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Review

Integrating connectivity and climate change into marine conservation planning

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ABSTRACT

Most applications of systematic conservation planning have not effectively incorporated biological processes or dynamic threats. We investigated the extent to which connectivity and climate change have been considered in an ecologically meaningful way in marine conservation planning, as an attempt to help formulate conservation objectives for population persistence, over and above representation. Our review of the literature identified 115 marine planning studies that addressed connectivity and 47 that addressed the effects of climate change. Of the statements identified that related to goals and objectives, few were quantitative and justified by ecological evidence for either connectivity (13%) or climate change (8.9%). Most studies addressing connectivity focused on spatial design (e.g. size and spacing) of marine protected areas (MPAs) or clustering of planning units. Climate change recommendations were primarily based on features related to MPA placement (e.g. preferences for areas relatively resilient and resistant to climate change impacts). Quantitative methods to identify spatial or temporal dynamics of features related to connectivity and/or climate change (e.g. functionally well-connected or thermal refugia areas) were rare, and these accounted for the majority of ecologically justified statements. Given these shortcomings in the literature, we outline a framework for setting marine conservation planning objectives that describes six key approaches to more effectively integrate connectivity and climate change into conservation plans, aligning opportunities and minimizing trade-offs between both issues.

Contents

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1. Introduction

Despite a rapid increase in applications of systematic conservation planning (hereafter "conservation planning") over the last two decades (Bottrill and Pressey, 2012), challenges persist. One challenge is the dependence of successful planning on explicit goals, preferably translated into quantitative, operational objectives (Leslie, 2005; Game et al., 2013; Pressey and Bottrill, 2009). Conservation planning also needs to move beyond merely representing biodiversity features to ensuring the persistence and long-term viability of species assemblages (Sarkar et al., 2006), but this aspect of spatial prioritization is not yet well developed (Pressey et al., 2007). Planning for persistence, over and above representation, is inherently more complex and demanding of information. For instance, setting objectives for ecological processes can be problematic inasmuch as protection of natural processes must be based on their spatial surrogates rather than the processes themselves (Rouget et al., 2003), and requires understanding of associated spatial and temporal dynamics (Ban et al., 2012). Accordingly, relatively few studies have developed explicit objectives for persistence (but see Airamé et al., 2003; Fernandes et al., 2005; Green et al., 2009). Thus, there is an urgent need to advance objective setting in marine conservation to guide conservation efforts, making explicit objectives more defensible and facilitating their refinement over time.

Connectivity – the movement of organisms encompassing dispersal of propagules and movement of adults – is a key mechanism underlying the persistence of populations, and hence is importance for marine protected area (MPA) design in any region. The success of MPA networks and complementary management strategies is contingent upon the maintenance of ecological connectivity processes because larval connectivity between MPAs ensures the persistence of populations within their boundaries (Berumen et al., 2012), and larval export from MPAs to fished reefs can make a significant contribution to the replenishment of populations (Bode et al., 2012; Harrison et al., 2012). In general, areas that are periodically disturbed require functional connectivity to other areas for immigration of temporarily extirpated species (Birrell et al., 2008; Hughes et al., 2003; Salm et al., 2006) conferring ecosystems with resilience (Cowen et al., 2007; Foley et al., 2010; Mumby and Hastings, 2008). Although an understanding of connectivity is clearly crucial to effective conservation outcomes, it has been poorly incorporated into existing design protocols for MPA networks (Almany et al., 2009). In the face of major declines in fishery stocks, increasing anthropogenic disturbance of marine ecosystems, and calls for ecosystem-based management, it is fundamental to maintain larval or adult exchange and recruitment of populations over demographically relevant time scales.

Climate change is of major interest for conservation because it acts simultaneously as a driver of biodiversity processes and a dynamic threat (Pressey et al., 2007), adding additional challenges to spatial planning. For example, catastrophic events related to warm anomalies in sea surface temperature can potentially negate the contribution made by MPAs to protecting a region's biodiversity (Game et al., 2008b). Projected future climate change will undoubtedly result in even more dramatic shifts in the distributions of species and composition of many marine ecosystems, both directly and indirectly (Lawler, 2009). Protective management of large, functioning ecosystems cannot directly address such external influences on marine environments. Climate change has typically been addressed in marine planning through generic strategies or design principles with the aim of minimizing threats to ecosystems, including requiring higher representation and replication of features, and spacing protected areas to spread risk and represent differences in composition or genetics (Fernandes et al., 2005; Lawler, 2009; McLeod et al., 2009; Salm et al., 2006). On the whole, however, few approaches to MPA planning have been based on knowledge of the directional or stochastic changes resulting from climate change and their effects on species and ecosystems. This limitation underlines the importance of new approaches to designing MPA networks that will help clarify management requirements for avoiding or mitigating climate change impacts or promoting recovery after disturbance.

Connectivity and climate change also interact. Climate-related disturbances not only disrupt larval dispersal pathways by reducing larval export from affected areas and changing hydrodynamics, but might also cause a shift in spawning phenology (earlier spawning of adults), larval transport (shorter pelagic larval durations), larval mortality (reduced exposure to lethal temperatures and shorter larval life), and behavior (increased larval swimming speed) (Cowen and Sponaugle, 2009; Lett et al., 2010; O'Connor et al., 2007). The spatial scales of population connectivity might be reduced in the future due to these diverse effects on habitat fragmentation (Munday et al., 2009). Simultaneously, connectivity can influence post-disturbance recovery and the ability of organisms to adapt to rapid climate change (Munday et al., 2008). Altered species distributions might also limit or expand the connectivity of sites in the future. Conservation planners should thus consider all possible interactions between connectivity and climate change that might act on species occurrences and abundances and influence the future efficacy of MPAs.

Despite recent literature emphasizing the need to incorporate connectivity (Almany et al., 2009; Foley et al., 2010; Fox et al., 2012; Pressey et al., 2007; Roberts et al., 2003) and climate change effects (Game et al., 2008b; Heller and Zavaleta, 2009; McLeod et al., 2009; West and Salm, 2003) into the design of MPA networks, little work has been done to critically examine their integration into conservation planning. Here we review approaches to incorporating connectivity and climate change into marine conservation planning to evaluate the extent to which ecologically informed strategies have been recommended or applied. We also explore what approaches have been recommended or applied to combine connectivity and climate change considerations, revealing integrative approaches and potential trade-offs. Additionally, we identify the main shortcomings of goals and objectives related to connectivity and climate change in marine conservation planning and suggest how these might be overcome in future applications.

Our review adds to the body of knowledge on marine planning for dynamic processes in having four key characteristics: (i) comprehensive – previous efforts have focused on particular aspects of protected area configuration such as size and spacing; (ii) synthetic – studies to date are scattered in published studies and grey literature (e.g. reports by nongovernmental agencies), so their findings are not readily available and not collated to identify patterns, trends and gaps; (iii) addressing tradeoffs between sets of objectives – tradeoffs between objectives for connectivity and climate change and opportunities for aligning them have not been adequately addressed in previous work; and (iv) marine focused – given the pronounced differences in dispersal patterns for marine vs. terrestrial species and the high sensitivity of marine ecosystems to large-scale environmental change, exploring marine-based approaches is of particular relevance. More specifically, given that explicit conservation objectives are critical in shaping the subsequent stages in the conservation planning process, and that this phase is subject to frequent mistakes made by planners (Game et al., 2013; Pressey and Bottril, 2008; Pressey and Bottrill, 2009), a review of marine conservation planning in relation to connectivity and climate change increases the accessibility of evidence to support more effective frameworks for decision making.