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Developing indicators and a baseline for monitoring demersal fish in data-poor, offshore Marine Parks using probabilistic sampling

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ABSTRACT

The number of Marine Protected Areas (MPAs) has increased globally as concerns over the impact that human activities are having on the world's oceans have also increased. Monitoring is a key requirement to determine if MPAs are meeting their objectives. However, many recently declared MPA's are large, offshore, or form part of an expansive network and spatial information about the habitats, communities and species that they contain is often lacking. This presents challenges for deciding exactly *what* to monitor and developing strategies on *how* to monitor it efficiently. Here we examine these issues using the Flinders Marine Park in Australia as a case study. We trial a two-stage version of a spatially-balanced, probabilistic sampling design combined with Baited Remote Underwater Videos (BRUVs) to perform an initial inventory, and we evaluate the potential of six commercially and ecologically important demersal fish as indicators within the Marine Park. Using this approach we were able to (1) quantitatively describe the distribution of the fish species in the Marine Park; (2) establish quantitative and representative estimates of their abundance throughout the Marine Park to serve as a baseline for future monitoring; (3) conduct power analyses to estimate the magnitude of increase we may be able to detect with feasible levels of sampling effort. Power analysis suggested that for most of our potential indicator species, detecting increases in abundance as small as 50% from present values should be feasible if sampling is restricted to a species' preferred habitat and the same sites are sampled through time. Our approach is transferrable to other regions where monitoring programs must be designed based on limited spatial and biological data, assisting with decisions on *what* and *how* to monitor.

1. Introduction

Spatial management options are becoming increasingly prevalent as concerns escalate over the impact that humans are having on marine ecosystems. These impacts include declines in key species, loss of biodiversity (Worm et al., 2006), catastrophic ecosystem regime shifts (Johnson et al., 2011), and climate-related range shifts (Poloczanska et al., 2013). An important tool in the conservation toolbox is Marine Protected Areas (MPAs) which are regions of ocean afforded varying levels of protection from human interference. Currently, MPAs cover approximately 7% of the world's ocean (UNEP-WCMC and IUCN, 2017). Recent MPAs tend to cover large areas (Spalding et al., 2013) or incorporate a series of interconnected MPAs, a strategy that is generally more effective at achieving conservation objectives (Edgar et al., 2014). However, in order to assess whether MPAs are meeting their objectives, and to inform adaptive management, carefully designed monitoring programs that track changes in the abundance and/or health of indicator species, key groups or assemblages are required (Ferraro and Pressey, 2015). In contrast to the numerous studies that report on monitoring programs and the effects of MPAs in coastal waters (e.g. Barrett et al., 2007; Denny et al., 2004; Kelaher et al., 2014), fewer studies exist for large, and often remote, offshore MPAs (but see Alemany et al., 2013). Developing monitoring programs for offshore MPAs is difficult. Often there is a lack of baseline data or detailed prior knowledge on the distribution of habitats and ecological features upon which to build a monitoring program that is inherently spatial. Combined with the logistics of working in remote environments, this presents challenges for deciding exactly *what* to monitor and developing strategies on *how* to monitor it efficiently.

Here we examine these issues in the Australian context. In 2012, the

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Australian government proclaimed a network of Australian Marine Parks (DOTE, 2014). The network amalgamated 33 previously declared Marine Parks with 27 new Marine Parks. Protection within the Marine Parks ranges from sanctuary zones (IUCN 1a) to multiple use zones (IUCN VI). The network covers approximately 3.1 million square kilometres, all of which is offshore (> 3 nm), a large proportion of which covers deep waters (> 100 m), and some of which is remote and difficult to access. The network of Marine Parks aims to 'reasonably reflect the biotic diversity of marine ecosystems' (Althaus et al., 2017; DOTE, 2014). Following the declaration of the network, there is a need to develop monitoring programs to evaluate the performance of individual Marine Parks. Whilst the best available information was used to delineate the Marine Parks and their values, the objectives of specific Marine Parks are often quite broad including, for example, protecting habitats, communities and ecosystems representative of the region (Director of National Parks, 2013). Translating these high level objectives into tangible metrics for monitoring can be difficult. This is exacerbated by the fact that while broad-scale biogeographic information was available to delineate the Marine Parks, fine-scale, spatially explicit information on benthic (and pelagic) habitats as well the composition and distribution of communities and key species is often lacking (Lawrence et al., 2015). As a result, monitoring programs must begin with an inventory to inform *what* exactly to monitor. In addition, the vast size of Marine Parks and their remoteness means larger vessels must be used which increases costs, there are large distances between sampling sites, sites may not be able to be sampled due to weather or other unforeseen circumstances, multiple sampling gears will be used concurrently to satisfy multiple objectives and sampling should be non-destructive. This has implications for *how* to monitor.

