Boat-based and other recreational fishing in Western Australia: Analysis of site choice, access values and bag limit effects

Alemken Jegnie[a], Atakelty Hailu[a*], Michael P. Burton[a]

[a]UWA School of Agriculture and Environment, The University of Western Australia, Crawley, WA 6009, Australia

*E-mail address: atakelty.hailu@uwa.edu.au

30 March 2017
Working Paper 1703
UWA Agricultural and Resource Economics
http://www.are.uwa.edu.au

Citation: Jegnie, A., Hailu, A., and Burton, M.P. (2017) *Boat-based and other recreational fishing in Western Australia: Analysis of site choice, access values and bag limit effects*, Working Paper 1703, Agricultural and Resource Economics, The University of Western Australia, Crawley, Australia.

Boat-based and other recreational fishing in Western Australia: Analysis of site choice, access values and bag limit effects

Alemken Jegnie, Atakelty Hailu, and Michael P. Burton

Abstract

This study investigates the drivers of recreational fishing site choice and the effects of bag limits among boat-based and other fishers in Western Australia. A site choice model incorporating expected catch and other variables is estimated and used to assess the implications for angler welfare and fish harvest of different management strategies. The study reveals that site choice is determined by distance to fishing site, expected catch rate and coastal length. Fishing efforts (time spent and size of the party), fishing methods used (boat, target and bait), abundance of fish (stocks) and types of the fishing site are the most important factors determining catch rates. Site access values vary widely and for boat users the top four valuable fishing destinations are found to be Broom, Albany, West Kimberly and East Kimberly. The spill-over effects of bag limits on high value fish are found to be small while welfare losses associated with bag limits are highly skewed. The differences in site access values and the range of angler welfare loss estimates highlight the importance of empirical modelling to generate information valuable to policy-making.

Key Worlds: Boat-based recreational fishing, bag limits, fishing site choice access values, fishing site, random utility models

Boat-based and other recreational fishing in Western Australia: Analysis of site choice, access values and bag limit effects

1. Introduction

In Australia, fishing is a highly popular outdoor leisure activity with about 25% of households consisting of on average two members who fish (McManus *et al.* 2011, Nin *et al.* 2005). It is an activity enjoyed by different age groups including children and the demand for it is growing. Recreational fishing is also an important source of economic demand, with $650 million spent on tackle while the expenditure on boats and general fishing expenses (McManus *et al.* 2011). Concerns about deteriorating fish stocks have led to calls for better management of the growing impact of recreational fishing. However, actual management responses tend to be *ad hoc* and are rarely informed by empirical estimates of economic values.

An understanding of the value of recreational fishing is key to informed decision making and to resolving existing controversies regarding the appropriateness of management choices. There have been numerous studies on recreational fishing but these have been conducted mainly in the US and Europe, e.g. Thomas and Stratis (2002), Morley *et al*. (1991), Navrud (1999) and Bockstael *et al*. (1989). Western Australian examples are limited and include Raguragavan *et al*. (2013), Zhang *et al*. (2003), Gao and Hailu (2011), Weetman (2012), Wise et al. (2012) and Van Bueren (1998). Further, the number of studies on boat-based recreational fishing is limited.

This is the first study attempting to examine boat-based recreational fishing throughout WA using random utility modelling to investigate site choice behaviour and responses to management change. All eight major fishing regions in the State, stretching along the coast from Esperance in the south to the Kimberly in the north, are covered in the study. Fish are grouped into five major categories and negative binomial expected catch rate models are estimated for each fish category. Fishing site choice behaviour is modelled by a random utility model which is used to generate values for fish and sites. The model is then used to estimate the effects of alternative fishery management policies.

The paper is organized as follows. Section 2 briefly discusses the modelling framework used in this research context. The framework consists of a negative binomial fish catch rate model and random utility model of site choice behaviour. Section 3 describes the data. This is followed by a presentation of the results including catch rate models, site choice behaviour, site access values and the effects of different bag limit based management strategies. Section 5 summarises and concludes the paper.

2. Modelling framework

The modelling framework used here closely follows that in Raguragavan *et al* (2013). The key model is the random utility model (RUM) of site choice which describes fishing destination decisions as a function of site and angler characteristics. A supporting model is the fish catch rate model which predicts what an angler expects to catch at a site. These models are described below.

Random utility models are used to estimate choices among discrete alternatives and are now the most commonly used approach in non-market valuation and site choice (McConnell *et al.* 1995). The RUM describes a choice occasion in which person *i* has a set of C alternative fishing sites to choose from. Choice is driven by the relative utility of a visit to a site. The model starts by hypothesizing that the utility V_{ij} derived by angler i from a trip to a fishing site j depends on a vector q_{ij} of distance and other attributes of the site as perceived by i as well as a vector of angler characteristics z_{ij}. That is:

$$V_{ij} = V(q_{ij}, z_{ij})$$

Angler *i* will visit site *j* if the utility of site *j* is greater than the utility of any other site *k*, where *k* = (*1, 2…, j-1,j+1 …, n*). However, the model recognizes that the utility of a site cannot be fully observed or modelled. To obtain an empirically estimable model, one needs to recognize that utility is the sum of two components: a systematic or observable component (Vij) and a random or unobservable component (ε_{ij}):

$$U_{ij} = V(q_{ij}, z_{ij}) + \varepsilon_{ij} \qquad (1)$$

To implement the RUM, we use the multinomial logit (MNL), which assumes that the ε_{ij} terms are independent and identically distributed as type I extreme value variates. The MNL probability, $prob_{ij}$, that individual *i* chooses site *j* out of *n* sites can then be expressed as:

$$prob_{ij} = \frac{e^{V_{ij}}}{\sum_{k=1}^{k=C} e^{V_{ik}}} = \frac{e^{V(q_{ij}-z_{ij})}}{\sum_{k=1}^{k=C} e^{V(q_{ik}-z_{ik})}} \qquad (2)$$

