AN AGENT-BASED MODEL FOR RECREATIONAL FISHING MANAGEMENT EVALUATION IN A CORAL REEF ENVIRONMENT

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Abstract: This paper presents an integrated agent-based model of recreational fishing behaviour within a reef ecosystem as a platform for the evaluation of recreational fishing management strategies. Angler behaviour is described using econometrically estimated site choice models. Site choice among anglers is driven by site attributes and angler characteristics. The biophysical model represents the marine reef environment as a system with different trophic levels identifying algal and coral growth as well as two types of fish (piscivores and herbivores). Ecosystem dynamics are driven by interactions within the trophic levels and fishing activities. The model is capable of simulating the biophysical and economic welfare impacts of management strategies in a manner that accounts for feedback effects.

1 INTRODUCTION

Recreational fishing provides economic benefits that can be substantial but are not reflected in market transactions. At the same time, fishing activities can threaten valuable fish stocks and cause damage to marine environments. Consequently the management of recreational fishing is a controversial subject in most jurisdictions. A careful balance needs to be struck between providing opportunities to enrich the experiences of recreationists and minimizing impacts on the natural environment and fish stock sustainability.

Causality in recreational fishing choices runs in both directions: fishing choices are affected by the availability of fish stocks and the condition of fishing sites; and fishing activities affects not only fish stocks but also other trophic layers in the marine environment. Formulating management strategies for these complex systems requires the use of integrated models. Through model-based simulation, resource managers are able to explore the implications of different management scenarios and then make informed decisions.

This paper presents an agent-based model that combines a fishing site choice model and a biophysical model of a coral reef environment. An agent-based model (ABM) is a bottom-up approach that abstracts a complex system as a collection of interacting, autonomous agents. ABM provides a number of significant advantages over traditional methods (Jennings, 2001). In our model, anglers as well as components of the biophysical model are represented as agents. The behaviour of the angler agents is represented by empirically based Random Utility Models (RUMs) (Schuhmann and Schwabe, 2004) that rationalize choices on the basis of attributes of the individuals, the features of alternative choices and recreational experience. It is possible not only to simulate fishing behaviour but also construct welfare estimates at the individual level. Then, these welfare estimates can then be aggregated up to the population level for use in cost-benefit analysis and the economic evaluation of changes in recreational management. The model makes it possible to undertake "what-if" scenario analysis and allows researchers and managers to better understand the economic and environmental implications of different management strategies.

While ABMs have been used to study natural resource management problems, there have been very few studies that have employed behavioural models that are grounded in econometrically

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estimated choice models. The trophic-dynamic model is used to simulate the interactions among algae, corals, herbivorous and piscivorous fish in the recreational angler's chosen site. This model is incorporated into the ABM-RUM framework as a means of attributing the environmental changes to the recreational fishing site.

The paper is organized as follows. The next section describes the structure of the ABM-RUM model. This is followed by a description of strategy evaluation for recreational fishing management. An application case study for the Ningaloo marine park and preliminary simulation results for recreational management strategy evaluation are presented in Section 4. Finally, the paper concludes in Section 5.

2 AN INTEGRATED MODEL OF A CORAL REEF FISHING

The proposed ABM-RUM model has six sub-models: *trip demand model*, *site choice model*, *trip timing model*, *trip length model*, *catch rate model*, and *trophic-dynamic model*.

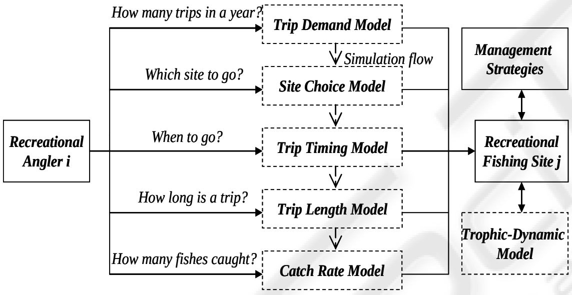

Figure 1: The framework of the ABM-RUM model.

Recreational anglers and angling sites are all modeled as agents. A recreational angler has demographic attributes (such as age, income, education level, employed status, and so on) and behaviors (such as choosing sites and catching fish). A fishing site has environmental attributes (such as coral cover, algal cover, herbivorous fish biomass, piscivorous fish biomass, area, and coastal length) and biophysical activities (interactions among dynamical environmental attributes).

