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Modelling fishing location choice and spatial behaviour of fishers near a marine protected area

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Fishing
location choice
and spatial
behaviour

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Abstract

Purpose – This study investigates whether higher catch rates near a marine protected area (MPA), and/or in other fishing areas within a choice set, attract more fishers. A survey conducted in the fishing grounds near an MPA located in south east of Mauritius in the Indian Ocean shows concentration of fishers in regions with lower catch rates. This contrasts with the predictions of the “fishing the line” hypothesis and the ideal free distribution (IFD) that fishers are likely to be attracted near the MPA with higher resource abundance.

Design/methodology/approach – Using the random utility model as the framework and the random parameter logit (RPL) model, the study attempts to explain spatial behaviour of fishers. Expected catch and catch variability are modelled using the Just and Pope (JP) production function. The study also estimates effort elasticities with respect to expected catch and catch variability and simulates the relocation of effort from area closure.

Findings – The paper concludes that higher catch does attract fishers but is a partial and very restrictive explanation of fishers’ behaviour. The “fishing the line” hypothesis does hold to some extent, but it should not be taken for granted that rising catch rates in adjacent waters will increase fishing pressure. The paper concludes that factors such as catch variability, distance from homeport to fishing ground, potential physical risk and attitudes towards risk of fishers affect spatial behaviour of fishers and should be considered for the placement and size of MPAs. The study also finds that the responsiveness of effort to catch rates is lowest in areas which are already heavily fished and easily accessible.

Practical implications – The identification of fishing areas as complements (when fishing in one area increases fishing effort in another) and substitutes is valuable information for determining the placement and size of an MPA. A larger reserve is likely to have more displacement effect in this case than a smaller one. Therefore, a small or a network of a small reserve may be appropriate. The premise to select the site and size of the reserve is to avoid overconcentration of fishers in alternative fishing areas, which can be vulnerable to excessive fishing and unintended effects from fishers.

Originality/value – The paper contributes to an understanding of fishing behaviour and its impact on the configuration of marine reserves. It discusses the importance of effort elasticities to determine the placement and size of an MPA. Studies on this topic are very scanty in the Indian Ocean region. It also shows the application of location choice model, the RPL model and the JP production function in the fisheries sector for a small island.

Keywords Marine protected areas, Fishers’ behaviour, Effort elasticities, Location choice, Random parameter logit model

Paper type Research paper

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TO BE ADDED LATER

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Introduction

There is widespread agreement that marine protected areas (MPAs) or marine reserves generate conservation benefits (Smith *et al.*, 2005; Lorenzen *et al.*, 2010; Norse *et al.*, 2010; Smith, 2010; Kamil *et al.*, 2017). However, there is an ongoing debate as to whether they improve long-term harvests for fisheries (Smith *et al.*, 2006; Pérez-Ruzafa *et al.*, 2017; Lloret *et al.*, 2018). In the years that follow its creation, it is expected that an MPA will increase the abundance of fish, and that this increase will lead to spillovers in the forms of adult and juvenile migration and the export of larvae to adjacent areas. These are important benefits to fisheries and are used to assess the effectiveness of marine reserves over a defined period of time (Chapman and Kramer, 1999; Gell and Roberts, 2003; Forcada *et al.*, 2009; Norse, 2010; Bellier *et al.*, 2013; Kamil *et al.*, 2017; Lloret *et al.*, 2018).

One of the key arguments against the use of MPAs as a fisheries management tool is that the spillovers simply draw fishing effort to the reserve boundaries (Hopf *et al.*, 2016; Pérez-Ruzafa *et al.*, 2017; Lloret *et al.*, 2018). Such behaviour may impact negatively on marine ecosystems by inducing localised overfishing and altering the habitat in over-concentrated fishing grounds (Hopf *et al.*, 2016). This effort redistribution has been referred to as “fishing the line” (Kellner *et al.*, 2007; van der Lee *et al.*, 2013). The “fishing the line” hypothesis inevitably throws doubt on the effectiveness of marine reserves as remedies to fisheries degradation, since it suggests that fishing pressure is likely to increase in areas near reserves, and the fisheries may fall back to the same condition they were in before the reserve was created (Smith, 2004, 2005; Smith and Wilen, 2003; Daw, 2008; Hopf *et al.*, 2016).

This concern is particularly relevant in the island of Mauritius, which has established MPAs around its coasts since 1983 to protect the habitat for fish species, the diverse marine fauna and flora and the nursing grounds for juvenile marine species (UNDP 2012). The process of establishing new protected areas and expanding existing ones is ongoing, especially as an option for marine spatial planning (Kelleher, 2017; Smith, 2000). However, an aspect currently overlooked is that MPAs also modify the behaviour and effort of artisanal fishermen.