To implement this model, one needs to identify the set of site attributes to include in the specification of the systematic utility component. Cost of travel to the site is a key influence. Other key attributes are the expected catch rates for the different categories of fish. One way to estimate expected catch rates (henceforth CR's) for a site is by computing the average number of fish caught by all anglers. However, this approach to CR estimation does not specifically accommodate differences in catch rates or target species preference among anglers (Bockstael et al. 1991). In reality, expected catch rates for a particular fish type will be different for different anglers.

To overcome the catch rate measurement problem, many studies (e.g. Schuhmann and Schwabe 2004; McConnell et al. 1995) have modelled individual angler expected catch rates using Poisson models, in which the intensity variable in the Poisson model (i.e. expected catch rate) is specified as:

$$CR^{e}_{ijf} = \exp\left(\beta x_{ijf}\right) \qquad (3)$$

where CR^{e}_{ijf} denotes the expected catch rate for fish *f*, x is a covariate vector and β is a vector of regression coefficients. However, the Poisson model has a drawback in that it assumes uniform dispersion in the Poisson random variable Y (catch rate in our case) since, for a Poisson model, the expected value and variance of the random variable are same and equal to the intensity variable, i. e. E[Y] = Var[Y] = CR^{e}_{ijf}. This property is too restrictive, as over dispersion is often observed in practice. One way to avoid this restrictive dispersion assumption in the Poison model is to introduce unobserved heterogeneities which lead to a negative binomial distribution form for the catch rate variable. Negative binomial models, which incorporate heterogeneities by expressing the intensity variable as follows, were first introduced into economics by Hausman et al. (1984).

$$\widetilde{CR}^{e}_{ijf} = CR^{e}_{ijf} . u_i \qquad (4)$$

where u is unobserved and distributed as a one parameter gamma variable Γ(θ, θ) with the mean and variance as shown below:

$$E[u] = 1 \text{ and } var[u] = \theta^{-1} \tag{5}$$

This leads to the following negative binomial distribution for the marginal distribution of Y (Green 2008):

$$f(CR_{ijf}|\theta,\beta) = \frac{\Gamma(1+CR_{ijf})\left(\frac{\theta}{\theta+CR_{ijf}^{e}}\right)^{\theta}\left(\frac{CR_{ijf}^{e}}{\theta+CR_{ijf}^{e}}\right)^{CR_{ijf}}}{\Gamma(1+CR_{ijf})\Gamma(\theta)} \tag{6}$$

Taking the limit of $\theta \rightarrow \infty$ makes the negative binomial distribution converge to the Poisson distribution. Thus the negative binomial model nests (or is a generalization of) the Poisson regression model.

In this study, we use the negative binomial model to predict angler and fish specific expected catch rates for the different fish types by regressing actual catch rates on fisher and site characteristics. The following log-linear form is used:

$$lnCR_{ijf}^{e} = \beta_0 + \beta_1 stock_{if} + \beta_2 S_i + \beta_3 X_i \tag{7}$$

where: CR_{ijf}^{e} is expected catch per trip of angler i at site *j* for fish type *f*, $stock_{jf}$ is the stock of fish type *f* at site *j*; S_i is the vector of other site characteristics that impact on the catch rate; and, X_i represents a vector of angler attributes that influence expected catch rates. The stock ($stock_{jf}$) variable is a proxy measure of the abundance at site *j* of fish type *f* which is approximated by the average catch of all anglers at that site. The set of other site attributes in the model include indicators of shore type (manmade, inshore, estuary or beach). The model also incorporates the following angler attributes: age, whether the angler fished with a group (party), target, hours spent fishing, membership in the fishing club, retirement status, and employment status. The variables are outlined in Table 2. The catch rate model in (7) was estimated separately for the five fish types by maximizing the likelihood for the negative binomial distribution.

The expected catch rate predictions are then used to generate angler/site specific variables for the utility specification in the random utility model of site choice, which uses the following specification for the utility function:

$$V_{ij} = \beta TC_{ij} + \sum_{f} \beta CR^{e}_{ijf} + \beta CL_{ij} \qquad (8)$$

Where V_{ij} is angler i's observable utility from a visit to site j; TC_{ij} is the cost of travel to the site; CR^{e}_{ijf} represents the specific predicted or expected catch rate of fish type (*f*) for angler *i* at site *j*; and CL_j represents the length of coast line (km) for the site. The coefficients of the expected catch rate variables are expected to be positive.

