Chapter 2
A Case Study on Characterising and Parameterising an Agent-Based Integrated Model of Recreational Fishing and Coral Reef Ecosystem Dynamics

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2.1 Introduction

Managing recreational fishing is among the most difficult natural resource management problems. The complex nature of the impacts caused by management changes makes it difficult to identify the full range of ecological and socio-economic effects. It is difficult to distinguish approaches that are effective from those that are not. For example, the evaluation of area closure strategies needs to incorporate the relationships among stock dynamics, angler responses and consequent changes in the geographical distribution of fishing efforts. Empirically-based tools are needed to predict responses to, and outcomes from, management decision that affect fish stocks and fishing benefits. To address this, an integrated agent-based model (ABM) of recreational fishing and a coral reef system is developed to evaluate ecological and economic impacts.

Recreational fishing is an individual based activity, with individuals making decisions on fishing site based on their own preference, knowledge and expectations. In this model, the behaviour of angler agents is represented by empirically based Random Utility Models (RUMs) (McFadden 1974; Schuhmann and Schwabe 2004) that rationalize choices on the basis of attributes of the individuals, the characteristics of alternative sites and recreational experience. With this approach, it is possible not only to simulate fishing behaviour but also construct welfare estimates at the individual level (i.e. for each angler), allowing resource managers and policy makers to assess the impacts of management change on different segments of society. Further, these welfare estimates can be aggregated up to the population level

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(i.e. for all anglers) for use in cost-benefit analysis and the evaluation of changes in recreational management. The model makes it possible to undertake "what-if" scenario analyses and allows researchers and managers to better understand the wide range of economic and environmental implications of management strategies.

While ABMs have been used to study different natural resource management problems, there have been very few studies that have employed behavioural models that are grounded on empirically estimated choice models. In addition, our model couples these behavioural models with a coral reef ecosystem model that simulates the interactions among algae, corals, herbivorous and piscivorous fish. This model is incorporated into the ABM-RUM framework as a means of attributing environmental changes to recreational fishing sites.

The integrated ABM has been used to undertake demonstrative simulations and these results have been reported in several conference proceedings and journal articles (Gao et al. 2010; Gao and Hailu 2010b, 2011a, b, 2012, 2013). The two-way interaction between fishing site choices (human behaviour) and ecosystem dynamics is complex. The implications of this complexity are that it is difficult to determine the socioeconomic and biological outcomes of a management change or the relative performance of alternative management strategies without the benefit of integrated modelling. For example, Gao and Hailu (2011b) illustrate this by simulating the effects of three alternative site management strategies: a baseline strategy where no fishing sites are closed; a 2 month closure of a site; and a 6 month closure of a site. The alternative strategies are compared in terms of fish biomass and angler economic welfare outcome streams obtained over time. Further, these comparisons are done for two different fishing pressure environments: a low level (or baseline) fishing pressure level and a high fishing pressure level. Among the model's surprising conclusions is that, under low fishing pressure in a coral reef ecosystem, closing fishing areas for 2 months instead of 6 months can result in larger fish stocks and better fishing opportunities. These observations highlight the need for the use of simulation platforms to track complex outcomes and to help managers and other stakeholder explore conservation and economic tradeoffs implied by alternative resource management choices. Further details are provided in Gao and Hailu (2011b).

2.2 Model Description Based on ODD

In this section, we use a model documentation protocol, ODD (Grimm et al. 2010), to describe the integrated ABM.

2.2.1 Purpose

As indicated above, the purpose of the integrated ABM model is simulating recreational fishing and reef ecosystem dynamics. It allows resource managers to evalu-