Do fishermen respond to rising catch rates at the border of a marine reserve? This “fishing the line” behaviour is often simply assumed (Cabral *et al.*, 2017). Even if the economic theory predicts that potential rents are squandered in an open access fishery and that fishers will earn normal profits only, fishers’ choice of fishing grounds is far more complex than suggested by the simple assumption that rising catch will attract more fishers. When the aim is to assess the distributional impacts of MPA benefits to a specific study site, a before-after-control-impact (BACI) experiment would be most appropriate, comparing variables such as fish density, biomass, size of organisms, species diversity and more importantly fishing effort (for e.g. Halpern, 2003). In many cases, these data are not available and such before-and-after analyses cannot be made. However, a scientific and systematic analysis of fishing effort in the vicinity of the MPA and the factors influencing it can provide insights into whether efforts have been distributed to benefit spillovers.

To shed light on the above question, this study examines the determinants of fishers’ location choices in the adjacent waters of the Blue Bay Marine Park (BBMP) in the south-east coast of Mauritius and tests the hypothesis that whether rising catch rates will attract fishers at the border of the BBMP. It also examines other determinants of fishers’ location choices, building on work done elsewhere by Bockstael and Opaluch (1983), Eales and Wilen (1986), Campbell and Hand (1999), Bingham *et al.* (2011), Andersen *et al.* (2012), Van Putten *et al.* (2012), Girardin *et al.* (2016), Dabrowska *et al.* (2017) and Watson *et al.* (2018). Once the socioeconomics and trip-related determinants have been established, the study conducts a simulation exercise. This is to calculate the responsiveness of fishing effort with respect to changes in the factors identified as drivers of fishing location choice. The simulation also

separates the waters surrounding the MPA into those that are complements to it and those fishing areas that are its substitutes and eventually calculates the marginal rates of substitution. This process establishes the opportunity cost of the reserve's creation. Finally, a simulation exercise is undertaken to estimate the expected change in fishing effort should the area of the MPA be increased. Effort displacement is also simulated for the closure of other fishing areas to showcase the issue of spatial connectivity across fishing areas.

A brief review of the fishing literature on spatial choice

Expectations that fishing effort will be relocated is important for the design and site selection of a marine reserve (Smith 2004; Smith and Wilen 2003; Smith, 2010). If the aim of the MPA is to protect a breeding site, a rare species, or a recreational site for divers and if the area protected is fairly small, then it may fail in its objectives if fishers target its boundaries. On the other hand, if the reserved area is large relative to the fishable area, a reserve can reduce fishing opportunities, forcing people with limited alternative occupations to abandon fishing altogether.

The details of fisher effort relocation can therefore be crucial since it affects the broader costs and benefits of a reserve: in particular, its impacts on expected catch, catch variance, targeted species and fishing costs. Valcic (2009) makes the point that one may design the appropriate regulations and incentive structures to minimise the impacts of such effort displacement. The starting point is to determine the factors, trip-related and other, influencing fishing location choice.

From both a theoretical and an empirical perspective, fishing is non-random (Gillis *et al.*, 1992). The economic theory goes beyond a simple analysis of effort distribution and adopts a perspective which is consistent with the “ideal free distribution” (IFD) of behavioural ecology (Gillis *et al.*, 1992; Abernethy *et al.*, 2007; Gillis and van der Lee, 2012).

The IFD predicts that, assuming free movement and perfect knowledge, fishing pressure should increase with resource abundance. Ultimately, efforts will be adjusted among fishing areas so as to equalise catch per unit of effort (CPUE) across all areas. In reality, CPUE frequently varies across neighbouring fishing grounds. When there are differential catch rates, factors other than expected catch or revenue may be affecting the fishers' choice of fishing ground (Holland, 2000).

H. S. Gordon's (1954) pioneering paper showed how economic theory has been used to inform fisheries management. It was followed by a number of studies evaluating fishers' behaviours in terms of the economic theory (for example, Wilen, 1976; Eales and Wilen, 1986; Curtis and McConnell, 2004). The economic framework, typically using micro-level analysis of fishers' behaviours and discrete choice models, provided both the theoretical underpinnings and quantitative techniques for a systematic analysis of spatial behaviour in fisheries. Fishers are assumed to choose between finite discrete alternatives, each having a set of possible outputs or closely substitutable inputs. In this respect, there are several key factors which determine site selection.