3. Data

This paper uses data obtained from the National Survey of Recreational Fishing (NSRF) that was conducted in 2000-2001. The NSRF was a nation-wide survey conducted by WA Department of Fisheries. The survey was the first multifaceted national examination of the non-commercial aspects of Australian fisheries and the fisheries statistics were collected on a variety of issues relating to recreational fishing and its management. Information gathered includes:

- Fishing site (there are 48 sites identified)
- Primary target and secondary target species
- Fishing hours and date of fishing trip
- Catch details (member of kept and released fish and total catch)
- Fishing method (five major categories these are line fishing, fishing with pots or traps, fishing with nets, diving, and other collection methods)
- Party size (number of people in the fishing trip)
- Driving distance (length of distance in kilometre travelled by the fisher)
- Fishing mode (fishing from the shore or boat-based fishing)
- Fishing sub-region (inshore, offshore, estuary, river or lake)
- Shore type (beach, manmade, or natural rock)

The survey also collected demographic information (e.g. age, gender, and education, party size, club membership, employment status, education, retirement and the presence of kids and females). The eight fishing regions are shown in Figure 1.

FIGURE 1 HERE

4. Results

4.1 Estimating catch rate model

The coefficient estimates for the negative binomial model in equation (6) and (7) are shown in Table 1. The size of the fishing party (*Party*), (log of) time spent fishing (*Lnhour),* whether the angler was targeting the fish type *(Target),* use of bait *(Bait)* and abundance of the fish stock at the site *(stock*) were found to be statistically significant influences on catch for all the fish categories. Whether the angler fished from a boat *(Boat)* was also statistically significant except in the case of the key sports fish category. The estuary nature of a site (*Estuary*) has a negative and significant effect on catch. The time of the year (*Quarter)* is also significant. Other site and individual characteristics such as type of site (beach or manmade), fishing sub-region (estuary or inshore), age, level of education, club membership, retirement, and the presence of kids and females are found to be significant in the catch rate models for some fish types. For example, the presence of kids (*Kids*) is found to have a negative effect on catch rate for all fish types except reef fish, while the presence of females in the group (*Females*) is statistically significant only butterfish catch rates.

TABLE 1 HERE

4.2 Site choice model

The empirical specification of the RUM model of site choice specified in equation (1) initially considered a set of site and personal attribute variables:

$$V_{ij} = \quad ASC_i + \beta_1.\text{distance}_{ij} + \beta_2.\text{PrizeFish}_{ij} + \beta_3.\text{R}eef\text{Fish}_{ij} + \beta_4.\text{KeysportsFish}_{ij}$$
$$+\beta_5.\text{TableFish}_{ij} + \beta_6.\text{ButterFish}_{ij} + \beta_{7j}.\text{K}ids_i + \beta_{8j}.\text{MeanAge}_{i} + \beta_{9j}.\text{Boatdummy}_{i}$$

The specification was refined by excluding variables that were not significant at the 95% significance level. The final two models are presented in Table 2. Both models (1 & 2) include alternative specific constants, distance to the site and expected fish catch rates for the five fish types. The models also include interactions between alternative specific constants and two angler attributes, namely, whether the fishing party includes children (*Kids*) and the mean age of that party. Model 2 differs from Model 1 in that the former includes interactions with an additional angler variable (a boat dummy). To save space, the estimated alternative specific constants and interaction term coefficients are not included in Table 2.

Expected catch rates have statistically significant and positive effect on site choice. Distance to fishing site has a highly significant but negative effect on the attractiveness of a site to an angler. The coefficients for key sports fish, prize fish and table fish are greater than those for reef fish and butterfish. This is consistent with the fact that prize fish and key sports fish are valued more than table or butterfish. However, the coefficient size for reef fish being smaller than that for table fish is not consistent with a priori expectation.

TABLE 2 HERE

4.3 Welfare and harvest effects of management changes

A calculation of welfare changes for multinomial logit model is based on the work of Small and Rosen (1982) and uses the following formula for compensating variation (CV) relating to changes in site quality vector (q):

$$CV = \frac{-1}{\beta}\left[ln\left(\sum_{j=1}^{J} \exp V_j(q^1)\right) - ln\left(\sum_{j=1}^{J} \exp V_j(q^0)\right)\right] \qquad (9)$$

Where: J denotes the number of alternative fishing sites; V_j is the utility function for site j; q^0 and q^1 represent, respectively, site attributes before and after the change; and β is the absolute value of the price coefficient in the utility function. If sites have been improved, the compensating variation refers to the maximum that an angler would be willing to pay for the change in fishing quality.

4.3.1 *Effects on angler welfare*

Limits on fish harvest are one of the policy options available to resource managers to reduce fish mortality, improve fish stocks and control overfishing and, in the long run, to sustain or improve quality of fishing experience for the anglers. Bag limits are set in terms of the number of fish of a particular category that an angler is allowed to take. These limits are in addition to limits on the minimum size of fish that can be caught. We evaluate the effects on fish harvest and angler welfare of the alternative policy options shown in Table 3. These effects are defined relative to the base or business as usual case (Policy Base) where no bag limits are imposed.