Five econometric models (*trip demand model*, *site choice model*, *trip timing model*, *trip length model*, and *catch rate model*) underpin the decision-making and expected behaviors for a recreational angler agent. These models predict, respectively, the number of fishing trips an angler takes in a year, the choice of recreational site in any one trip, the timing of a trip in a year, the length or duration of a trip, and the agent's expected catch. All of these models were estimated based on a national survey of recreational fishers (Burton et al., 2008).

Trophic-dynamic model describes interactions among four components in a reef environment, namely, algal growth, coral cover as well as herbivores and piscivores. The structure of the model makes it possible to evaluate, at a reasonably detailed level, the impact on the ecosystem.

2.1 Recreational Behaviour Models

Site choice, trip demand and catch rate models

Site choice models, or models that focus on discrete alternatives in general, are usually formulated as multinomial logit (McFadden, 1974) models. These models describe the relationship between individual and/or alternative characteristics and the predicted probability of choice. In the case of fishing site choice problems, for example, the interest is in determining the probability, $prob_{ij}$, that an angler agent i chooses a recreational angling site j out of M sites. In a logit model, this probability takes the form expressed in equation (1).

$$prob_{ij} = e^{U_{ij}} \Big/ \sum_{k=1}^{M} e^{U_{ik}} \qquad (1)$$

where, U_{ij} is the utility that i derives from recreating at site j and is dependent on the attributes of the site and the individual as shown as follows.

$$U_{ij} = \beta_j + \beta_c \cdot Cost_{ij} + \sum_f \beta_f \cdot CR_{ijf} + \sum_k \beta_k \cdot S_{kj} \qquad (2)$$

where β_j is the base utility of a site, $Cost_{ij}$ is the cost to i of recreating at site j (mostly travel cost), CR_{ijf} represents the number of fish of type f that the individual expects to catch at the site, and S_{kj} stands for other site attributes that affect choice (e.g. coastal length). The expected catch rates depend on fish stocks and the angler's experience. In our model, these rates are generated by another econometric model, the *catch rate model*, estimated by (Burton et al., 2008). An angler's propensity to visit a site is negatively affected by cost but is positively affected with increases in expected catch rates and other desirable site attributes such as coastal length.

The number of fishing trips taken by an angler can vary. While it is possible to use a distribution histogram based on empirical data to determine trip numbers, a more general approach would be to link trip demand to the utility of fishing trips (and thus to site attributes) and to demographic variables that measure the influence of employment, age and other relevant influences on recreational behaviour. In *trip demand model* used here, the actual number of trip demanded is predicted as a Poisson distribution (Burton et al., 2008). The logarithm of number of trips in a year λ_i is specified as a function of the expected maximum utility from a fishing trip, known as "inclusive value" (IV) in the economics literature, and a set of socio-economic characteristics of the angler. In particular, the model is specified as equation (3).

$$\ln \lambda_i = \beta_0 + \beta_1 \cdot IV_i + \sum_m \beta_m y_m \tag{3}$$

where y_m represents individual characteristics such as age, education, employment, etc. IV is calculated from site utility data as in equation (4).

$$IV_i = \ln\left(\sum_{j=1}^{M} e^{U_{ij}}\right) + 0.5772 \tag{4}$$

Anglers' expectations regarding fish catch influence their site selection. These expected catch rates are inputs into the *trip demand model*. Instead of using historical rates, it is more useful to estimate functions that predict rates depending on angler characteristics and fish availability. Catch rates for each type of fish is estimated using a negative binomial model with the following specifications (Burton et al., 2008).

$$\ln \lambda_{ijk} = \beta_0 + \beta_1 \cdot stock_{jk} + \beta \cdot S \tag{5}$$

where: λ_{ijk} is the expected catch per trip of angler agent i at site j of fish type k; $stock_{jk}$ is the annual total stock at site j of fish type k; S is the vector of the attributes (such as if it is man-made, if it is a beach, and so on) of fishing site j and the demographic characteristics (such as age, education, employment, experience, whether the fish was a target species or not etc.) of angler i that influence expected catch.

*Trip timing and length model*s

As in the case of trip numbers, one can use empirical data to determine trip timing and trip length which both vary between individuals. However, a more versatile approach is to describe these as function of day or calendar and person attributes. Geographic location of the destination site also affects timing and length of trip. For example, an angler who is employed will be inclined to choose a weekend or public holidays for a fishing trip. Further a trip to cooler (warmer) regions is more likely in the summer (winter) months than in the winter (summer) months. We used actual survey data to estimate a logit model for trip timing; this model is used in the agent-based model to determine the dates for fishing trips by angler agents.