There have been numerous examples: Wilen (1976) in a study of aggregate behavioural responses concludes that fishers respond to profitability in their long-term decision to enter or exit a fishery. Similarly, Bockstael and Opaluch (1983), in a study of location and species choice of New England fishers, used a utility-based framework to model the micro-level behaviour of fishers and also found that fishers react positively to expected profits. Eales and Wilen (1986) found that expected catch explained the choice of fishing site in the Alaskan Pink Shrimp Fishery, while Campbell and Hand (1999) made a similar observation in the western Pacific tuna fishery.

Bockstael and Opaluch (1983) broadened these insights into fisher behaviour by adding risk as an explanatory variable. Their analysis noted that fishing location choices were negatively affected by risk, modelled by the variance of output. Dupont (1993) expanded this

approach further in the British Columbia salmon fishery. After generating expected profit through price forecasts derived from an autoregressive integrated moving average (ARIMA) model, she found that not only expected seasonal profit and its variability but also expected wealth and its variability were determinants of fishing location choice. [Mistiaen and Strand \(2000\)](#) considered price as a deterministic variable and harvest as a stochastic variable to construct expected profit: using a multinomial logit as well as a random parameter logit (RPL) model for fishers in the North Atlantic fishery, they also found that expected profit and its variability affect locational decisions by fishers.

Since profit is not driven by revenue alone, the economic approach also treats fishing cost as an important driver of fisher behaviour ([Girardin *et al.*, 2017](#), [Watson *et al.*, 2018](#)). Fishing cost in turn is strongly linked to distance from homeport to fishing location. Distance travelled to a site is found to negatively influence the likelihood of its selection by [Campbell and Hand \(1999\)](#), [Mistiaen and Strand \(2000\)](#), [Berman \(2006\)](#), [Bingham *et al.* \(2011\)](#) and [Andersen *et al.* \(2012\)](#). [Campbell and Hand \(1999\)](#) further noted an elastic response to expected value of catch and an inelastic response in respect to travel cost.

In an uncertain environment, if a particular location is high yielding but has higher than average catch variability, the extent to which it is used will, to a large extent, depend on whether fishers are risk-averse or risk-loving ([Mistiaen and Strand, 2000](#); [Eggert and Tveteras, 2004](#); [Eggert and Lokina, 2007](#); [Girardin *et al.*, 2017](#)). According to [Smith and Wilen \(2005\)](#), commercial fishermen are inherently risk-loving; however, this generalisation is clearly an oversimplification. [Salas and Gaertner \(2004\)](#) pointed out that some fishers are willing to sacrifice high catches to minimise personal and economic risk, and a number of empirical studies have concluded that fishers are risk-averse ([Dupont, 1993](#); [Mistiaen and Strand, 2000](#); [Eggert and Lokina, 2007](#)). Discrete choice models, usually modelled by a parametrisation of mean and standard deviation of revenue [1], are one way to infer the degree of risk aversion among fishers. However, this can also be obtained via separate experiments that provide information on risk preferences ([Eggert and Martinsson, 2004](#); [Eggert and Lokina, 2007](#); [Brick *et al.*, 2012](#)).

While expected catch rates, risk-related factors, fishing costs and risk attitudes remain as the main determinants of fishing location choices, there are also other factors which have been identified. These are fishers' individual characteristics ([Holland and Sutinen 2000](#); [Eggert and Tveteras 2004](#), [Van Putten *et al.*, 2012](#)), fishing equipment and tactical decisions ([Eales and Wilen 1986](#); [Salas and Gaertner, 2004](#); [Christensen and Raakjaer, 2006](#)) and site characteristics, including the biophysical ocean and weather conditions ([Bingham *et al.*, 2011](#), [Van Putten *et al.*, 2012](#)) and social factors such as rules, institutions, local traditions, culture and habits ([Dow, 2008](#); [van Putten *et al.*, 2012](#)).

Conceptual framework, estimation method and data

The conceptual framework of this paper is based on the random utility model with a sub-model of expected catch following work of [Eales and Wilen \(1986\)](#), [Campbell and Hand \(1999\)](#) and [Eggert and Tveteras \(2004\)](#). The location choice estimation method is the RPL model, also known as the mixed logit model ([Train 2009](#)) [2]. As an innovative method, the RPL model is a modified conditional logit model, which relaxes the independence of irrelevant alternatives (IIA) property. The IIA property assumes that the random error component is independent across choices for each decision-maker, and that the change in, or the introduction of, or the elimination of an existing attribute of an alternative would cause proportional changes in the probabilities of the other alternatives, i.e. the ratios of the probabilities would remain unchanged ([McFadden, 1974](#)). In this respect, the RPL model accommodates fishers' heterogeneity and is more appropriate for modelling fishing choices ([Wilen *et al.*, 2002](#); [Hutton *et al.*, 2004](#); [Abott and Wilen 2011](#); [Tidd *et al.*, 2012](#)). The RPL model's overall explanatory power is given by the likelihood ratio statistic ([Pradhan and Leung, 2004](#)).