TABLE 3 HERE

Policies 1 & 2 impose limits on high value fish (prize fish, reef fish, and keys sports fish) but not on table and butterfish. Policy 1 is the least restrictive alternative to the base case and is a policy where a bag limit of 2 is set for each of the high value fish. Policy 2 imposes a limit of 1 on the high value fish. Policies 4, 5 & 6 impose the same limit of 1 on high value fish but involve progressively more restrictive limits on table and butterfish.

On average, an angler household suffers a loss of between \$18.5 and \$33.75 under the bag limit policies (Table 4). These translate into average annual losses ranging from \$118.20 to \$212.50 as shown in the second half of the table. With Policy 1, which allows for the harvest of up to 2 catches for high value fish, the effect on the majority of anglers is negligible (the median loss is only \$2.45 per annum). However, when the limits on high value fish are reduced to 1, this median annual loss increases to \$16.80. With the imposition of limits on low value fish, which are caught by most anglers, the median angler welfare loss jumps to \$43.20 per annum. Unlike Policies 1 & 2, the policies that include limits on low value fish affect more than three quarters of the angler community. Finally, in all policy scenarios, the effects are highly skewed. For example, in the case of Policy 5, the welfare costs imposed by bag limits on the majority of anglers are below \$60 a year. But in 25% of these cases, these costs are above \$202, positively skewed with a maximum of over \$6000.

TABLE 4 HERE

4.3.2 *Effects on catch rates*

The study calculated the simulted number of fish caught for each fish type under each strategy. These detailed results are not included here to save space but can be requested from the authors. Under the base policy in which no access limit is imposed, a total number of 88,141 fish are caught, almost half of these are butterfish. A significant reduction in catch rates occurs when the policies are imposed. For instance, under Policy 1, total catch falls from 88,141 to 60,025 fish. This reduction is due to primarily smaller amounts of reef and key sports fish caught, the harvest levels of these falling by 95% and 63%, respectively. The effect on prize fish harvests of this policy are lower (38%) since anglers tend to catch small amounts of these fish (i.e. a limit of 2 is not very constraining). The impact of moving from Policy 1 to Policy 2, where the limits on high value fish are reduced to 1, has a relatively bigger impact on the harvest of prize fish which is now reduced by 19%. Setting limits on low value fish (table and butterfish), reduces the harvest of these fish by between 46 and 67 percent (Policies 4, 5 and 6) but have no side effects on high value fish harvest levels. Under Policy 5, total harvest is reduced by 65,162 fish or by about 74%.

4.4 Site access values

Access value identifies the aggregate value that fishers gain from a fishing site or conversely what they would lose if they were denied access to that site. The per trip access values for all fishing sites are calculated and can be summarized as follows (detailed results available from authors upon request). Three sets of results are derived: (1) welfare loss suffered by all anglers; (2) welfare loss suffered by just boat users; and (3) the welfare loss suffered by non-boat users. Among the 48 fishing sites, access values are the highest at Albany which has a value of $11.69, $9.49 and $12.84 for the three groups, namely, all anglers, boat and non-boat fishers. The access values at Mandurah are the second highest at $10, $6.37 and $10.37. At the other end of the spectrum of site access values are two urban sites, namely, Burns Beach and West of Garden Island. It should, however, be noted that these values are per trip not aggregate site values and that the latter depends on the total number of visitors to the site, a figure that would be higher for some of the urban sites such as Burns Beach. The magnitude of welfare losses depend on the availability of substitute sites, with isolated sites being valued more than sites with close substitutes. Welfare losses from the closure of sites with substitute sites close by are smaller. The average per trip welfare losses (across all sites) are $2.34, $2.36, and $2.32 for all anglers, boat users and non-boat users, respectively.

Site values differ for the different fishing subgroups. Figure 2 compares values between boat users and all fishers (first sub figure) and also between boat and non-boat fishers (second sub figure). For many of the sites highlighted in the figure, access values differ between boat and non-boat fishers. Boat users value sites such as Broom, West Kimberly and Dampier much higher that shore fishers. On the other hand, Albany, Esperance and Mandurah sites have higher per trip values for non-boat users.

FIGURE 2 HERE

5. Summary and conclusion

This study estimates a site choice model and uses it as a foundation for the analysis of recreational fishing management strategies. The research finds that site choice can be explained using a host of angler and fishing site attributes. Expected catch rates for all fish categories are found to have significant affects on site choice. And, as expected, the chance of catching high value fish (prize, reef or key sports) affects site choice more than the chance of catching low value fish (table and butter). Since expected catch rates depend not just on fish abundance at a site but also on multiple angler characteristics (demographic and others), site choice is determined by many more influences than those directly included in the random utility model. Among angler’s attributes affecting catch rates, fishing effort (mainly the time spent and the size of the party) and the fishing method applied (principally target, bait and boat) are among the most important ones. Other socio-economic variables such as age, education, retirement, membership in a fishing club and gender also contribute in influencing catch rates of some but not all fish types. Among site characteristics, the level of stocks and the type of site (whether an estuary or not) significantly influence catch rates. In addition, fishing season is also found to be a determinant factor in affecting catch rates of the five fish types. The relative impact of season on catch rate is that anglers would tend to go to the North during winter season and to the South during the hotter summer months.

Distance or cost of travel is also a significant influence on site choice. These findings are consistent with those in (Raguragava et al. 2013). The study also finds that the age of the fishing party and wether the party is fishing from a boat or includes kids or females has an effect on site choice.