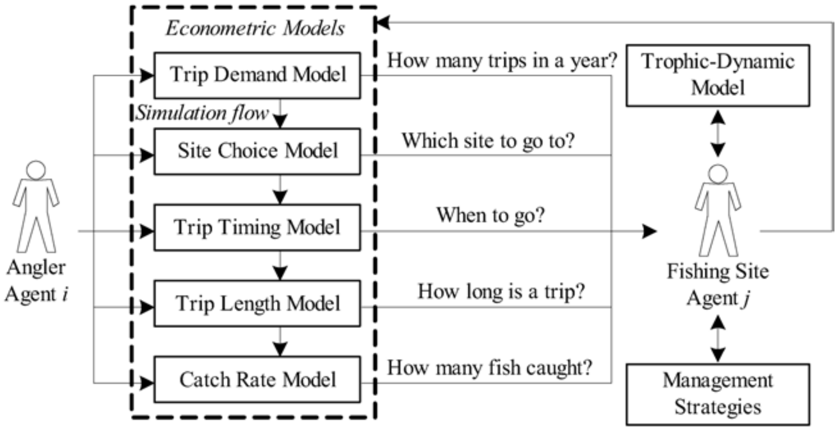

Figure 2.1 The integrated ABM. (Source: Modified from Gao and Hailu 2011b)

ate both the welfare and biophysical impacts of proposed or potential changes in management.

2.2.2 *State Variables and Scales*

The ABM combines a host of econometric models with a trophic-dynamic model of a coral reef ecosystem. A schematic diagram of the major components in the integrated ABM is presented in Fig. 2.1.

This ABM model is the first model to combine econometrically estimated models of agent behaviour with a biophysical model of coral reefs. Recreational anglers and fishing sites are all modelled as agents. As shown in Fig. 2.1, five econometric models (trip demand model, trip timing model, trip length model, site choice model, and catch rate model) underpin the decision-making process on which a recreational angler's behaviour is structured. These models predict, respectively, the number of recreational trips taken in a year, the timing of a trip in a year, the length or duration of a trip, the choice of recreational site in any one trip, and the agent's expected fish catch for any given site. The coral reef ecosystem model describes interactions among four components in a coral reef environment, namely, algal growth, coral cover, herbivore fish and piscivore fish. These constitute the simulation platform and are described in the "sub models" section.

2.2.3 *Process Overview and Scheduling*

Its main process can be summarized briefly as follows. For each angler, the simulation system generates a schedule of fishing trips and fishing site choices using behavioural models that are econometrically estimated using observed data. The angler's fishing schedule and choice of sites depends on personal or angler attributes, his/her fish catch expectations (site by site) and the set of fishing sites available as well as the nature of those sites. If an angler agent is fishing on a particular day, then that angler will make a trip to his/her chosen site for that trip. Fish catch for angler at the chosen site will depend on the fish stocks at the site as well as on the angler's demographic or personal attributes. This catch is again determined by an empirically estimated model as described later in the section on "sub models". Thus a fishing trip is affected by the conditions on the site. Fishing activities in turn affect fish stocks (and the rest of the ecosystem) at a site. Each fishing site is a coral reef ecosystem (modelled as a trophic-dynamic system) where fish stocks, coral cover, and algal cover are affected by the fishing behaviours of angler agents. These effects will then feedback into fishing site choices through impacts on catch rates. That is, there is effect going both ways, from the biological to the economic and back. And these effects are complex. For example, when a site is closed, the choice available to the angler is limited. This redistributes fishing effort and has the potential to affect conditions in other sites. The consequence of this redistribution will have further effects on fishing behaviour, etc. The integrated model is used to tease out these effects in a consistent manner so that the socioeconomic and ecological consequences of changes in management strategies are easier to evaluate.

2.2.4 Initialization

The Initialization in the integrated ABM involves specification of fishing site agents and angler agents. A number of fishing site agents are created with corresponding data on fish stocks, coral cover, and algal cover, which are based on information about the study areas and collected field data. A scaling method is used to initialise a population of anglers with demographic characteristics and recreational fishing attributes. In addition, the simulator works on a daily basis, meaning that one modelling time step is equivalent to a 24-h day in reality.

2.2.5 Input

Further inputs are required once the model is initialized. The characteristic information of a calendar day, such as whether the day is a weekend, a public or a school holiday, are incorporated into the ABM and affect the angler agent's make decisions on trip timing and trip length. Information on the species of fish caught and the distance between sites is used as input to enable a more accurate modelling of fishing costs.