Random utility and location choice model

The random utility model follows the work of [Bockstael and Opaluch \(1983\)](#), [Smith \(2004\)](#), [Eggert and Tveteras \(2004\)](#) and [Jiménez-Alvarado \(2019\)](#), among others. When a fisher i makes a choice to fish in a location j from a finite set of J mutually exclusive fishing alternatives [$J = 1, \dots, n$], his maximum utility (U_{ij}) has both observed (V_{ij}) and unobserved (ε_{ij}) component. In additive linear form, the utility function is written as follows ([McFadden, 1974](#)):

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (1)$$

The term ε_{ij} , through extreme value distribution, has a zero mean and is uncorrelated across choices, allowing for the IIA property in the choice model. This means that outcome categories are distinct in the eyes of each fisher.

When faced with alternatives l and j , the fisher chooses alternative j if $U_{ij} > U_{il}$ for $l \neq j$. Since the unobserved component for the two alternatives ε_{ij} and ε_{il} are random variables, the difference between them is also random. The standard model predicts that the probability that the fisher will choose alternative j is

$$P(Y_i = 1 | X_{ij}, W_i) = \frac{e^{V_{ij}}}{\sum_{j=1}^J e^{V_{ij}}} \quad (2)$$

where X_{ij} are attributes, which vary across choices, and W_i are the characteristics of the individual whose values are invariant to the choice a fisher makes.

V_{ij} can be further specified as follows:

$$V_{ij} = \theta Z(X_{ij}, W_i) = X_{ij}\beta + W_i\gamma \quad (3)$$

where θ , β and γ are the vectors of coefficients providing information on the marginal utilities with respect to their relevant characteristics.

Assume the indirect utility is a linear function of the mean and variance of profits such that,

$$V_{ij} = (E[\text{WEA}_i + \text{REV}_{ij} - \text{COS}_{ij}], \text{var}[\text{WEA}_i + \text{REV}_{ij} - \text{COS}_{ij}]) \quad (4)$$

where WEA_i is initial wealth, REV_{ij} is revenue of fisher i to fishing location j and COS_{ij} is the cost incurred during the trip.

By using a composite price for fish species caught during the trip, [Eqn 4](#) can be converted to a model in which utility is effectively driven by the catch rather than by short-term variations in the prices fetched by individual species. Revenue is defined as follows:

$$\text{REV}_{ij} = P \times \text{CAT}_{ij} \quad (5)$$

where P is a composite price index in a multi-fish species environment and assumed to be constant for the period. An important caveat of the composite price index is as follows: some species may be more targeted than others and probably sell at better prices; in this respect, fishers may decide on their locations based on the abundance of a single desirable species rather than on all fish in general, as the use of a composite price index would suggest.

However, the use of catch data is justified on several grounds. First, the aim of the study is to connect fishers' behaviour with the change in catch rates as a result of spillovers from the marine reserve. Using expected catch is consistent with the fact that spillovers are often evaluated in terms of CPUE as a measure of abundance or catch arising from adult and juvenile migration ([Chapman and Kramer, 1999](#); [Forcada *et al.*, 2009](#); [Bellier *et al.*, 2013](#)). In many fishing communities, where the most visible measure of output is the catch, there is also a perception that many fishers are not profit maximisers but prefer catch weight maximisation ([Herrero and Pascoe, 2003](#)). [Abbott and Wilen \(2011\)](#) further argue that

simply lumping species together into a single revenue index is not realistic when fishers' behaviour has much to do with catching different species. Price effects can obscure changes in the catch rate following changes in conditions in the fishing grounds. Price variability is also a factor in the decision, but according to [Eggert and Tveteras \(2004\)](#), it is a less important source of risk, as changes occur over a longer time and fishers usually have information on prevailing market prices. For these reasons, prices are non-stochastic and exogenous. Expected catch is therefore the main motivation to fishers at a particular site.

