Area Closures as a Management Tool In A Multi-Species Coral Reef Line Fishery

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EXTENDED ABSTRACT

The multi-species, spatially structured nature of coral reef fisheries makes them difficult to manage. Closing areas to fishing is one strategy that has been advocated and implemented in many coral reef fisheries, including the Great Barrier Reef, Australia.

Using a simulation model, we examine the effect of different amounts of area closure and effort on the fishery and stock of two important species on the Great Barrier Reef: coral trout (*Plectropomus leopardus*) and red throat emperor (*Lethrinus miniatus*). Results indicated that spatial closures had a greater effect on the more sedentary species, coral trout, and little effect on red throat emperor, which was assumed to move among reefs. The effects on coral trout of closing areas to fishing was also influenced by the nature of the area closures, as closing reefs that were more productive, with high historical catches supported, had a greater effect than closing less productive or desirable reefs.

1. INTRODUCTION

Tropical fisheries, particularly coral reef fisheries, are characterised by their multi-species nature, which makes them particularly difficult to manage. The difficulty of the task is compounded by the fact that coral reef systems are inherently highly spatially structured. This characteristic has lead to the adoption in many coral reef fisheries of spatial management strategies in the form of marine reserves, or no-take areas, where fishing is prohibited.

Some advocates of marine reserves have suggested that fisheries could benefit in such a way that catches would increase in concordance with an increase in the biomass. Although the degree to which such fisheries benefits night occur is uncertain, the conservation benefits of closing areas to fishing are well documented, and result from protecting habitat and the animals that use it from fishing, particularly the less mobile species. Preventing fishing in areas through the creation of marine reserves or Marine Protected Areas (MPAs) is currently a popular conservation management strategy in multi-species fisheries (Hilborn et al. 2004) like those associated with coral reefs. Coral reef fish communities are typically very complex and contain species of diverse characteristics, with target species having different movement rates and home ranges. In this study, we examine the effect of marine reserves on two main target species of a multi-species coral reef fishery using a computer simulation model.

The Great Barrier Reef (GBR) is one of the largest coral reef ecosystems in the world, with over 2900 individual coral reefs. The Coral Reef Finfish Fishery (CRFFF) on the Great Barrier Reef a commercial sector (with a total allowable catch across all species of 2,610 t annually), a charter fishing sector that caters to a lucrative tourism industry which harvests about 50t, and a private recreational sector that harvests about 2000 t annually (Mapstone et al. 2004). The annual economic value of the CRFFF is about AU$60-100 million (Williams 2003). All sectors use similar gears consisting of single baited hooks on heavy line with a rod or hand reel. The fishery is multiple species with over 125 species groups recorded in the compulsory commercial logbook system managed by the Queensland Department of Primary Industries and Fisheries (DPI&F) (Mapstone et al. 1996), but the two major target species are common coral trout (*Plectropomus leopardus*) and red throat emperor (*Lethrinus miniatus*), which together comprise over 50% of the total catch by this sector (Higgs 1996; Mapstone et al. 1996; 2004). The reef line fishery is managed by the state of Queensland (Queensland Fishery Act 1994) and current management strategies for the fishery include seasonal spawning closures and size limits for all sectors, bag limits for the recreational and charter sectors. The commercial sector is managed with limited entry and in 2004 an Individual Transferable catch Quota (ITQ) system for the commercial sector and hook was implemented.

The Great Barrier Reef Marine Park (GBRMP) was established in 1975 to facilitate conservation management of most of the GBR and an area including the GBRMP was inscribed on the World Heritage list as the GBRWHA in 1981. The GBRMP contains a number of no-take zones or areas where extractive activities such as fishing are prohibited, with the best known and most widespread being the Marine National Park (MNP) Zones. The legislation for the GBRMP sets broad objectives of zoning, which require both conservation and protection of biodiversity, whilst also allowing multiple uses, including fishing, in some areas. Until recently, no-take zones accounted for about 5% of the total area of the GBRMP and approximately 24% of the area of the mapped coral reef habitat in the Marine Park. A major rezoning program, resulted in no-take zones increasing to 33% of the entire Marine Park (GBRMPA 2004).

Due to gaps in our knowledge of the biology of the major target species there has been considerable uncertainty about the effects of current harvest levels. However, research in recent years (Mapstone et al. 2004, Williams 2003) has led to an improved understanding of: 1) the biology of the major target and by-product species with a particular focus on common coral trout and red throat emperor; and 2) the characteristics and fishing practices of the different sectors of the fishery.