Likewise, *trip length prediction* is done using a Tobit model that we estimated. Tobit models link explanatory variables to non-negative dependent variables such as trip length. The explanatory variables in our model include the socio-economic characteristics of the individuals, the characteristics of the day, and an interaction between the direction of the trip and the time of the year. These two model specifications and the results are based on (Gao and Hailu, 2009).

2.2 Trophic-dynamic Model

To describe interactions among algae, corals, and fish at a site, we use a a trophic-dynamic model based on a modified Lotka-Volterra model of predator-prey interactions and inter species competition developed by Kramer (Kramer, 2008). Since difference equations are most appropriate when organisms have discrete, non-overlapping generations (Allen, 2007), our trophic-dynamic model converts the continuous model (Kramer, 2008) into difference equations using a numerical scheme (Liu and Elaydi, 2001). Further, the fish harvest variables in the trophic model are based on the agent-based model for fishing site choice described above. The difference equation version of the model is presented below. The equations describing the dynamics in algal growth, coral cover, herbivorous fishes, and piscivorous fishes, are shown in equations (6)-(9):

$$A(n+1) = \frac{[1+\phi_A(h)\cdot r_A]\cdot A(n)}{1+\phi_A(h)\cdot[\frac{r_A}{K_A}\cdot A(n) + \frac{r_A \cdot a_{AC}}{K_A}\cdot C(n) + a_{AH}\cdot H(n)]} \tag{6}$$

where $A(n)$ is algal cover as proportion of sea floor at time step n, r_A is algal intrinsic rate of growth, K_A is algal carrying capacity as cover, a_{AC} is a competition coefficient of coral on algae, and a_{AH} is an interaction coefficient of herbivores on algae.

$$C(n+1) = \frac{[1+\phi_C(h)\cdot r_C]\cdot C(n)}{1+\phi_C(h)\cdot[\frac{r_C}{K_C}\cdot C(n) + \frac{r_C \cdot a_{CA}}{K_C}\cdot \frac{A(n)^{Slope}}{A(n)^{Slope}+HA^{Slope}}]} \tag{7}$$

where $C(n)$ is coral cover as proportion of sea floor at time n, r_C is coral intrinsic rate of growth, K_C is coral carrying capacity, a_{CA} is a competition coefficient of algae on coral, *Slope* and *HA* are the slope and a half saturation constant of Hill function.

$$H(n+1) = \frac{[1-\phi_H(h)\cdot a_{HH}]\cdot H(n)}{1+\phi_H(h)\cdot[-a_{HA}\cdot A(n)+a_{HP}\cdot P(n)]} - \sum_{i=1}^{N} Catch_H^i(n) \tag{8}$$

where $H(n)$ is herbivorous fish density at time step n , a_{HH} is a density-dependent coefficient of herbivorous fish, a_{HA} is an interaction coefficient of algae on herbivorous fish, a_{HP} is an interaction coefficient of piscivores on herbivores, N is the number of recreational anglers, and $Catch_H^i(n)$ is the biomass of herbivorous fish caught by angler i .

$$P(n+1) = \frac{[1-\phi_P(h)\cdot a_{PP}]\cdot P(n)}{1-\phi_P(h)\cdot a_{PH}\cdot H(n)} - \sum_{i=1}^{N} Catch_P^i(n) \tag{9}$$

where $P(n)$ is the piscivorous fish density at time step n , a_{PP} is the density-dependent coefficient of piscivorous fish, a_{PH} is an interaction coefficient of herbivores on piscivores, and $Catch_P^i(n)$ is the biomass of piscivorous fishes caught by angler i .

$\phi_X(h)$ (*X* is *A*, *C*, *H*, or *P*) in equations (6)-(9) is a conversion function, and

$$\phi(h) = e^{r_X \cdot 0.5} - 1 \Big/ r_X \tag{10}$$

where r_X is an intrinsic rate of growth of *X* (algae, coral, herbivourous fish, or piscivorous fish).

3 EVALUATION OF MANAGEMENT STRATEGIES

There are a range of strategies at the disposal of resource managers when it comes to regulating recreational fishing. Commonly used measures include: site closure, limits to fish harvest (or bag limits), and exclusion of fish species from the allowable list of target species. Resource managers can also employ incentive-based strategies such as license fees, which are used in many jurisdictions.

The model presented above can be used to evaluate both the economic and reef ecosystem impacts of management scenarios. The economic impacts that should be central to decision making are the economic surplus that anger's derive from fishing activities. These surpluses are not measured by the values observed in market transactions that an angler undertakes as part of a fishing trip or activity. The true measure of the benefits of recreational fishing is the satisfaction that the angler derives from the activity over and above the costs incurred. For the site choice model presented above, this economic surplus measure is captured by the inclusive sum and can be aggregated over anglers to obtain the social impact of a management change.