The cost function is based on the cost per trip which is a function of the travel distance from their homeport to the point at which the traps are laid (DIS_{ij}) and a unit cost of travelling c , again assumed to be constant:

$$COS_{ij} = c \times DIS_{ij} \quad (6)$$

A fisher's location decision is based on the catch expectation, $E(CAT_{ij})$, and not on the catch actually achieved. Fishers would form expectations about the types of fish species, number of individual fish and weight of the fish that would be caught and variance of catch, $var(CAT_{ij})$. Utility is positively related to expected catch measured in weight, consistent to the fishing the line hypothesis, such that $\frac{\partial U}{\partial E(CAT)} > 0$ and is negatively affected by travel distance from the homeport $\frac{\partial U}{\partial DIS} < 0$.

If fishers are risk-neutral, then only the mean matters; if they are risk-averse, they will make a trade-off between expected catch and variance of catch $\frac{\partial U}{\partial var(CAT)} < 0$; finally, if they are risk-loving fishers, utility rises with variance of the catch and $\frac{\partial U}{\partial var(CAT)} > 0$ ([Eggert and Martinsson 2004](#)).

In linear form, [Eqn 4](#) reduces to

$$V_{ij} = \alpha_0 WEA_i + \alpha_1 E(CAT_{ij}) + \alpha_2 DIS_{ij} + \alpha_3 var(CAT_{ij}) \quad (7)$$

[Eqn 7](#) can be used to estimate the sensitivity of site choice, i.e. α_0 , α_1 , α_2 and α_3 , with respect to initial wealth, expected catch, travel distance and variability of catch, respectively. Eventually, they can be further used to provide insights into the effect of risk preferences of fishers on fishing location choices.

Operationalising the model: the Just and Pope production function

One of the main problems faced by location choice models is how to replicate the process of catch expectations formation. It is assumed that fishers' implicitly model expected catch on the basis of past catch rates when they are choosing between different fishing grounds. This study follows [Eggert and Tveteras \(2004\)](#) and models expected catch and variance using the JP production function ([Just and Pope, 1979](#)) to estimate the sub-model for expected catch rate and its variability.

Consider the following relationship between the input and output:

$$y = g(x) + u = g(x) + h(x)^{1/2} \varepsilon \quad (8)$$

where x is a vector of K inputs, $g(x)$ is the mean function (or deterministic portion of the production function), $h(x)$ is the variance function or risk portion and ε is an exogenous shock with $E(\varepsilon) = 0$ and $Var(\varepsilon) = \sigma_\varepsilon^2$. The vector of inputs, x , influences both mean catch and output risk because $var(y) = var(u) = h(x)\sigma_\varepsilon^2$. A key requirement of the JP method is that there should be no *a priori* restrictions on the effects of inputs on output risks. In other words, the production function should be general enough to accommodate both increasing and decreasing risks.

Each fisher has to choose only one fishing location per trip among eight alternatives. For the chosen ground, the choice-specific attributes take the expected values of the fisher, as measured by [Eqn 9](#). The mean function is estimated using ordinary least squares as follows:

$$\begin{aligned} \text{CAT}_{ijt} = & a_0 + a_1 \text{HRS}_{ijt} + a_2 (\text{HRS}_{ijt})^2 + a_3 \text{NBAS}_{ijt} + a_4 (\text{NBAS}_{ijt})^2 + \sum_{m=2,10} a_m \text{DUM}_m \\ & + \sum_{i=2,100} a_i \text{DUM}_i + u_{ijt} \end{aligned} \quad (9)$$

CAT_{ijt} is the catch, HRS_{ijt} is hours fished and NBAS_{ijt} is the number of traps for fisher i at time t in the fishing ground j . DUM_m is a dummy variable representing the month the trip was made, and DUM_i is a dummy variable for each fisher.

The parameters of the variance function are estimated using the predicted residuals from Eqn 9:

$$\text{var}(u_{ijt}) = \exp \left(b_1 \text{HRS}_{ijt} + b_2 (\text{HRS}_{ijt})^2 + b_3 \text{NBAS}_{ijt} + b_4 (\text{NBAS}_{ijt})^2 + \sum_{m=2,10} b_m \text{DUM}_m + \sum_{i=2,100} b_i \text{DUM}_i \right) \quad (10)$$

In the first stage of the estimation, Eqns 9 and 10 are used to calculate the predicted values of catch (ECAT_{ijt}) and standard deviation of catch (SDCAT_{ijt}). These values are then averaged in each of eight fishing areas (Figure 1) to approximate expectations of catch (ECAT_j) and standard deviation of catch (SDCAT_j). This technique implies that the calculated expectations are also assigned to fishers for the non-chosen alternatives, assuming that these alternatives are also available to the fishers (Pradhan and Leung, 2004). Pradhan and Leung (2004) use the mean of expected values of similar size and trip type.

