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Accounting for spatiotemporal dynamics in conservation planning for coastal fish in KwaZulu-Natal, South Africa

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ABSTRACT

Systematic conservation planning methods to design marine protected area (MPA) networks can provide more meaningful results by addressing the spatiotemporal variability of biota, and by using these data to inform target assignment. This study used Marxan software to design candidate MPA networks to meet conservation targets for 67 coastal fish species on the east coast of South Africa. Species were selected for conservation importance, and included both resident and seasonal migrants. The distribution range of three phases of a species life cycle was generated using either cartographic habitat range models or maximum entropy models, and each used as a separate conservation feature. Two sets of conservation features were developed from this: A static set of 77 distribution models for features which ignored seasonal dynamics, and a seasonal set of 147 distribution models which included seasonal dynamics. Conservation targets depended on a species' extinction vulnerability and its seasonal abundance. Three scenarios were used to test the effects of incorporating seasonal spatial and abundance dynamics into MPA design: Scenario 1 tested the effect of using static or seasonal distribution data; Scenario 2 tested the additional effect of adjusting conservation targets based on seasonal variations in abundance; and Scenario 3 tested the additional effect of incorporating existing MPAs into the MPA network. In all three scenarios, the spatial configuration of MPA networks differed between the two datasets (Kappa 0.37, 0.25, 0.3), and static-designs did not fully meet targets for a number of species or critical life cycle phases of some species, however, larger and more expensive areas were required to design MPAs that could meet all conservation targets for seasonal features. Seasonal abundance adjusted targets was useful to elevate the prioritisation of seasonally abundant migratory species. Including existing MPAs did not change the differences observed between static and seasonal outcomes. We believe this will be true for any marine system that demonstrates seasonal spatial life-history differentiation and abundance dynamics, and advocate its use while giving due consideration to the increased cost associated with spatiotemporal planning.

1. Introduction

Systematic conservation planning (SCP) is regarded as an effective tool to design marine protected area (MPA) networks to protect marine habitats and ecosystems (Ban et al., 2014, 2013) and has been used globally (Álvarez-Romero et al., 2013; Fernandes et al., 2005; Grantham et al., 2013; Micheli et al., 2013). SCP can help to develop MPA networks that achieve persistence of a representative sample of biodiversity, while optimising the socio-economic costs and benefits that would be associated with an increased MPA network area within the planning domain (Pressey and Bottrill, 2009). Products generated by SCP analyses provide ecological and socio-economic information for marine spatial plans, which are emerging rapidly in many parts of the world (Mills et al., 2015; Portman et al., 2013). However, SCP still faces challenges in providing a sound rationale for objectively setting quantitative conservation targets (Agardy et al., 2003; Carwardine et al., 2009), and in accounting for spatiotemporal variability of biota (Pressey et al., 2007; Runge et al., 2016).

Most MPA networks are fixed in time and space (i.e. static), and are not designed to accommodate seasonal spatial and abundance dynamics of biota (Gell and Roberts, 2003; West et al., 2009), and consequently risk over or under estimating MPA efficiency for such species (Martin et al., 2007; Runge et al., 2015). Species distribution ranges are often regarded as static to assess conservation priorities (Myers et al., 2000; Venter et al., 2014), when in fact many are dynamic in space and time. The importance of including spatiotemporal data to inform conservation planning has been recognised for a wide variety of taxa, e.g. fish (West et al., 2009), birds (McGowan et al., 2013), and cetaceans

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(Hooker et al., 1999) in an attempt to ensure that these species are protected when they move outside of existing protected areas.

A large component of marine species are migratory or highly mobile (e.g. Block et al., 2011; Shillinger et al., 2008). Many marine fish undertake seasonal ontogenetic migrations (Grüss et al., 2011; Mumby, 2006), thereby occupying different distribution ranges during each life cycle phase (Apostolaki et al., 2002; Breen et al., 2015; West et al., 2009). The vulnerability to fishing impact has been shown to increase with the spatial scale of the movement (Grüss et al., 2011) as they are exposed to many pressures during their extensive movements (Lascelles et al., 2014). Some species congregate in high densities during spawning aggregations (Rhodes and Sadovy, 2002; Robinson et al., 2008) or when migrating along paths in particular seasons (Meltzer, 1994). These vulnerable life history characteristics are associated with migratory processes, which are predictable and often exploited (Bijoux et al., 2013; Sadovy and Domeier, 2005). The need to protect areas occupied during each life cycle phase has been raised by Grüss et al. (2011) and Breen et al. (2015). During times of seasonal high densities over small areas, a fish species can be particularly vulnerable to over-exploitation because fishing effort is focused to reap these high rewards (Erisman et al., 2011; Mann, 2007; Sadovy de Mitcheson and Erisman, 2012).

Species migrations therefore leads to three challenges in SCP, namely, 1) seasonal changes in species distribution ranges, 2) different areas occupied during different life cycle phases, each phase with a different level of vulnerability, and 3) different vulnerabilities associated with differences in seasonal abundance.