One of the most commonly used tools in managing recreational fisheries is a bag limit. In WA there are a limited numbers of management strategies applied for recreational fisheries (Fisheries Western Australia, 2000). The declared objective of these management policies is to ensure that WA will continue to provide a quality recreational fishing experience through managing the recreational fishing community’s share of the total catch within the limits a fish stock can sustain (Fisheries Western Australia, 2000). Bag limits are currently set as a social standard for a “fair day’s catch” for an individual angler. Another key role of bag limits would be in playing a role to share the available catch among thousands of individuals who are involved in catching fishes. This study simulates the effects of different bag limits, including some much more stringent that those currently in places.

The results of this study indicate that bag limits need to be carefully set if they are going to generate the desired effects. Limits of 2 on high value fish, for example, had effect on reef and key sports fish harvest but no effect on prize fish. A more stringent limit would be required if the harvest levels of the latter are going to be affects. A bag limit of 1 on high value fish would reduce harvests of prize fish by 58%, key sports fish by 74% and those of reef fish by 96%. The changes in harvest effects (drastic reductions in prize fish catch between similar policies, e.g. Policies 1 & 2) point to the importance of considering other management policies besides simple bag limits that apply throughout the year. Alternatives could include seasonally varying limits or seasonal site closures (Gao and Hailu, 2011).

Our results also indicate that the spill-over effects on low value fish harvest of limits set on high value fish are small. For example, the harvest levels of low value would go up by less than 1% as a result of the stringent limits on high value fish just described.

Welfare effects of bag limits are significant but the average estimates hide an important detail, that these welfare effects are highly skewed. Most policies have little effect on the bottom quarter or anglers (and even on the bottom half in the case of policies targeting only high value fish) but the effects on the most affected quarter are high and range from $80 per annum to several thousands. Policy makers need to consider these skewed effects when considering changing management arrangements.

Managers also need to take into account that site access values vary widely in the State. These variations depend on location of sites and also on whether the values are for boat or non-boat users. For anglers with boats, northern sites such as Broom, Albany, West Kimberly and East Kimberly have higher access values. Some sites, close to the metropolitan areas, have very low values on a per trip basis although their aggregate values are significant on an aggregate basis because they are visited by a bigger number of anglers.

In summary, the management of recreational fishing can be greatly improved through the use of empirical estimates of site and fish values as well as models describing fishing site choice behaviour. The knowledge generated from these estimates enable resource managers to set policies more effectively and in ways that balance resource conservation objectives and angler welfare changes. Where simple policies are not the most effective, the estimated values and models can be used to evaluate whether approaches that mix strategies are worthwhile.

References

Adamowicz, W., Louviere, J. and Williams, M. (1994). Combining revealed and stated preference methods for valuing environmental amenities. *Journal of Environmental Economics and Management* 26, 271-292.

Alpizar, F., Carlsson, F. and Martinsson, P. (2003). Using choice experiments for non-market valuation. *Economic Issues-stoke on Trent-* 8, 83-110.

Bateman, I.J., Carson, R.T., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S. and Özdemiroglu, E. (2002). *Economic valuation with stated preference techniques: a manual, Economic valuation with stated preference techniques: a manual*. Edward Elgar, Cheltenham, UK.

Beard Jr, T.D., Cox, S.P. and Carpenter, S.R. (2003). Impacts of daily bag limit reductions on angler effort in Wisconsin walleye lakes. *North American Journal of Fisheries Management* 23, 1283-1293.

Bennett, J. and Blamey, R.K. (2001). *The choice modelling approach to environmental valuation.* Edward Elgar, Cheltenham, UK

Bockstael, N.E., McConnell, K.E. and Strand, I.E. (1989). A random utility model for sportfishing: Some preliminary results for Florida. *Marine Resource Economics* 6, 245-260.

Champ, P.A., Boyle, K.J. and Brown, T.C. (2003). *A primer on nonmarket valuation*. Kluwer Academic Publisher, The Netherlands.

Cox, S.P., Walters, C.J. and Post, J.R. (2003). A model-based evaluation of active management of recreational fishing effort. *North American Journal of Fisheries Management* 23, 1294-1302.

Douglas, A.J. and Johnson, R.L. (2004). The travel cost method and the economic value of leisure time. *International Journal of Tourism Research* 6, 365-374.

Dovers, S. (1994). Recreational fishing in Australia: review and policy issues. *Australian Geographical Studies* 32, 102-114.

Fisheries Western Australia, 2000. *Management directions for Western Australia's recreational fisheries*, Fisheries management paper 136, Fisheries Western Australia, Perth.

Fleming, C.M. and Cook, A. (2008). The recreational value of Lake McKenzie, Fraser Island: An application of the travel cost method. *Tourism Management* 29, 1197-1205.

Gao, L., and Hailu, A. (2011). An agent-based integrated model of recreational fishing and coral reef ecosystem dynamics for site closure strategy analysis. Proceedings of the MODSIM 2011, 19th International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, Perth, Western Australia.

Gao, L. and Hailu, A. (2011). Evaluating the effects of area closure for recreational fishing in a coral reef ecosystem: The benefits of an integrated economic and biophysical modelling. *Ecological Economics* 70, 1735-1745.