2.2.6 Sub Models

In this section, we describe in more detail the sub models, starting with the econometric models that form the basis of our angler behaviour characterisation. The section concludes with a brief description of the coral reef ecosystem model that is coupled with the human behavioural model to provide an integrated model that takes into account the two-way interaction between fishing behaviour and biophysical outcomes.

The *trip demand model* predicts the actual number of trips taken by an angler (in a year) as a Poisson process (Raguragavan et al. 2013). 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 in Eq. (2.1).

$$\ln \lambda_i = \beta_0 + \beta_1 \cdot IV_i + \sum_m \beta_m \gamma_m \tag{2.1}$$

where γ_m represents m-th individual characteristic, such as age, education, employment, etc. β_0, β_1, and β_m are regression coefficients. The IV_i variable, which is a measure of the expected maximum utility from a set of choices, is routinely used to evaluate environmental changes in the non-market literature (McFadden 1974). It is calculated from site utility values using the formula in Eq. (2.2).

$$IV_i = \ln \sum_{j=1}^{M} e^{U_{ij}} + 0.5772 \tag{2.2}$$

where U_{ij} (also see Eq. 2.4) is the utility that angler agent i derives from recreational fishing at a recreational angling site j out of M sites. The variables and coefficient estimates in the *trip demand model* are presented in Raguragavan et al. (2013).

The *trip timing* decision is a discrete choice problem, with the choices being the days in the year when an angler starts their fishing trip(s). We used the timing information in the survey data to estimate a logit model for trip timing and this model is used in the agent-based simulation to determine the dates for fishing trips by a given angler agent i. The probability p_{ir} that the angler agent i starts a trip on day r among all possible sets of days s is given by the following logit formula:

$$p_{ir} = \frac{e^{\left(\sum_k \omega_k \cdot D_{kr} + \sum_l \sum_m \omega_{lm} \cdot X_{li} \cdot D_{mr}\right)}}{\sum_s e^{\left(\sum_k \omega_k \cdot D_{ks} + \sum_l \sum_m \omega_{lm} \cdot X_{li} \cdot D_{ms}\right)}} \tag{2.3}$$

where D_{kr} (or D_{mr}) is the k-th (or m-th) characteristics of day r, X_{li} is the l-th characteristics of angler agent i, and ω_k and ω_{lm} are coefficients to be estimated.

Trip length on the other hand is a continuous variable that takes a value of 1 or higher. We estimated a limited dependent variable model, Tobit, to provide a means of predicting fishing holiday lengths. Trip length in days (*TL*) is assumed to be a function of personal characteristics and the characteristics of the period during which the trip is taken:

$$TL = \sum_{u} \varphi_{U} \cdot D_{ug} + \sum_{v} \sum_{w} \varphi_{vw} \cdot X_{vi} \cdot D_{wg} \tag{2.4}$$

where D_{ug} (or D_{wg}) is the *u*-th (or *w*-th) characteristics of the trip start day *g*, X_{vi} is the *v*-th characteristics of angler agent *i*, and φ_u and φ_{vw} are the coefficients to be estimated. These trip length and trim timing model specifications are based on (Hailu and Gao 2012).

A random utility model (RUM) is used to predict angler preferences among a set of alternative sites. Fishing *site choice* is driven by cost of visit to the site, expected catch rates, the isolation score of the site, as well as other recreational attributes of the site. The most common RUM formulation is the multinomial logit (McFadden 1974), which provides the following closed form for the expression of the probability ($prob_{ij}$) that a person *i* chooses site *j* from *M* sites depending on the utilities expected from each of those sites.

$$prob_{ij} = \frac{e^{U_{ij}}}{\sum_{k=1}^{M} e^{U_{ik}}} \tag{2.5}$$

where, U_{ij} is the utility that angler *i* derives from fishing at site *j* and is dependent on site and angler characteristics as shown in Eq. (2.6).

