has been shown to help alleviate monetary constraints imposed by traditional surveying techniques (Stepath, 2002). However, stringent protocols must be in place to ensure that the data collected are of reputable quality. Underwood & Chapman (2002) highlight the issues surrounding the collection of data without clearly defined aims and sampling protocols by community-based monitoring programmes. The present study addressed this issue by ensuring that all community-based divers were trained and assessed in the required sampling methods and identification skills through an internationally accredited research diver course and practical identification sessions prior to participation in the monitoring programme.

Although it is recognized that habitat maps are an imperfect model of the marine environment the results of this study have shown that significant opportunities exist. Because the 'Sea Search' programme was specifically designed to complement professionally collected data, the spatial databases were also structured in a form to allow future marine habitat mapping studies to be integrated, queried, compared and analysed as more information becomes available.

Habitat maps are often derived from remotely sensed data through some form of classification analysis. The value of the map is clearly a function of the accuracy of the classification (Robbins, 1997). This study cross-validated all maps with an independent data set and established the error involved. This gives us a quantitative measure of the accuracy of the maps produced.

It is also noted that temperate subtidal reef habitats are not static. The extents of the macroalgal assemblages may vary from year to year (Dayton *et al.*, 1984). The seasonal die-off of macroalgae contributes a strong pulse of detritus to the ecosystem during low-light winter months, supporting detritivores and upper trophic levels when primary productivity in the water column wanes (Mayakun & Prathep, 2005). As such, time-series, GIS-derived habitat maps are required to assess temporal change. However, the generation of temporal maps also has inherent problems. The application of remote optical sensing to map temporal marine biological distributions has been successfully used in some tropical coastal marine areas (Chauvaud *et al.*, 1998), but is generally limited to areas of shallow (<15 m) and consistently clear water (Pasqualini *et al.*, 1998). The issues surrounding high levels of turbidity in temperate marine waters, compared to their tropical counterparts, have resulted in fewer applications of remote optical sensing in these regions. Remote sensing in the marine environment has great application in littoral, shallow, and clear waters, and sea surface applications (Green *et al.*, 1996). These conditions, however, are often hard to find in southern Australia. In southern Australia, most fieldwork can only be carried out safely during the summer months when the seas are calm. Due to less cloud cover, this is also the time when most aerial photographs are taken. As a result, the use of community-based SCUBA divers to collect the validation information for the generation of temporal maps during the winter months is very difficult. Consequently, alternative methods should be sought. In the absence of these biological data, many recent attempts at habitat classification at both regional and local scales have used easily available physical and/or oceanographic data as surrogates for biological distributions (Roff & Taylor, 2000) or reverted to Delphic methods of classification (Hockey & Branch, 1997). Non-biological information is clearly relevant, and in some instances can be used to predict biological distributions quite accurately (Long *et al.*, 1997). However, there are disadvantages in basing habitat classification solely or primarily on physical surrogates (Edgar *et al.*, 1997). Given that the objective is to represent patterns of biodiversity, in order to provide the basic rigour, the predictions of biological distributions from physical data would involve extensive validation data input (Stevens & Connolly, 2005). In areas deeper than about 10 m, the difficulties of major