Computer modelling of fish populations have been used extensively to understand the general nature of harvest and management measures on the resource (Sainsbury et al. 2000); in particular to examine alternative options for managing resource exploitation in the medium- to long-term. Recently, there has been increased demands for ecological or ecosystem-based assessments and the development of management strategy evaluation (MSE) as a tool to explore trade-offs across multiple objectives for alternative management strategies (Sainsbury et al., 2000; Mapstone et al., 2004). Such approaches are well suited to evaluating the potential interactions between MPAs and conventional fishery management strategies. We have developed a multi-species meta-population model, the Effects of Line fishing Simulator (ELFSim) to evaluate management options for coral trout and red-throat emperor on the GBR (Mapstone et al. 2004, Little et al. 2007a, Little et al. 2007b). The model captures the dynamics of the two species and also the fishing effort dynamics. In this study we use ELFSim, to show the potential effect of closing areas to fishing on two coral reef species with different migration characteristics, coral trout with a migratory larval phase which settles on coral reefs, and red throat emperor which also has a migratory larval phase, settles and then migrates with increasing age.

2. METHOD

The Effects of Line Fishing Simulator (ELFSim) is a decision support tool designed to evaluate options for managing the harvest of reef fish species in the reef line fishery on the GBR. Initially developed to explore the implications of management options on coral trout (Mapstone et al 2004, Little et al. 2007a) it has since been updated with the secondary target species, red throat emperor (Little et al. 2007b).

ELFSim operates with a monthly time step with each simulation consisting of two parts. The first (‘initialization’) step operates historically from the beginning of the fishery (1965) to the ‘present’ (in this case 2003), using information from recent visual surveys, catch records from the fishery, and the physical characteristics of the reefs, to determine the initial (e.g. 1965) and present size of the population on each reef (Little et al. 2007a). The reef populations are then projected into the future by calculating a catchability coefficient for each reef based on data from 1989-2003, and simulating fishing dynamics, which is, in turn, affected by user-specified management regulations

(Little et al. 2007a). The management regulations available involve area closures (including rotational closures), changes to gear selectivity, minimum legal sizes for harvest. Since in this paper we do not implement output controls on the fishery, the user is also required to set an annual effort for each of the fishing sectors. ELFSim can incorporate multiple ‘vessel classes’, each of which potentially uses a different strategy for allocating effort spatially and temporally. The current implementation includes three such classes to represent the commercial, recreational and charter sectors of the fishery.

2.1. Biological model

Two species are modeled in ELFSim: common coral trout (*Plectropomus leopardus* Lacepède) and red throat emperor (*Lethrinus miniatus* Forster). The biological model details can be seen in Little et al. 2007a, and Little et al. 2007b, but to summarise both species are modeled similarly in a spatially explicit, age-, size- and sex-structured model consisting of many local post-larval-settlement populations, each associated with a single reef and linked through larval dispersal. Each species however has its own characteristic biological functions of natural mortality and growth, but the main difference between the species is that red throat emperor exhibit post-settle migration among reefs, whereas coral trout are not known to move between reefs after settling from the larval stage.

2.2. Simulated Fishing Pressure and Spatial Effort Allocation

The effort allocation model determines the amount of effort (proportion from a pre-specified annual total) on each reef during the projection period. The model operates by first allocating an amount of effort to each month based on the seasonal pattern experienced historically, and then distributing the effort for each month spatially across reefs. Simulated fishing in the projection period occurs as described in Little et al. (2007a) except applied in a multi-species context. Specifically, in each month all the reefs are ranked according to their historical CPUE. Historical CPUE is calculated by time discounting the CPUE experienced on each reef. In a multi-species context a weighted average of the different species CPUEs is obtained based on the historical beach price for the two species ($14.75 for coral trout, and $4.18 for red throat emperor). The monthly amount of effort is allocated from highest to lowest ranked reefs, in units equal to the average amount of effort found on that reef historically, until there is no effort remaining to be allocated.

2.3. Management Scenarios

Management scenarios considered involved three levels of area closures and three levels of total annual effort. Management simulations were assumed to be those operating prior to 2004, when the ITQ system was implemented, and so the simulations did not include constraints on fishers due to current TAC levels. Area closures involved those implemented under the Representative Areas Program (RAP) in 2003, as well as the areas closures that were in place prior to RAP in 2003. This amounts to approximately 32% and 16% of the GBR respectively. We also considered an amount of area closure higher than these, which amounted to 50% of the GBR.