$$U_{ij} = \alpha_0 + \alpha_1 \cdot cost_{ij} + \sum_{f} \alpha_f \cdot ECR_{ijf} + \sum_{k} \alpha_k \cdot S_{kj} \tag{2.6}$$

where α_0 is the base utility of a site, $cost_{ij}$ is the cost to angler agent *i* of recreational fishing at site *j*, ECR_{ijf} represents the number of fish of type *f* that the individual expects to catch at the site, S_{kj} stands for other site attributes that affect site choice (e.g. coastal length). Note that α_0, α_1, α_f, and α_k are regression coefficients. The estimation results for the model used here are presented in Table 9 in Hailu et al. (2011). The expected catch rates in the model depend on site attributes (particularly fish stocks) and the angler's experience. These rates are generated by another econometric model, the catch rate model, shown below in Eq. (2.7).

$$\ln ECR_{ijf} = \gamma_0 + \gamma_f \cdot stock_{jf} + \sum_{j} \gamma_j \cdot S_j + \sum_{i} \gamma_i \cdot X_i \tag{2.7}$$

where: ECR_{ijf} is the expected catch per trip of angler agent i at site j for fish type f; $stock_{jf}$ is the stock at site j of fish type f; S_j is the vector of other site attributes (such as if the site is man-made, if it is a beach, and so on); and X_i represents 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. γ_0, γ_f, γ_j, and γ_i are regression coefficients obtained through econometric estimation. The catch rate functions used in our study are based on those reported in Table A5 in Raguragavan et al. (2013). We refer readers to (Gao and Hailu 2011b; Hailu and Gao 2012; Hailu et al. 2011; Raguragavan et al. 2013) for detailed model specifications and discussion of estimates.

The coral reef ecosystem model uses a local-scale model of trophic dynamics (Fung 2009) to describe interactions among algae, corals, and fish at a site. This model was originally developed as ordinary differential equations (ODEs) which have been parameterized as ranges in the Indo-Pacific region and the Western Atlantic region. Equilibrium behaviour and parameter sensitivity of the model have been examined in detail (Fung 2009). Since the coral reef ecosystem targeted (Ningaloo reef) has insignificant amounts of turf algae and sea urchins, this model has been simplified with only five functional groups, namely, hard corals (C), macroalgae (A), grazed epilithic algal community or EAC ($E=1-C-A$), herbivorous fish (H), and piscivorous fish (P). All the parameters in the coral reef ecosystem model are calibrated against recent observations of five functional groups in Ningaloo using a comprehensive learning particle swarm optimizer (Gao and Hailu 2010a). Details of the coral reef ecosystem can be seen in Fung (2009) and Hailu et al. (2011).

2.3 Overview: Framework-Specific Sequence

The ABM presented in this chapter has been applied to the assessment of alternative management strategies for recreational fishing in the Ningaloo coral reef marine park of Western Australia. Based on data from Tourism Research Australia on site surveys, it can be calculated that the number of tourists to the Ningaloo Coast for 2005 was about 203,580 (Schianetz et al. 2009). A recent survey report (Jones et al. 2011) in this area shows that 49 % visitors fish from the shore while 40 % fish from boat. This means that the model would work with a large population and it becomes necessary to develop a representative sample of the population being simulated.

Expert knowledge (EK) and participant observation (PO) are used to understand agents and their actions (M1). The expert knowledge used consists of the economic principles of utility maximization that govern angler choice among alternatives as well as scientific knowledge describing the dynamics of a coral reef ecosystem. Angler activities include choice of fishing site, choice of target fish, and expenditure on fishing related items such as bait. Detailed agent attribute data (M2) are elicited by conducting sample surveys, while agent behaviour (M3) derive from choice models, which are econometrically estimated based on collected survey responses. Further, we assume that the sample (collected responses of distributed surveys) used to generate attributes and behavioural parameters is representative, proportional up-scaling can be carried out, in which random sampling is used to generate the whole population (M5).

2.4 Technical Details

2.4.1 Data Summary

The work first conducted a survey of people who were fishing and recreating in the Ningaloo region of Western Australia, which is the target area of the study. The questionnaire was revised on at least two occasions. These revisions were based on feedback from staff members who visited the region and interacted with respondents who were willing to participate in the survey.