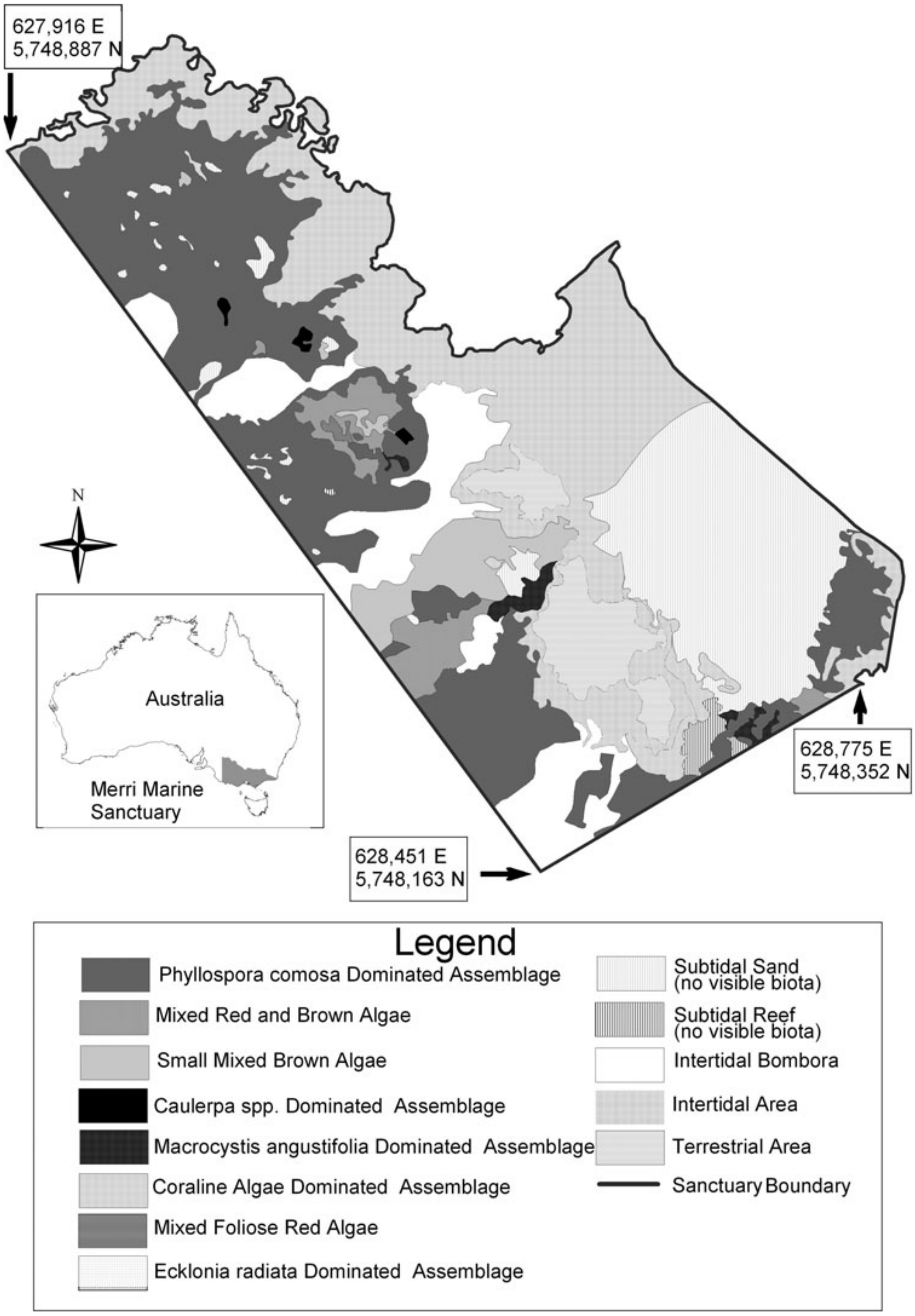

Fig. 1. The Merri Marine Sanctuary study area, south-west Victoria, Australia. Distribution of algal habitat assemblages within the Sanctuary.

underwater (SCUBA-based) validation data surveys quickly erode the cost and logistical savings of using such surrogate datasets.

Although there are alternative methods, such as combining sonar and visual sampling techniques (Stevens & Connolly, 2005; Ierodiaconou *et al.*, 2007), that can yield higher degrees of classification accuracy and can enable more extensive sampling than that provided by either SCUBA surveys or grab sampling techniques (Engel & Kvitek, 1998), the costs associated with such a sampling regime are cost prohibitive at the spatial scales considered in this project. To use such techniques cost-effectively, spatial scales of 100s of hectares are required. The utilization of community-based SCUBA divers to collect ground-truth information and optical remote sensing techniques provided a cost-effective alternative to create habitat maps at the spatial scales required by management for these smaller marine sanctuaries.

