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Research article

Site closure management strategies and the responsiveness of conservation outcomes in recreational fishing

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ABSTRACT

We develop and use an empirically based model, which integrates fishing behaviour and a coral reef system, to evaluate outcomes from site closure strategies to manage the effects of recreational fishing. The model is designed to estimate management effects in complex settings with two-way feedback effects (between fishing and ecosystem dynamics) as well as spillover effects where the closure of a site (or sites) leads to the redistribution of fishing effort. An iconic coral reef system is used as a case study. The results demonstrate that some site closure strategies provide little incremental benefits over less stringent approaches. They also show that some strategies targeting more sites are actually inferior to more limited strategies, demonstrating that, in the analysis of complex problems involving feedback effects and substitutions, there is little substitute for the use of empirically based and sound modelling as the basis for informed conservation decision making and stakeholder consultation. These findings have direct relevance not only for policies aimed at improving recreational fishing management but also for securing the supply of marine ecosystem services.

1. Introduction

Nearly one quarter of Australians engage in recreational fishing at least once per year, making fishing a multi-billion dollar activity in Australia (Recreational Fishing Advisory Committee, 2011). Increases in coastal population, leisure time, affluence, and demand for seafood could lead to further growth in recreational fishing activities. Recreational fishing accounts for a growing share of total fish catch globally (Coleman et al., 2004; Cooke and Cowx, 2006), but its impacts remain largely unmonitored (Mc Phee et al., 2002; Lewin et al., 2006). The trade-offs between the large socio-economic benefits that the activity generates and ecological responses to the activity make it difficult to manage the recreational exploitation of fish resources without controversy (Pope et al., 2016). For instance, in some regions of Western Australia (WA), recent regulatory changes to seasonal closure, licence fees, and penalty levels in recreational fishing generated controversy (Raguragavan et al., 2013).

It is also difficult to quantify the ecological and socio-economic effects of management changes or to screen effective management measures. This is further complicated by the fact that some socio-economic benefits generated are largely intangible values and thus not revealed through market transactions. Hence, various groups are able to make different claims regarding the significance to society of recreational fishing. Therefore, it is important that the trade-offs are estimated and weighed carefully (Thébaud et al., 2014; Gao and Bryan, 2017). Particularly, resource managers need to strike a delicate balance between offering opportunities to enrich angler experience, on the one hand, and minimizing negative effects on fish stocks and other ecological resources, on the other.

Fishery area closure is one of the primary management tools considered for the protection of fish stocks (Dinmore et al., 2003; Little et al., 2009; Powers and Abeare, 2009; White and Costello, 2014); and it can facilitate the efficient achievement of broad biodiversity and fishery goals (McClanahan, 2008; Martins et al., 2011). However, the implementation of this management tool calls for deliberate planning and full-scale assessment (Hilborn et al., 2004; Bobiles et al., 2016; Dunn et al., 2016). Most site closure strategies were implemented without considering and

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understanding the feedback loops among fish stock dynamics, angler responses, and geographic distribution of fishing effort (Arlinghaus et al., 2013; Fenichel et al., 2013; Kincaid et al., 2017). As a result, it is difficult for resource managers to assess the impacts (intended and unintended) of strategies that alter fishing opportunities (Siberta et al., 2012; Davies et al., 2017). Therefore, models that integrate the key aspects of the problem are required to facilitate the design and the evaluation of management strategies.

Early models of recreational fisheries focused on utility functions and willingness-to-pay values among anglers without modelling ecosystem dynamics (e.g., McConnell and Sutinen, 1979; Anderson, 1993; McConnell et al., 1995; Aas et al., 2000), or developed a coupled system that failed to link anglers' actions to fish populations and to the sensitive aspects of the marine environment (e.g., Lupi et al., 2003). These studies suffer from two key shortcomings. Firstly, impact reports for management changes generated from these models might not provide a complete picture because the feedback effects between fishing activities and ecological outcomes are not taken into account (Arlinghaus et al., 2013; Fenichel et al., 2013; Hunt et al., 2013; Alvarez et al., 2014). Secondly, in the face of opposition from vested interests or stakeholders with conflicting objectives, these models can be hard to defend, partly due to the lack of rigour in the modelling effort and/or lack of good data for assessing the impacts of management decisions on multiple management objectives (e.g., ecological, economic, and social) (Arnason, 2009; Gao and Hailu, 2012, 2013; Hamilton et al., 2015). Subsequent efforts have built complex simulation models of recreational fishing by integrating anglers' decisions and rich ecosystem dynamics. The resulting models (e.g., Carpenter and Brock, 2004; Massey et al., 2006; van Poorten et al., 2011) are capable of capturing the interactions between socioeconomic and ecological components, as well as the impact of management changes on these components. Recent research highlighted the importance of modelling heterogeneity of angler behaviours (Johnston et al., 2010; Hunt et al., 2011; Nguyen et al., 2013) and called for integration of tools from agent-based modelling (Grimm et al., 2005; Gao et al., 2012, 2013; Sun and Müller, 2013) and economic theory (utility theory) (McFadden, 1974; Kragt et al., 2011), two methods that have been popular in the study of recreational choice behaviours and the diversity and complexity of angler choices (Hunt et al., 2007; Gao and Hailu, 2011). However, there have been only a few studies that assess site closure strategies for recreational fishing (Lynch, 2006; Gao and Hailu, 2011). Other studies evaluating the impacts of fishery closures (e.g., Little et al., 2007; Chen et al., 2009; Powers and Abeare, 2009) have focused on commercial fisheries.