The third area-specific attribute is the depth, measured at the fishing site in metres (DEPTH_j). The data were collected from Google Maps platform.

A fourth area-specific attribute is the distance travelled from homeport to the fishing locations (DIS_j) (Campbell and Hand, 1999).

Data

Study site. The Republic of Mauritius is a set of islands located in the southwest Indian Ocean, with a total land area of 2040 km². The main island of Mauritius has an area of 1865 km² and a

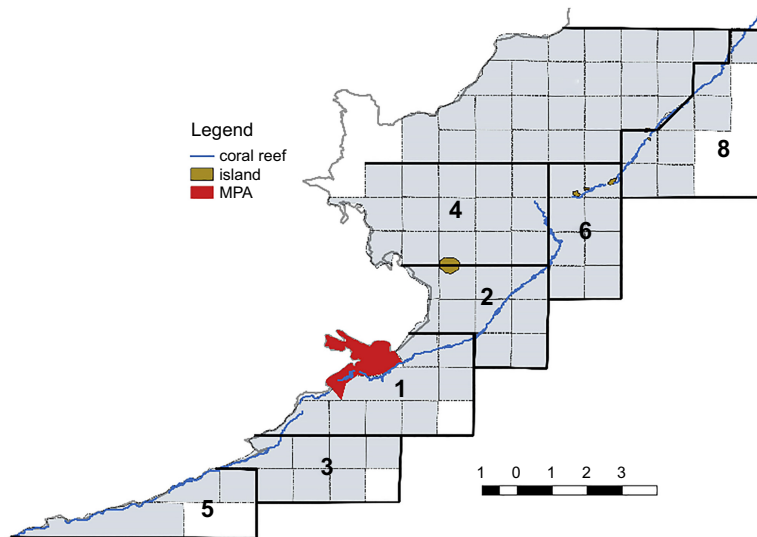


Figure 1.
Fishing location grids
near the MPA

lagoon area of about 243 km² (Bhagooli and Kaullysing 2018). The study area comprises of a multispecies-fishing ground of roughly 90 km² of waters off the south-east coast of island of Mauritius. The site is the biggest lagoon area of the island and is home to 40% of the island's artisanal fishers.

The area also hosts the Blue Bay Marine Park (see Figure 2), located on the south-east coast of Mauritius, and was declared an MPA and designated a Marine Park in June 2000 under the Fisheries and Marine Resources Act 1998 (Convention on Biological Diversity [CBD], 2016). The total area of the Marine Park currently has an area of 353 hectares (3.53 km²). The water depth in the park varies from 1 to 150 metres (Albion Fisheries Research Centre [AFRC], 2008). The main fish species, which are observed from the fishing grounds, include *siganus sutor*, *naso unicornis*, *scarrus ghobun* and *lethrinus nebulous*. Other fish species can also be found such as *E. pinephelus fasciatus kyphosus*, *lethrinus mahsena*, *Parupeneus sp.*, *Acanthurus sp.*, *Caranx sp.* and *Hypseleotris cyprinoides* (AFRC 2008). There is no study specifically on spillover from the Marine Park. However, biodiversity inventories show some improvements (Conand et al., 2016). The oceanographic survey conducted in 2010 revealed that the marine biodiversity is higher in the deeper areas of the Blue Bay Marine Park than in the shallow ones (Republic of Mauritius 2010). However, the report also noted that many corals are heavily damaged or eventually dead. Enforcement of the Park falls under the purview of the Blue Bay Marine Park Centre, and there are no enforcement issues highlighted in those inventories reports. A traffic lane provides entry into or passage through the park by motorised boat with a speed not exceeding three knots. Buoys with red and white vertical stripes demarcate the traffic lane. Use of non-motorised boats, fishing, snorkelling, swimming and diving are not allowed in the traffic lane. A ski lane is designated for water skiing, and no other activity is permissible.

Collection of data. To collect and construct the covariates, a questionnaire was prepared and was administered to a sample group of fishers. There are approximately 350 trap fishers in the region of the study, from which 100 fishers, registered with the fishing authority in Mauritius, were randomly selected. For each fisher, data were collected for ten trips per year (averaging one trip per five weeks). For each trip, the interviewer recorded the catch as soon as the fisher reached the fish landing stations. The questionnaire recorded (among other data) the following: (1) total catch in kg; (2) fish species caught with their weights in kg; (3) number of traps; (4) length and width of the trap; (5) number of hours spent fishing and (6) number of fishers on the boat.