The survey questionnaire consisted of three sections, with the first two of these sections being the ones relevant for this study[1]. The first set of questions relate to the demographic details of the respondent and included information on country of origin, length of stay in the region, by what means the respondent travelled in the region as well as the size of the cohort with which the respondent was travelling. This section of the survey also collected information pertaining to the previous 12 month recreational and fishing experience in the region. For those who were fishing, information on the skill and experience of the angler as well as cost of the angler's fishing equipment was collected.

The second section of the survey asked participants to keep a log book of the fishing trips that they undertook to fishing sites in the Ningaloo region. The data requested in this section included: the site; the time at which fishing occurred; and the location at which the respondent lodged the night prior to the day of the fishing trip. The participants, when choosing a site, were asked to allocate a rank to a set of choice reasons and site attributes, i.e. they were asked to rank site scenery, importance of time availability, and other factors that might have affected their choice. Other information solicited through the survey included the species and number of fish caught and released and cost incurred as part of the trip (including the cost of bait, tackle, boat hire, boat fuel and food). Anglers were also asked to identify any fish species that they were targeting. It should be noted here that, as the data collection progressed, the log book approach was found to lead to low response rates. This is because the surveys were long and respondents had little incentive to fill out detailed information for multiple trips. Therefore, at a later stage in the data collection, it was deemed necessary that a face-to-face interview be used to improve response rates. The face-to-face interviews were conducted using the same questionnaire but

[1] The third section of the survey collected information on non-fishing recreational trips and was used for a separate study on non-fishing recreation.

it meant that one data point was obtained from each respondent instead of multiple data points as was initially hoped. The switch was successful and the project was able to generate a good enough sample through the face-to-face interview.

A total of 426 visitors were surveyed, and 402 of these provided trip information. Data collected covered a total of 774 trips. The data collected in the survey are stored in an Excel spreadsheet with a worksheet for each of the survey sections, i.e. demographic, fishing trips and recreational trips. Each section of the survey has been analysed and the results are reported in a summary report produced by Durkin (2009). These data described in Durkin (2009, p. 916) underpin the development of revised econometric models for recreational site choice and econometric models for fishing in Ningaloo.

During the initial data analysis, it became apparent that the survey information would be better stored in a database. The database not only records the information collected in the survey but also tables pertaining to fish species, the geographic distance between sites and a reference point, as well as information on respondents who were visiting in groups. This latter piece of information would enable a more accurate analysis of cost data for people fishing in groups. We refer readers to (Durkin 2009; Hailu et al. 2011) for further details on the data and analysis done on it.

2.4.2 Key Steps for Characterising and Parameterising Recreational Angler Agents

A recreational angler agent has demographic attributes (such as age, income, education level, employed status, and so on) and behaviour (such as choosing sites and catching fish). A fishing site is regarded as an agent that has environmental attributes (such as coral cover, algal cover, herbivorous fish biomass, piscivorous fish biomass, area, and coastal length) and ecological activities (interactions among dynamic environmental attributes). But in this chapter, we focus on the characterisation and parameterisation of recreational angler agents. So in this chapter, unless otherwise specified, "agents" refers to anglers. The structure of the econometric models that were estimated as a basis for empirically based behavioural models for recreational fishing anglers has been described in the "sub models" section above. Below, we provide an overview of the approach used.

The key steps involved in the econometric modelling of recreational choice and associated benefit calculation are outlined in Table 2.1 above. For recreational fishing, the first step is to obtain data on visitors and the choices they make. In our case, these data have come primarily from the survey conducted in Ningaloo. Data from the National Survey on Recreational Fishing was also used for a state-wide fishing study that included three sites in the Ningaloo region (Gao and Hailu 2011b; Raguragavan et al. 2012). In the second step, a theoretical model is used to provide a framework for describing observed behaviour or choices made. The key theoretical framework is the random utility modelling (RUM) framework for describing site choice. Other supporting models are specified using economic/econometric theory