Our own previous work (Gao and Hailu, 2011) models angers and fishing sites as agents, and develops an integrated agent-based simulation (ABS) model that incorporates recreational fishing behaviour models and a coral reef system model. In the model, the behaviour of angler agents is represented by empirically based Random Utility Models (RUMs).[1] And the coral reef ecosystem model captures interactions among four key trophic levels—algae, corals, herbivorous and piscivorous fish. The ABS was applied to the evaluation of site closure strategies among three recreational sites located in the Ningaloo Coral Reef Marine Park of Western Australia. However, that work had several limitations. Firstly, the econometric models that underpin the site choice behaviour of angler agents were estimated using a national survey data of recreational fishers from 2000/2001 (Henry and Lyle, 2003). More recent and local data for Ningaloo would allow a more accurate representation of the decision making process among anglers. Secondly, the coral reef ecosystem model in Gao and Hailu (2011) was adapted from a modified Lotka–Volterra formulation that describes predator–prey interactions and inter species competition as developed by Kramer (2008). As Fung (2009) pointed out, in Kramer's model algea and corals are modelled as strongly competitive using a non-linear factor, a relationship that does not seem to always hold (McClanahan et al., 2002, 2007) and is not supported by the recent field data for Ningaloo (van Keulen and Langdon, 2011). In addition, exogenous recruitments of corals and fish, which could significantly affect coral cover and reef fish dynamics (Fung, 2009) are not modelled in Kramer's model. Finally, Ningaloo has about a dozen key sites and most of these are not modelled in Gao and Hailu (2011). The full range of the fishing area needs to be included to provide a more complete representation of the implications of site closure strategies.

Therefore, this paper improves on previous work by Gao and Hailu (2011) in the following aspects: (1) recreational behaviour models are estimated based on recent survey data specific to the Ningaloo area (Hailu et al., 2011); (2) a local-scale coral reef ecosystem model developed by Fung (2009) is adapted to Ningaloo and calibrated against recent Ningaloo data to more accurately represent interactions among different functional groups in the ecosystem; (3) twelve new and more realistic management strategies are evaluated; and (4) this study covers all the main fishing sites in the Ningaloo Marine Park. The model explicitly incorporates individual fishing behaviour and is useful for evaluating how management changes affect individual anglers and the community of anglers in aggregate. Key questions about management change that can be answered using the model include: Will site closure strategies have significant effect on fishing effort or do they simply shift the effort to sites that are not closed? What are the effects of variations in the length and timing of site closure? How do gains in fish stocks in protected sites compare with losses at sites that are still fully accessible? What are the economic welfare impacts of closure decisions?

The paper is organized as follows. In the next section, we describe the structure of the integrated model, with the help of a schematic diagram illustrating the relationship among the different components. The management change scenarios evaluated are presented in Section 3. Section 4 presents and discusses the results from a baseline and alternative management scenarios. Effects on fishing site choice, conservation outcome gains as well as welfare losses are presented and discussed. The section also includes a discussion of what strategies are likely to be dominated by others. Section 5 concludes this work.

2. The integrated ABS model of recreational fishing

There are two major components in the integrated model as shown in the schematic diagram in Fig. 1. The first component is a set of econometrically estimated models that help predict the answers to the following questions about angler choices:

1) How many trips would an angler expect to take in a year?
2) What would the expected length of the average trip be?
3) What would the timing of the trips be?
4) How much fish (of a certain type) would an angler expect to catch in a given site?
5) What recreational fishing sites are likely to be chosen by an angler?

These five models combined form the foundation for the structure of the recreational anger behaviour in the agent-based model.

[1] In economics, RUMs have been used extensively to study recreational site choice behaviour and choice among discrete alternatives (e.g. in transportation).