Choosing appropriate indicators for monitoring complex biological systems can be difficult, even when prior knowledge of the management region is good; a difficulty illustrated by the profuse number of ecological indicators proposed for marine systems (Teixeira et al., 2016). Here we consider demersal fish species as potential indicators in a long-term monitoring program within the Marine Park network. Demersal fish are often a significant component of the biodiversity that MPAs are intended to protect. They typically have smaller ranges than pelagic species and hence are more likely to be responsive to management interventions, such as zoning arrangements, within MPAs. In qualitative modelling undertaken during the development of Australia's Marine Park network, demersal fish emerged as consistent and sensitive indicators on the state of a range shelf ecosystems (Dambacher et al., 2011). Demersal fish have proven useful indicators of the effectiveness of smaller and/or more coastal MPAs (Barrett et al., 2007; Bornt et al., 2015; Denny et al., 2004; Stuart-Smith et al., 2017) and they are also relevant to and easily interpreted by management and the public. Thus demersal fish fulfil several key criteria for selecting indicators as recently summarised by Hayes et al. (2015). However, indicators must also be feasible to monitor and this is influenced by their abundance, distribution and variability across the region, as well as the availability of suitable monitoring equipment, and we assess these aspects using relatively inexpensive sampling methods for six key demersal fish species.

Choosing an appropriate sampling design and sampling gear are a core component of *how to* monitor. Sampling designs used for inventory and monitoring in large, offshore Marine Parks must be able to draw inference across the whole region of interest with relatively few sites. They must also be sufficiently flexible to accommodate multiple and potentially changing objectives. Sampling that is representative of a region is best achieved using a probabilistic sampling design, where every part of the sampling region has a quantifiable probability of being selected (Smith et al., 2017). This includes randomised designs but contrasts with judgemental sampling, where sites are chosen *a priori* based on expert knowledge or some other criteria, that is sometimes used for monitoring coastal MPAs (e.g. (Barrett et al., 2007). The best known probabilistic sampling design is simple random sampling (Thompson, 2012). Whilst simple random sampling provide unbiased estimates of the status and trends within an MPA, they may not be *efficient* in that many sites may be required to reduce uncertainty to acceptable levels. An emerging alternative is to utilise spatially-balanced probabilistic designs (e.g. Robertson et al., 2013; Stevens and Olsen, 2004) and here we trial and evaluate the use of one such design called Generalised Random Tessellation Stratified (GRTS) sampling (Stevens and Olsen, 2004). GRTS is flexible and efficient at achieving spatially-balanced sampling under a range of scenarios, and has shown promise for monitoring natural resources in aquatic systems (e.g. Dambacher et al., 2009).

Sampling gear is another key consideration for monitoring, and within MPAs the choice of sampling gear is ideally non-extractive. However, the depth of the Australian Marine Park network precludes the use of some traditional non-extractive approaches such as SCUBA-based surveys. Baited remote underwater stereo videos (stereo BRUVs) have been effective in censuses of fish in coastal waters (Malcolm et al., 2007; Watson et al., 2009) and here we examine their use for monitoring within the Australian Marine Park network.

We focus on demersal fish within the Flinders Marine Park (FMP) shelf, which is one of the Marine Parks within the Australian Marine Parks network, as a case study for determining *what* and *how* to monitor in a region where little prior knowledge is available. The Flinders Marine Park was established in 2007 and the continental shelf is a multiple use zone (IUCN VI). Knowledge on the spatial distribution and abundance of benthic habitats, communities and key species in this region is very limited and our work forms part of a broader survey program conducted in 2012 aiming to redress this issue to inform monitoring efforts (Hill et al., 2014; Lawrence et al., 2015; Monk et al., 2016). We trial and evaluate the efficacy of using the GRTS spatially balanced survey design, using BRUVs, for developing representative baseline estimates of the distribution, size structure and relative abundance of six species of demersal fish within the Flinders AMP shelf (i.e. the *how* to monitor). To evaluate *what* to monitor, we conduct power analyses using GRTS -based estimates to determine the magnitude of trends that we may be able to detect for each of the six species with feasible sampling effort.

2. Materials and methods

2.1. Study region

The Flinders Marine Park (FMP) lies offshore of the north-east of Tasmania extending from approximately 35 m depth to 3000 m depth. Our study region is restricted to the ~813 km^2 multiple use zone on the continental shelf between 40 and 180 m (Fig. 1); where most of the anthropogenic pressure is concentrated. The region falls within the Commonwealth Fisheries South East Trawl Sector and the Gillnet and Shark Hook Sector. Low to moderate (~2000 kg/year) commercial fishing effort occurred on the shelf before the declaration of the FMP in 2007. Demersal trawling was concentrated on the outer shelf, while hook, line and gillnet fishing were more dispersed across the shelf (Pitcher et al., 2016). Since 2007 demersal trawling has been prohibited (Director of National Parks, 2013). At the same time, the Australian Fisheries Management Authority (AFMA) imposed a ban on hook and line methods for the area overlaying the FMP as part of an AFMA closure to protect Harrisson's Dogfish (*Centrophorus harrissoni)*. Reassessment of this closure in 2013 resulted in the shelf (< 180 m) being re-opened to hook and line methods (AFMA, 2012; Williams et al., 2013). Gillnets and recreational fishing are also allowed on the shelf of the Marine Park.

The FMP was established to protect 'representative examples of the ecosystems, communities and habitats' associated with the Tasmanian Shelf and Southeast Shelf Transition biogeographic provinces (Commonwealth of Australia, 2014; Director of National Parks, 2013). These provinces are considered cool-temperate in climate and are