The fishers were also asked to indicate the locations of their traps. To this end, they were provided with the map, as shown in Figure 1, on which the space was divided into 1 × 1 km grid blocks, numbered from 1 to 82. The interviewer recorded the number and the position on the map. Data collected also included the characteristics of fishers and of their fishing technology, including trap size and the number of traps used.

One important consideration is that the spatial aggregation leads to a set of geographical areas, which would be one of the objects of choice in the fishers' decision-making process. When the individual areas become smaller, the number of choices increases. According to the Curtis and McConnell (2004), this corresponds to the short-run decision of fishers. As spatial areas are aggregated into larger blocks, so the choice eventually shifts from being a short-run decision to being a medium to long-term fishing location choice. The smaller the spatial aggregation and therefore the area, the less aggregation bias and the greater the ability to model realistic policy measures. However, the smaller the site, the less likely is that the spatial data will provide much information about the site (Curtis and McConnell 2004). Following Bockstael and Opaluch (1983), Eales and Wilen (1986), Dupont (1993) and Campbell and Hand (1999), the aggregation was done so as to ensure continuity of fishing effort in each fishing area; hence, eight areas were selected for the study. The characteristics of these areas are provided in Table 1.

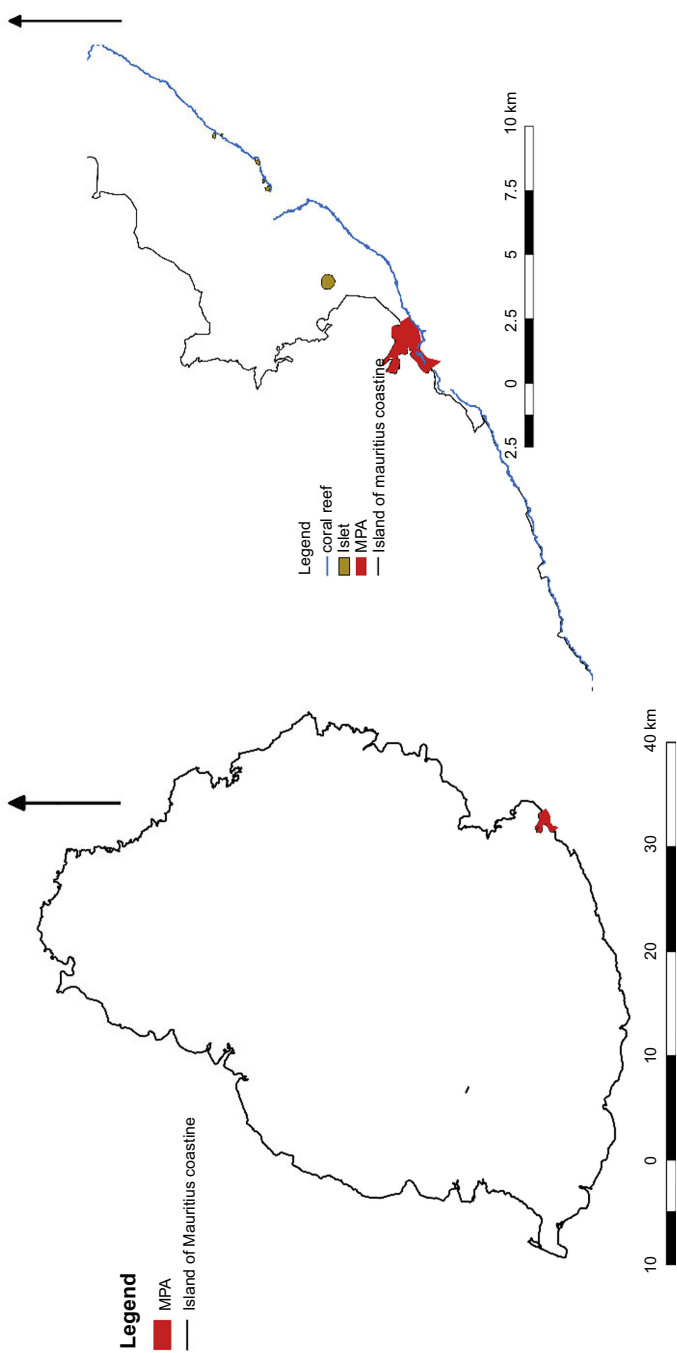


Figure 2.
Map of Mauritius and
study site

Table 1.
Variables and
definitions

Variables	Definition	Mean	Standard deviation	Minimum	Maximum
ECAT _{<i>i</i>}	Expected catch of the fisher <i>i</i> in the fishing ground <i>j</i> (kg)	13.77	3.54	0	31.60
DIS _{<i>ij</i>}	Distance from the homeport of fisher <i>i</i> to the fishing ground <i>j</i> (km)	8.38	3.37	1	18
DEPTH _{<i>j</i>}	Average depth in metres of the fishing ground <i>j</i>	16.17	7.80	5.30	26.6
SDCAT _{<i>ij</i>}	Standard deviation of the catch facing fisher <i>i</i> in the fishing ground <i>j</i> (kg)	2.19	0.47	0.36	6.10
NBAS _{<i>ij</i>}	Number of traps of the fisher <i>i</i> used in the fishing ground <i>j</i>	8.19	1.70	1	13
VBAS _{<i>ij</i>}	Size of traps of the fisher <i>i</i> used in the fishing ground <i>j</i> (m ³)	21.88	28.57	1.5	216

During the survey, interviewers also carefully collected information using a map on the route that was taken by fishers during their trips. An important consideration is that fishers sometimes follow different routes to the same location. Care was thus taken to measure the distance along the route, which each fisher actually took to the destination. When a fisher did not stipulate a particular route for the non-chosen alternatives, the path used by another fisher from a nearby port was taken as a proxy.