Table 2.1 Research steps in econometric modelling and welfare change analysis

Research steps	Recreational fishing studies
Observe choices and profiles	National Survey of Recreational Fishing data (2000/2001) and Ningaloo fishing survey data collected by the project since 2007
Use a theoretical framework/model (RUM) and other empirical models	Five models: expected catch rate model, Site choice model (RUM), trip timing (logit model), trip length (Tobit model), and trip demand model (Negative binomial model). These models are grounded on economic/econometric theory and previous empirical evidence highlighting influences on choice
Estimate model parameters (econometrics/MLE)	Data fitted to models using maximum likelihood estimation (MLE)
Use model to predict behaviour and derive welfare values	Value of fish (part worth), value of change in fish stocks, site attributes, total fishing site values

and information from previous empirical studies. In the third step, econometric estimation is undertaken to generate the parameters of the RUM model and the econometric models listed in Table 2.1. Finally, the estimated models are used to drive agent behaviour and to calculate economic welfare change estimates arising from site condition or site management changes.

2.5 Lessons/Experiences

The major challenge in the research was that the rate of responses obtained for our survey questionnaires handed out in Ningaloo was initially low. This is because the data required was detailed and the survey was too long for respondents. As a result, the empirical analysis was delayed. Consequently, we changed our approach to data collection and began employing face-to-face interviews to maximize completion rates of the questionnaires. This change in approach enabled us to generate a usable sample that was bigger than was initially planned. What is more, the data from face-to face surveys were standardised so that names of fishing and recreational sites as well as sites of accommodation were checked for consistency in spelling. Where possible the location of the site is entered before the site name itself for easy identification, e.g. Exmouth Ningaloo Lodge, and this helped avoid naming confusions that would have occurred if we had relied on questionnaires filled out by anglers.

We were also aware that, before the data are used to parameterize our agent-based models, it was necessary and useful to analyse the survey data. Each section of the survey has been analysed using SPSS and the results are reported in a summary report produced by Durkin (2009). It should be noted that this analysis was carried out so that there is a better understanding of the strengths and weaknesses of the collected data. These data underpin the development of revised econometric models for recreational site choice and econometric models for fishing.

The parameterized models can be used to undertake evaluation of different management strategies such as the following:

1. Analysis of site closure effects
   The economic welfare losses from site closure can be estimated in detail, per person per trip. These values are based on estimated site access values. This method can also be used to evaluate the value of new fishing sites, as, for example, when anglers are provided with the opportunity to fish at a new site (e.g. made accessible through the construction of a road or a change in regulation). For the Ningaloo recreational fishing studies described above, estimated site values are shown in Hailu et al. (2011). For the state-wide recreational fishing model, these results are reported in Raguragavan et al. (2013).
2. Analysis of changes in site attributes
   One can look at increases or decreases in desirable site attributes. These calculations have been undertaken for fishing recreation in Raguragavan et al. (2013) using the state-wide fishing site choice model and for Ningaloo recreational sites in Hailu et al. (2011). The models presented above can be used to simulate welfare changes for different combinations of changes in site attribute values such as fish stock levels.
3. Integrated modelling of economic and biophysical effects
   The integrated ABM can be used to evaluate changes in outcomes in ways that take into account the feedback effects between economic choices (fishing) and fishing site conditions. Several demonstrative simulations of changes in management strategies have been undertaken and the results are published. For example, site access and fishing bag limit changes are simulated in (Gao et al. 2010; Gao and Hailu 2010b) while seasonal site closure regimes are simulated in (Gao and Hailu 2011b). In particular, the results reported in Gao and Hailu (2010b) indicate that it is possible for some restrictive access policies to be welfare improving even for anglers, because the stock gains and improved catch effects can outweigh the losses from reduction in access times. For further details, see (Gao et al. 2010; Gao and Hailu 2010b, 2011b).

Finally, ABMs and econometrically estimated choice models are popular approaches in the study of recreational behaviour. The two focus on similar data and are based on individual decision-making to determine patterns of recreational use. ABMs often rely on expert experience for defining rules to drive agent behaviours, while choice models govern individual behaviours using statistically estimated parameters. In our case, we regard choice models as a complement to ABM. Theoretical justification for agent behaviour structures in ABMs is weak in many contexts. The approached used in this study addresses this shortcoming by using theory and empirical data to define agent behaviour.

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