Greene, G., Moss, C.B. and Spreen, T.H. (1997). Demand for recreational fishing in Tampa Bay, Florida: A random utility approach. *Marine Resource Economics* 12, 293-305.

Haab, T.C. and Hicks, R.L. (1997). Accounting for choice set endogeneity in random utility models of recreation demand. *Journal of Environmental Economics and Management* 34, 127-147.

Haab, T.C. and Hicks, R.L. (1999). Choice set considerations in models of recreation demand: History and current state of the art. *Marine Resource Economics* 14, 271-282.

Haab, T.C. and McConnell, K.E. (2002). *Valuing environmental and natural resources: the econometrics of non-market valuation*. Edward Elgar, Cheltenham, UK.

Haddon, M. (2001). *Modelling and qauntitative methods in fisheries*. Chapman & Hall/CRC, Boca Raton, Fla.

Hanley, N., Mourato, S. and Wright, R.E. (2001). Choice Modelling Approaches: A Superior Alternative for Environmental Valuation? *Journal of Economic Surveys* 15, 435-462.

Henry, G.W. and Lyle, J.M. (2003). *The National Recreational and Indigenous Fishing Survey, FRDC Project No. 99/158*, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

Hickley, P. and Tompkins, H. (1998). *Recreational fisheries: social, economic, and management aspects*. Fishing News Books, Malden, MA.

Johnston, F.D., Arlinghaus, R. and Dieckmann, U. (2010). Diversity and complexity of angler behaviour drive socially optimal input and output regulations in a bioeconomic recreational-fisheries model. *Canadian Journal of Fisheries and Aquatic Sciences* 67, 1507-1531.

Malcolm, H. (2001). Modelling and quantitative methods in Fisheries, Florida: CHAPMAN-HALL/CRC227-232.

McConnell, K.E., Strand, I.E. and Blake-Hedges, L. (1995). Random Utility Models of Recreational Fishing: Catching Fish Using a Poisson-Process. *Marine Resource Economics* 10, 247-262.

McManus, A., Hunt, W., Storey, J. and White, J. (2011). Identifying the health and well-being benefits of recreational fishing, FRDC Project.

Morales-Nin, B., Moranta, J., García, C., Tugores, M.P., Grau, A.M., Riera, F. and Cerdà, M. (2005). The recreational fishery off Majorca Island (western Mediterranean): some implications for coastal resource management. *ICES Journal of Marine Science* 62, 727-739.

Morley, E.R., Shaw, W.D. and Rowe, R.D. (1991). A discrete-choice model of recreational participation, site choice, and activity valuation when complete trip data are not available. *Journal of Environmental Economics and Management* 20, 181-201.

Navrud, S. (2001). Economic valuation of inland recreational fisheries: empirical studies and their policy use in Norway. *Fisheries Management and Ecology* 8, 369-382.

Parsons, G.R., Massey, D.M. and Tomasi, T. (1999). Familiar and favourite sites in a random utility model of beach recreation. *Marine Resource Economics* 14, 299-315.

Raguragavan, J., Hailu, A. and Burton, M. (2013). Economic valuation of recreational fishing in Western Australia. *Australian Journal of Agricultural and Resource Economics*, 57(4): 539-558.

Rolfe, J. and Prayaga, P. (2007). Estimating values for recreational fishing at freshwater dams in Queensland. *Australian Journal of Agricultural and Resource Economics* 51, 157-174.

Shrestha, R.K., Seidl, A.F. and Moraes, A.S. (2002). Value of recreational fishing in the Brazilian Pantanal: a travel cost analysis using count data models. *Ecological Economics* 42, 289-299.

Smallwood, C.B. and Beckley, L.E. (2012). Spatial distribution and zoning compliance of recreational fishing in Ningaloo Marine Park, north-western Australia. *Fisheries Research* 125, 40-50.

Smith, V.K. (1996). *Estimating economic values for nature: methods for non-market evaluation.* Edward Elgar, Cheltenham, UK

Smith, V.K. and Kaoru, Y. (1986). Modeling recreation demand within a random utility framework. *Economics Letters* 22, 395-399.

Thomas, M. and Stratis, N. (2002). Compensating variation for recreational policy: a random utility approach to boating in Florida. *Marine Resource Economics* 17, 23-34.

Train, K. (2003). *Discrete choice methods with simulation*. Cambridge University Press, New York.

Van Bueren, M., (1999). Economic Models of Recreational for Guiding Allocation Policy and Managing Stocks: An Application to the Recreational fishery of South Western Australia. PhD Thesis, University of Western Australia, Perth.

Walker, J. and Ben-Akiva, M. (2002). Generalized random utility model. *Mathematical Social Sciences* 43, 303-343.

Ward, F.A. and Beal, D.J. (2000). *Valuing nature with travel cost models: a manual*. Edward Elgar, Cheltenham, UK.

Whitehead, J.C. and Haab, T.C. (1999). Southeast marine recreational fishery statistical survey: distance and catch based choice sets. *Marine Resource Economics* 14, 283-298.