Furthermore, it is widely accepted that community-based monitoring activities address three major issues often faced by MPA managers (Stepath, 2002): (1) cost-effective collection of data; (2) developing public awareness of marine habitats; and (3) promoting knowledge about relationships between humans and the marine environment (Kelleher &

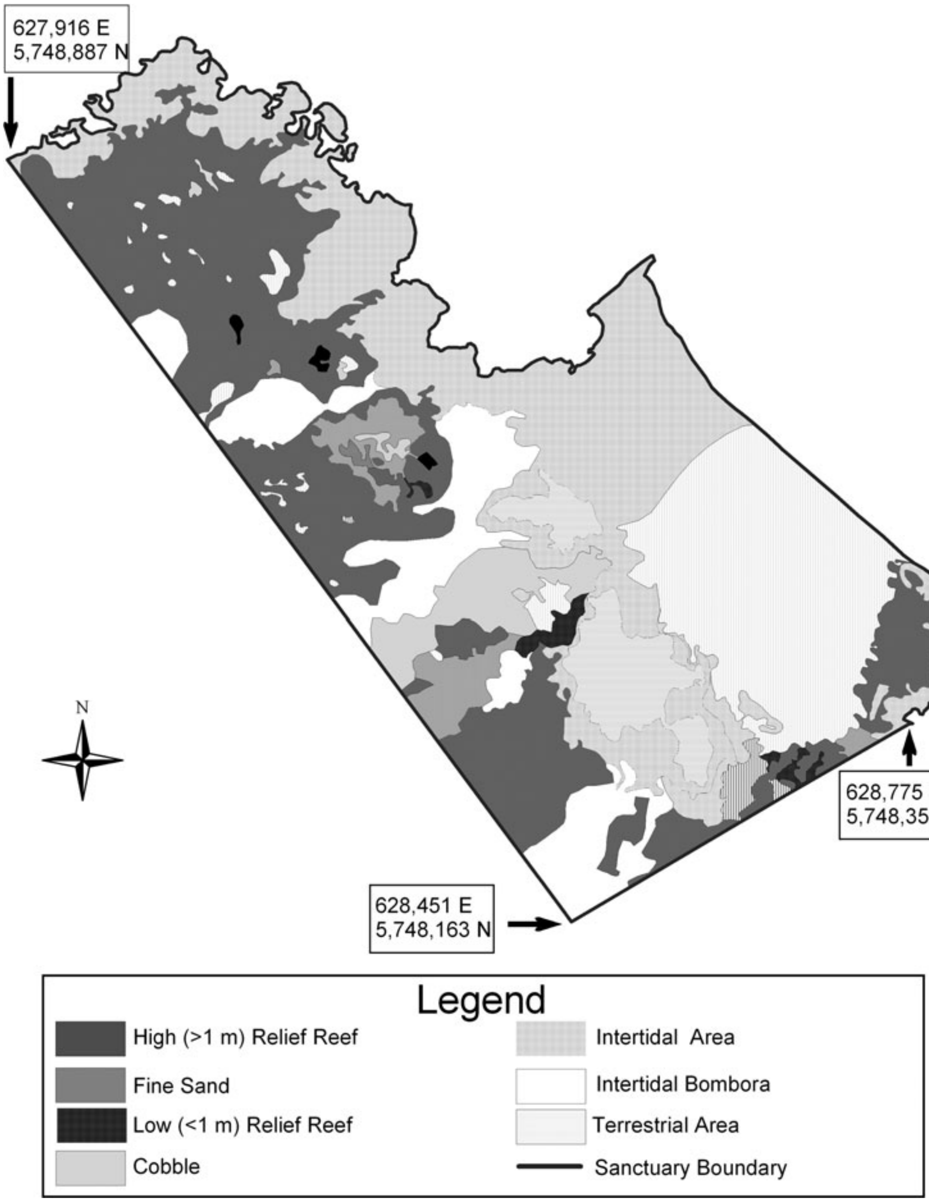

Fig. 2. The Merri Marine Sanctuary study area, south-west Victoria, Australia. Distribution of abiotic categories within the Sanctuary.