The welfare impact of a management change can be calculated as the difference between the inclusive sums after and before the change in management, as follows:

$$W = \sum_i^N \left(\frac{1}{\beta} \cdot \ln(\sum_{j=1}^M e^{U^1{}_{ij}}) \right) - \sum_i^N \left(\frac{1}{\beta} \cdot \ln(\sum_{j=1}^M e^{U^0{}_{ij}}) \right) \tag{11}$$

where β is the marginal utility of income from the site choice model; $U^1{}_{ij}$ and $U^0{}_{ij}$ are the utility angler i 's derives from site j after and before the change, respectively; M is the number of recreational sites for fishing; and N is the number of anglers.

The management strategies explored in this paper are *changes to site access rules* and *bag limits*. Changes to site access rules will have an impact on site choice and the value of recreation. For the case of site access changes, the model is capable of generating site values specific for each angler. These angler values can be aggregated to generate social welfare changes resulting from access changes. Bag limits specify the maximum number of fish that an angler can harvest. Changes to these limits affect the upper end of the expected catch rates and have no direct effect on anglers who achieve lower catch rates. If the new bag limits are binding, i.e. below the angler's expected catch rate, the changes imply a loss in welfare for that individual. These changes in benefits can be estimated from the model using the welfare change formula in equation (11).

While management changes that limit the opportunity for recreational fishing diminish economic welfare among the anglers, the impact of the changes on the coral reef and fish stocks is not captured in the measures described above. There could be benefits derived by other segments of society who recreate in the marine environment and are thus affected by fishing activity directly or indirectly. Changes in the coral reef can also be valued by non-users, and these non-use values are not reflected in these welfare measures. However, the model presented here makes it possible to simulate the impact on fish stocks and coral reefs, both of which are valued by society, and allows resource managers to make better informed decisions in resource allocation. Currently, resource management decisions are made with very little knowledge of the extent of recreational fishing values and the impact of fishing or management changes on marine resources and habitats (Westera et al., 2003). In Western Australia, the formulation of management strategies for commercial and recreational users is a difficult task due to the lack of definite information on abundance of many fish stocks and environment variations (Fisheries, 2000).

4 A CASE STUDY

Situated on the North West Cape of Western Australia, Ningaloo Reef is one of a declining number of relatively pristine major coral reefs in the world. Much of the 200-km long reef system falls within the Ningaloo Marine Park. The reef supports a wide diversity of marine species that attracts the recreational tourist and the reef fish are very popular with anglers (Wood and Glasson, 2005). Three recreational sites (Mandu, Osprey and Maud) located in the park have been chosen as case study sites for the modeling results presented in this paper.

Below we report results from a simulation of recreational angling activities and their interactions with recreational environment for a period of 16 years, from 2010 to 2025. First, we have a baseline or ‘business-as-usual’ strategy where there is no management change. Then, the following two separate management strategies are evaluated and compared with outcomes under the baseline strategy:

(1) The number of accessible sites is taken from three to two with Osprey closing in 2015. The effects of this change are shown in Figures 2(a)-(d).

(2) The bag limits in three sites are all reduced to 25% from 2015. The effects of these changes are shown in Figures 3(a)-(d).

The closure of a site reduces aggregate welfare. This welfare loss is matched by continuous increases in piscivores fish population in the closed site during the first three years after closure. The additional fish biomass gains per dollar lost in welfare change leads to about 0.01kg of piscivores biomass increments, as shown in Figure 2(a). However, these beneficial environmental effects (rises in piscivore populations) lead to lower herbivore populations, which leads to higher algal but lower coral covers in the site. Coral covers are major attraction for non-fishing recreationists. These cover changes are likely to have negative effects on recreational activities such as snorkeling, swimming, etc. However, as shown in Figure 2(b), the changes in coral cover are minimal. However, closing the target site, Osprey, brings opposite effects on the other two sites. One dollar lost in welfare change leads to about 0.003kg of piscivores biomass reduction and almost no change in coral covers in Mandu or Maud. Although the above biophysical effects and changes in welfare are not significant, after site closure, the average number of trips for all anglers decrease by 400 per year, 2.5% reduction per year. Average real catches