Wise, B., Telfer, C., Lai, E., Hall, N. and Jackson, G. (2012). Long-term monitoring of boat-based recreational fishing in Shark Bay, Western Australia: providing scientific advice for sustainable management in a World Heritage Area. *Marine and Freshwater Research* 63, 1129-1141.

Zhang, J., Hertzler, G. and Burton, M. (2003). Valuing Western Australia's Recreational Fisheries. Paper presented at the 47th AARES Annual Conference, Fremantle, WA.

Table 1. Estimated negative binomial catch rate models

Variables	**Prize Fish**			**Reef Fish**			**Key Sports Fish**			**Table Fish**			**Butterfish**		
Variable	Coef.	S.E	z	Coef.	S.E	z	Coef.	S.E	z	Coef.	S.E	z	Coef.	S.E	z
Constant	-4.0002	0.191	-20.94	-5.1193	0.3468	-14.76	-3.3777	0.198	-17.06	-3.5253	0.1813	-19.44	-1.7769	0.1395	-12.74
Stock	0.2571	0.0278	9.25	0.3248	0.0268	12.12	0.1565	0.027	5.79	0.2597	0.0191	13.62	0.1383	0.0053	26.27
Lnhours	0.3496	0.0604	5.79	1.2636	0.1147	11.02	0.5892	0.0688	8.57	0.8053	0.0607	13.27	0.4691	0.0462	10.15
Target	0.7167	0.0776	9.23	1.9712	0.1881	10.48	1.5305	0.0898	17.05	1.0942	0.0931	11.76	0.4932	0.0529	9.32
Bait	2.5227	0.0672	37.55	3.0404	0.1637	18.57	2.3549	0.0886	26.58	1.8719	0.0714	26.21	0.6588	0.0595	11.07
Party	0.1171	0.0309	3.79	0.2398	0.0546	4.39	0.1835	0.0335	5.48	0.2188	0.0306	7.16	0.1887	0.0251	7.51
Member	-0.9582	0.3697	-2.59	-0.5323	0.5857	-0.91	-0.9812	0.3421	-2.87	0.0095	0.2256	0.04	-0.6092	0.1801	-3.38
Age	0.0087	0.0029	2.96	-0.0032	0.0054	-0.6	0.005	0.0032	1.55	0.0105	0.0028	3.71	0.0146	0.0022	6.53
Retire	-0.5107	0.1102	-4.64	-0.328	0.1997	-1.64	-0.4143	0.1135	-3.65	-0.0344	0.0963	-0.36	0.1067	0.076	1.4
Education	-0.1694	0.066	-2.57	0.4101	0.1166	3.52	0.0625	0.0749	0.83	0.0742	0.0645	1.15	-0.0595	0.0513	-1.16
Estuary	-0.4244	0.0881	-4.82	-0.9345	0.1636	-5.71	0.7493	0.0813	9.22	-0.2487	0.0838	-2.97	-0.6228	0.0673	-9.25
Beach	0.0493	0.1037	0.48	-0.7558	0.2216	-3.41	-0.0674	0.1003	-0.67	-0.0888	0.0928	-0.96	0.2448	0.07	3.5
Manmade	0.5061	0.1335	3.79	-0.2987	0.2966	-1.01	-0.2902	0.1289	-2.25	-0.1689	0.1178	-1.43	0.4225	0.086	4.91
Boat	0.9083	0.0929	9.78	1.3665	0.1765	7.74	0.0976	0.0981	1	0.5718	0.0893	6.4	0.3058	0.0703	4.35
Kids	-0.339	0.1146	-2.96	-0.2007	0.1951	-1.03	-0.4624	0.1311	-3.53	-0.4194	0.112	-3.74	-0.2249	0.0862	-2.61
Females	0.0952	0.0754	1.26	0.0069	0.1399	0.05	0.0474	0.0871	0.54	-0.0909	0.0732	-1.24	-0.2613	0.0578	-4.52

Quarter 2	0.4489	0.0853	5.26	-0.1341	0.1601	-0.84	-0.1685	0.0952	-1.77	0.2687	0.082	3.28	0.0355	0.0633	0.56
Quarter 3	0.3138	0.0945	3.32	0.5605	0.1613	3.48	-0.2414	0.1068	-2.26	0.1925	0.0912	2.11	-0.3749	0.0734	-5.11
Quarter 4	0.0296	0.0939	0.32	-0.3328	0.172	-1.93	-0.0956	0.0896	-1.07	0.0591	0.0839	0.7	-0.1722	0.0643	-2.68

Table 2. Site choice model parameter estimates

	Model 1			Model 2		
	Coef.	S.E	t	Coef.	S.E	t
Distance	-0.0048	0.0001	-52.39	-0.0048	0.0001	-51.76
Prize fish	0.2062	0.0274	7.53	0.1616	0.0291	5.56
Reef fish	0.0020	0.0003	7.59	0.0017	0.0003	6.40
Key sports fish	0.2217	0.0146	15.20	0.2149	0.0147	14.60
Table fish	0.0616	0.0062	9.89	0.0663	0.0069	9.63
Butterfish	0.0096	0.0012	8.02	0.0099	0.0012	8.05
Log Likelihood		-17846			-17530	
Observations		6110			6110	