Including spatiotemporal dynamic distribution data in SCP analyses is important for a well-designed MPA network that protects migratory species (Pressey et al., 2007) and vulnerable life history phases (Nemeth, 2005). The number of marine spatial plans that incorporate spatiotemporal dynamics are growing as the concept is gaining support (e.g. Game et al., 2010, 2009; Grantham et al., 2011, 2008; Hobday and Hartmann, 2006). These studies often used fixed conservation targets, focussed on the highly mobile or migratory species, and did not always include static features in the same analysis (e.g. Hobday and Hartmann, 2006; Runge et al., 2016).

Application of fixed targets outside of the context for which these were developed may not achieve desired conservation outcomes (Agardy et al., 2016, 2003; Butchart et al., 2015; Carwardine et al., 2009). Conservation targets should not be chosen ad hoc, but rather be based on clear criteria (Carwardine et al., 2009) to help transparent decision making. Life history traits that predispose certain species to being more vulnerable to particular threats have been used to estimate intrinsic vulnerability to extinction in fish (Cheung et al., 2004; Dulvy et al., 2004, 2003; Musick, 1999).

SCP may need to consider both static and dynamic conservation features in the same analysis. During 2000–2012, a marine SCP, SeaPLAN, was conducted in the South African Exclusive Economic Zone (EEZ) adjacent to the eastern province of KwaZulu-Natal (Harris et al., 2012), which assessed the conservation status of 350 marine biodiversity features and evaluated the need to expand the existing system of spatially fixed MPAs, to include additional areas required to meet quantitative conservation targets. SeaPLAN now needs to consider the potential role of MPAs that take seasonal fish movement into account to update future planning.

Many of the fish species of conservation concern off the KZN coast are seasonal migrants, such as winter migrants, e.g. red steenbras (*Petrus rupestris*) and summer visitors e.g. king mackerel (*Scomberomorus commerson*) (Van der Elst, 1988). The MPAs of KZN are primarily located in the north, which largely overlap with summer migrant species moving south from Mozambique, rather than winter migrants, which move into southern KZN from the southern Cape waters, of which many are endemic and over-exploited (Mann, 2015). There are also important resident species, e.g. catface rockcod (*Epinephelus andersoni*), and species which have both resident and migratory populations e.g. galjoen (*Dichistius capensis*) (Attwood and Bennett, 1994; Mann et al., 2015). Few studies have been able to determine the factors that drive the movement patterns of fish in South Africa (Maggs and Cowley, 2016). In KZN movement studies have primarily revealed ontogenetic migrations to spawning grounds (Fréon et al., 2010; O'Donoghue et al., 2010), and the predatory pursuit of the annual sardine (*Sardinops sagax*) run, e.g. bronze whaler (*Carcharhinus brachyurus*), and certain life history stages of dusky sharks (*Carcharhinus obscurus*), spinner sharks (*Carcharhinus brevipinna*) and smooth hammerhead sharks (*Sphyrna lewini*) (Dudley and Cliff, 2010), and combination of reproductive and feeding regulated movement in bull sharks (*Carcharhinus leucas*) (Daly et al., 2014).

Using static distribution ranges and fixed conservation targets in a SCP for KZN may thus not provide efficient conservation solutions for species with spatiotemporal changes in the distribution, and differing vulnerabilities and abundance in space and time. To address the spatial component in SCP, the area occupied during different life cycle phases, and seasons, can be modelled as separate conservation features, and conservation targets can be set for each feature in each season (Lieberknecht et al., 2010). Conservation targets for more vulnerable life cycle phases can be increased to match the scale of the threat (Cowling et al., 2003). SCP can address the differing vulnerability associated with seasonal abundance by scaling conservation targets to match abundance values. Varying abundance has more often been addressed through distribution modelling processes in SCP (Schmiing et al., 2014), but adjusting conservation targets to incorporate the increased vulnerability associate thereto needs investigation.

We address the three highlighted challenges to SCP, by modelling seasonal and life cycle spatial and temporal variations in fish distribution and abundance, and we designed MPAs to exclude, and then include these dynamics. We then compared the resulting MPA configurations, and showed that MPAs designed in the absence of dynamic distribution data can place species at risk of reduced protection during particular seasons, or phases of their life cycles.

2. Methods

2.1. Conservation features

We modelled the distribution ranges of 67 fish species from the KZN coastal region, and used Marxan software to design candidate MPAs based first on data sets and targets that ignored seasonal distribution and abundance data, and second on data sets and targets that included these data. The 67 species were selected using criteria which addressed conservation status, spatial distribution, rarity, and an index of vulnerability to extinction (Supporting information 1), and include species that are considered resident and migratory. The lifecycle phases of the 67 species were split into three components namely, adult persistence, adult reproductive, and juvenile, each regarded as a separate conservation feature, for which we attempted to model a distribution range. All species had sufficient data to model adult persistence areas, and 10 species had sufficient data to model reproductive ranges, while no species had sufficient data to model juvenile nursery areas. A total of 77 conservation features (features hereafter) were used in this study.

2.1.1. Feature distribution models

We applied two modelling techniques to generate feature distribution models (FDMs) at a resolution of 1 km^2. Models were clipped to the provincial boundaries of KZN. Cartographic habitat range models (CHARMs) were generated for species with good descriptive range information from the literature, but fewer than 20 occurrence records, and maximum entropy models were generated for species with more than 20 occurrence records, using Maxent v3.3.3a software (Phillips et al., 2004).

CHARMs were developed by matching species range and habitat information to binary environmental GIS raster layers used in SeaPLAN,