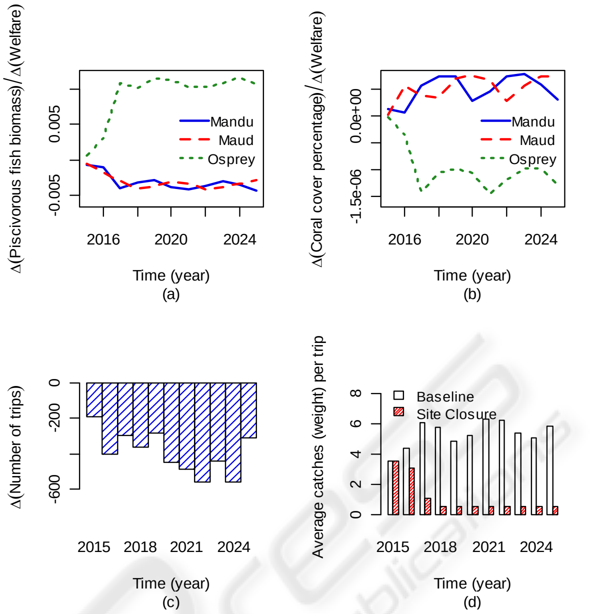

Figure 2: Piscivorous fish biomass and coral covers gains with changes in welfare, changes in number of trips, and average catches per trip after closing Osprey.

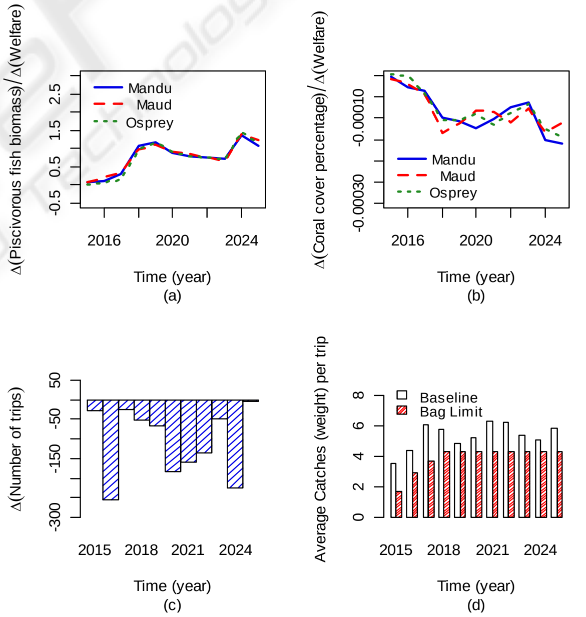

Figure 3: Piscivorous fish biomass and coral covers gains with changes in welfare, changes in number of trips, and average catches per trip after reducing bag limits.

(weight) per trip goes down from 6 kilograms to 0.55 kilograms after closing Osprey.

Bag limit changes have more significant biophysical effects compared to the effects obtained with site closure. Piscivorous fish biomass gains per dollar lost for all sites increase during the first four years, and then vibrate at about 1 kilogram per dollar. Correspondingly, coral covers losses with changes in welfare decrease during the first four years, and then vibrate at about 0.01% per dollar. In addition, after imposing a reduction of 75% to bag limits, the number of trips to all sites reduces by about 7% per year, and average real catches (weight) per trip reduces from 6 kilograms to 4.6 kilograms.

The simulation experiments conducted here are by no means comprehensive. They are presented to demonstrate the potential of the model. Further revisions to this study are under way and there will be a more comprehensive assessment of alternative management strategies. However, the results presented here do show that the effectiveness of different management strategies could be very different. For example, a naive look at a three-fourth reduction in the bag limit would lead one to expect substantial changes in catch rate per trip. What the results above show is that the effects of the closure were much more dramatic in this particular simulation. With better modeling tools, resource managers would be able to evaluate alternatives and choose strategies that are effective but also minimize impact less on recreational values.

5 CONCLUSIONS

This paper has provided the structure of our integrated model for simulating recreational fishing and reef ecosystem dynamics. The management of coral reefs such as Ningaloo and the Great Barrier Reefs in Australia is always the subject of controversy. The value of models that allow resource managers to evaluate both the welfare and biophysical impacts of proposed or potential changes in management cannot be overstated.

Some preliminary results from a simulation of two management changes show how the effectiveness of strategies and the distribution of their impacts can be very different from what one would expect without the benefit of an integrated model. Single site closure had substantial effect on real catches per trip compared to fishing bag limits that appear drastic and are likely to be resisted more by anglers. These simulations are presented as a demonstration of the benefits of integrated resource use modeling and not to generate information regarding implications of policy changes.

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