Table 3. Bag limits under various policies

	Policy Base	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
Prize Fish	No Limit	2	1	1	1	1
Reef Fish	No Limit	2	1	1	1	1
Key Sports Fish	No Limit	2	1	1	1	1
Table Fish	No Limit	No Limit	No Limit	4	2	2
Butterfish	No Limit	No Limit	No Limit	6	4	3

Table 4. Angler welfare losses associated with bag limits

	Household welfare losses per trip				
	Policy1	Policy2	Policy3	Policy4	Policy5
Minimum	0.00	0.00	0.00	0.00	0.00
1st Quarter	0.00	0.00	0.83	1.80	2.36
Median	0.01	0.02	5.66	8.03	8.76
Mean	18.50	23.77	30.57	32.76	33.25
3rd Quarter	2.80	15.31	26.67	31.03	31.53
Maximum	2605.00	2628.00	2645.00	2658.00	2659.00
	Household welfare lossless per year				
	Policy1	Policy2	Policy3	Policy4	Policy5
Minimum	0.00	0.00	0.00	0.00	0.00
1st Quarter	0.00	0.02	7.12	9.00	11.24
Median	2.45	16.79	43.20	53.6	56.20
Mean	118.20	151.90	195.37	209.40	212.50
3rd Quarter	80.24	126.00	179.08	198.50	202.00
Maximum	4370.00	4697.00	5319.64	5982.00	6017.00

Figures

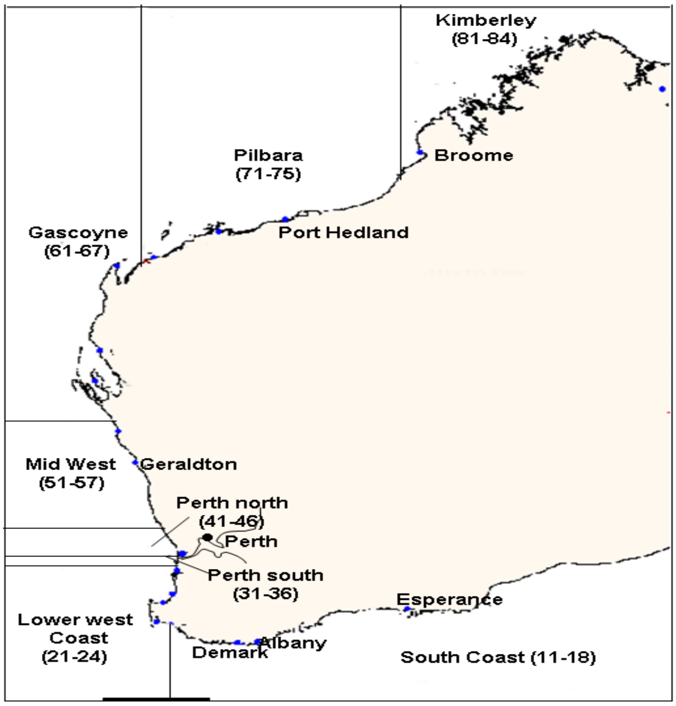

Figure 1. Major Fishing Regions of Western Australia (Raguragavan et al. 2013)

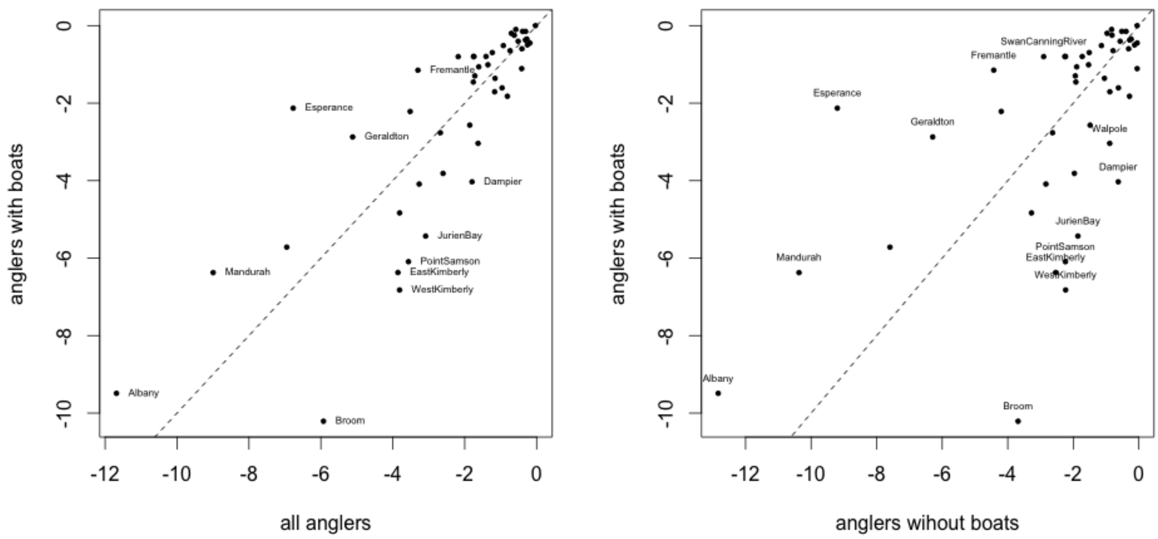

Figure 2. Comparing site closure welfare losses across angler groups ($/trip)