Each of these area closures, was combined with three different effort levels that spanned a broad range of effort scenarios that were thought to be plausible in the future. These effort scenarios were referenced to the effort expended in the fishery in 1996, a peak year of effort and one used by the fishery to reference effort increases or reductions, and consisted of 0.5 1996 effort levels, 1.0 1996 effort level, and 1.5 times the 1996 effort level (Mapstone et al 1996, 2004).

The projection period in ELFSim extended from 2003 to 2025. Because there are several sources of variability in the model (Little et al. 2007a), namely initial reef densities, natural mortality, recruitment, the relation between simulated fishing effort, and fishing mortality (i.e. catchability coefficient), several replicate simulations were run for each scenario. For each management scenarios, this involved ten replicate initialisations for each species, followed by ten replicate projections for each initialization.

3. RESULTS

Figure 1 shows the average amount of available biomass (biomass that is vulnerable to fishing as dictated by gear selectivity) on the closed reefs under each management strategy, relative to the amount of biomass under the management strategy closest to the status quo (1.0, 32%). As expected, the biomass in the areas closed to fishing increases with the amount of area closed.

Figure 2 and Figure 3 show that the available biomass on the closed and open reefs changed from the beginning of the projection period. Closing areas to fishing had a different effect on the two species. The most obvious difference was the effect of the 50% closures, which lead to a greater biomass recovery on the closed reefs for coral trout than for red throat emperor (Figure 2).

Conversely, on the open reefs the biomass of coral trout was depleted more than red throat emperor (Figure 3). The main reason for the species difference at the 50% area closure is that the area closures confer less protection on the mobile red throat emperor than on the more sedentary coral trout.

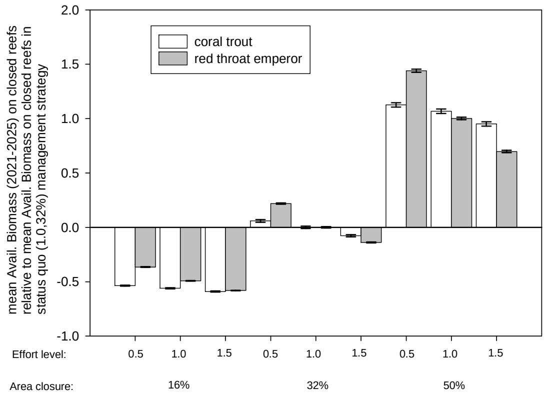

Figure 1 Average available biomass (2021-2025) on closed reefs relative to mean available biomass (2021-2025) in the Status Quo management strategy (1.0, 32%).

The results shown in Figures 2 and 3 do not indicate the amount of biomass on the closed or open reefs as in Figure 1, but rather the amount of biomass on the reefs relative to the same reefs prior to the projected simulations. These results show that there has been surprisingly little effect on coral trout between the 16% and the 32% area closures, but a substantial difference in the 50% area closure (Figures 2 and 3). The reason for this is due to the productivity of the habitat that is closed under each closure scenario. Specifically, in the 16% closure scenario, the historical amount of commercial effort that was allocated to the closed reefs, prior to them being closed, accounted for 7% of the historical effort. Doubling the area closed to 32% locked out reefs that accounted for 19% of the historical effort, and increasing the area closed to fishing to 50% precluded fishing on reefs that accounted for 43% of the historical effort. The implication therefore is that the additional closed reefs in the 50% area closure were reefs on which a disproportionate amount of fishing effort had occurred previously, and presumably catch taken.

Changes of effort had an effect on the biomass of both species. As effort increased the biomass recovery was less on both open and closed reefs (Figures 2 and 3). For coral trout, the effect of increased effort levels tended to be greater on the open reefs. On the closed reefs, red throat emperor was affected more than coral trout by increasing effort, because of the more mobile nature assumed for the species.

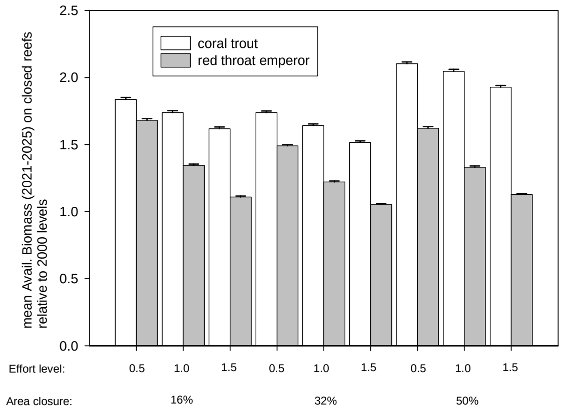

Figure 2 Average available biomass (2021-2025) on closed reefs relative to 2000 levels.