Kenchington, 1992). Thus, in addition to the scientific value of data collected by community-based volunteers, there are social benefits that also assist in the management of MPAs.

Whilst evaluating the 'Sea Search' programme, Koss *et al.* (2005b), surveyed active community group members. Questions sought qualitative and quantitative information, focusing on personal values of MPAs. The surveys included questions associated with community-based monitoring, MPA management and environmental issues affecting the marine environment. Responses from the study indicated that 50% of the volunteers participated in the programme to further their knowledge about scientific research, whilst 30% wanted the opportunity to work close to nature.

Table 2. Kappa coefficient of agreement (K_{hat}) and overall accuracy derived from an error matrix for algal habitat and abiotic features for the Merri Marine Sanctuary in south-west Victoria, Australia, obtained from aerial photographs and community-based SCUBA diver validation information.

	Overall accuracy (%)	K_{hat}
Algal habitat	76	0.66
Abiotic features	76	0.75

Despite the issues surrounding sample sizes in the Koss *et al.* (2005b) study, other studies have established similar results. Stepath (1999, 2006) discusses in great length that promoting responsible environmental behaviour requires changing human attitudes and that a very good way to do this is by linking attitudes to participation. If monitoring of MPAs can be linked to this behaviour change, as well as establishing baseline ecological information, it could be a very effective tool in marine resource management (Wilkinson, 1998). Another common problem faced by MPA management is the huge expanse of MPA areas that they are required to effectively monitor and manage, and the limited number of trained people involved in this monitoring. Management agencies that consider the use of localized volunteers are often concerned about the value and quality of the data obtained. As shown in this study, one way around this obstacle is to provide the opportunity to participate in a training programme. Training both raises the quality of the data collected and improves the communication of science to the community.

However, as highlighted earlier, in southern Australia, adverse weather conditions make it very difficult to dive all year round. This resulted in some volunteers not being actively involved for a number of months. We found that this caused some of the volunteers to forget the skills that are crucial to the monitoring programme success. As such, there is a need for ongoing training to enable current community volunteers to refresh their survey and identification skills.

In conclusion, this study demonstrates the advantages of using community-based monitoring data integrated into a GIS for the delineation of habitat information for shallow temperate marine environments. The integration of community diver surveys positioned using differential GPS, rectified aerial photography and digitizing techniques provides a cost-effective approach to rapidly map subtidal marine habitat assemblages. Furthermore, the utilization of community-based volunteers to collect this information provides the opportunity for them to develop a sense of ownership towards the area.

The implementation and training of community-based monitoring programmes provides an alternative to traditional monitoring methods that may be restricted due to cost or the lack of available personnel. The generation of these habitat maps and associated information collected by community divers provide a baseline assessment of the Merri Marine Sanctuary that may assist in making more informed management decisions.

Ongoing monitoring of these environments may help us understand the effectiveness of these systems for the variety of purposes that they were designed. Whilst community-based monitoring provides useful data sources, other available technologies should be explored. LIDAR imagery can provide detailed geophysical data of seafloor environments and has become a common tool in coastal threat and assessment studies (Bowen & Depledge, 2006; Campbell & Hewitt, 2006). Additionally, towed video information may provide an alternative method for understanding the seasonal variability in benthic marine habitats.

Furthermore, the methods employed in this study allowed for the collection of habitat information in a relatively small marine sanctuary, but we see no reason why the methods could not be used for larger shallow water MPAs as an alternative to traditional monitoring.

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