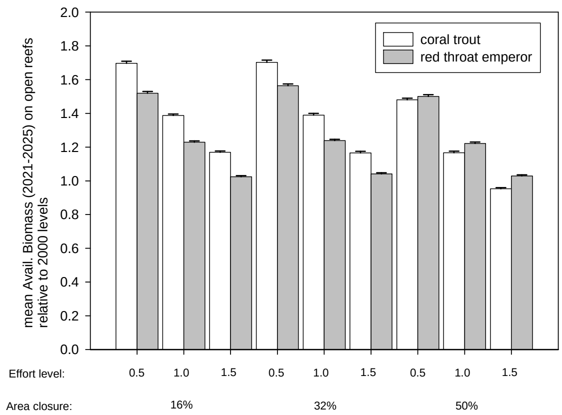

Figure 3 Average available biomass (2021-2025) on open reefs relative to 2000 levels.

The effects of the management strategies on the fishery are shown in the average CPUE over the final years of the simulation relative to a benchmark CPUE averaged over the historical period from 1996-2000 (Figure 4). A strong effort effect is apparent for both species. An area closure effect is apparent for coral trout, as a reduction in CPUE with increasing amounts of reefs closed to fishing, and the number of reefs open to fishing is reduced. Such an effect was not apparent for red throat emperor.

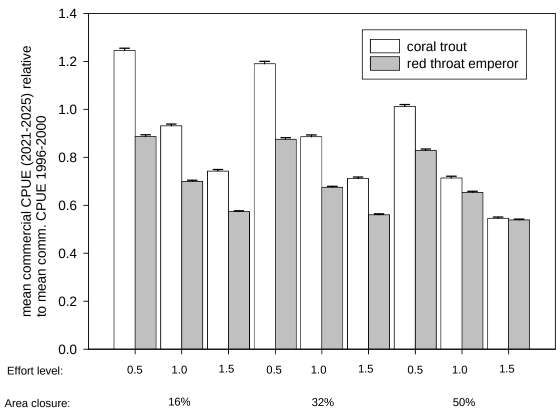

Figure 4 Average commercial CPUE (2021-2025) relative to average commercial CPUE 1996-2000.

4. DISCUSSION

The simulated strategies for managing the reef line fishery on the GBR had different outcomes, depending on the ecological characteristics of the species being managed. As expected, the effects of spatial closures on the relatively mobile red throat emperor were more muted compared to the more sedentary coral trout. Nonetheless, there are good reasons to use spatial closures in the management of mobile species (Gell and Roberts 2003). For example, the application of marine reserves to mobile animals could be done by targeting critical habitats for closure (Gell and Roberts 2003), making the reserves very large, or alternatively moving marine reserves dynamically (Hyrenbach et al. 2000, Norse et al. 2005).

We assume in the model of the fishery that spawning of red throat emperor occurs mainly in the southern GBR (Little et al. 2007b) and so increasing areas closed to fishing, particularly of the species habitat in the southern spawning areas, could have a great effect. Since ELFSim considers reef perimeter rather than reef area as an indicator of habitat, because much of the central area of most reefs on the GBR is either emergent consolidated substratum or sand, and is not suitable habitat for coral trout (Mapstone et al., 2004), the amount of reef edge closed from fishing indicates the degree the species could be protected. The percentage of reef perimeter, under the 32% RAP closures that is closed in the Swains and Capricorn-Bunkers region where red throat emperor spawning is thought to occur (Williams 2003) is 27%. Reducing the amount of habitat closed to fishing, under the pre-RAP closures, to only 11%, led to a maximum of 50% reduction in biomass on the closed areas (Figure 1). Increasing the amount of red throat emperor habitat closed to fishing, under the 50% closure scenario, to 40%, led to a minimum increase of about 75%. Thus increasing the amount of protected habitat in these regions could result in a disproportionate benefit to the status of the mobile species.

In general, the results also imply that the actual areas chosen to preclude fishing can potentially affect the performance of the management strategy. In the current results, management strategies that precluded areas that had high commercial effort, and presumably productivity, could have a great effect on the status of a species.

These results, in particular, imply that the RAP closures should have only a small effect on the fishery, and that there would be a greater effect of changes in effort. This has been seen in previous work (Mapstone et al. 2004). This is important because changes in effort are perhaps more likely now that the fishery has moved to an ITQ based management system, and market forces have the potential to change the effort level.

5. ACKNOWLEDGEMENTS

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