Data on initial wealth were initially proxied by the size of the boat. However, during the estimation, the number and size of traps were strongly correlated with the size of the boat. The latter was then dropped the analysis.

Results

Random parameters logit estimation

Table 2 shows key information of the trips by fishing areas collected from the sample (refer to Figure 1 for the geographical location). Almost 85% of homeports of the fishers

Table 2.
Distribution of trips
and average catch per
trip from survey

Fishing areas	Distribution of trips (%)	Average catch per trip	Standard deviation of catch rates (kg)	Other characteristics
Area 1	3.7	13.7	8.55	Adjacent to the MPA and off lagoon and high human risk
Area 2	6.1	11.97	7.9	Situated partly in the lagoon and partly off it and high human risk in waters off the lagoon
Area 3	2.5	17.88	9.08	High travelling cost and high human risk
Area 4	27.3	8.2	3	Low travelling cost and low human risk
Area 5	7.9	15.62	11.75	High travelling cost and high human risk
Area 6	26.8	12.81	5.02	Off lagoon but very productive reef area
Area 7	13.8	10.88	3.6	Low travelling cost and low human risk
Area 8	11.9	19.82	6.11	Off lagoon and high travel cost

are located in the north of the MPA. The remaining homeports are located in the south around 4 km on average.

The estimates from the RPL model in Tables 3 and 4 seek to explain the distribution of trips in the eight fishing areas. To facilitate interpretation, Table 1 provides summary characteristics of the covariates.

Fishing
location choice
and spatial
behaviour

11

Variables	Coefficient (SE) Model 1	Coefficient (SE) Model 2
ECAT _j	0.038(0.020)***	0.202(0.024)***
DIS _j	−0.167(0.0239)***	−0.175(0.028)***
DEPTH _j		−0.144(0.011)***
<i>Random parameter</i>		
SDCAT _j	−2.702(0.757)***	−2.953(0.826)***
SD of SDCAT _j	7.926(0.899)***	9.512(1.137)***
Number of observations	8,000	8,000
LR χ^2 (1)	1828.00	1903.61
Prob > χ^2	0.00	0.000
Log likelihood	−1015.63	−919.95
Note(s): SE = standard error; *** = significant at 1%, ** = significant at 5% and * = significant at 10%		

Table 3.
Random parameters
logit model 1 and 2

Variables	Coefficient (SE) Model 3	Coefficient (SE) Model 4
ECAT _j	0.189 (0.0269)***	0.236 (0.030)***
DIS _{ij}	−0.327 (0.038)***	
DEPTH _j	−0.067 (0.066)***	−0.178 (0.049)***
NBAS _{ij} × DUM ₂	−0.067 (0.0657)	−0.115 (0.074)
NBAS _{ij} × DUM ₃	−0.091 (0.069)	−0.166 (0.074)**
NBAS _{ij} × DUM ₄	−0.251 (0.059)***	−0.334 (0.070)***
NBAS _{ij} × DUM ₅	0.1017 (0.107)	0.039 (0.119)
NBAS _{ij} × DUM ₆	0.076 (0.052)	−0.024 (0.059)
NBAS _{ij} × DUM ₇	0.131 (0.080)*	0.070 (0.0876)
NBAS _{ij} × DUM ₈	0.065 (0.108)	−0.019 (0.119)
VBAS _{ji} × DUM ₂	−0.031 (0.012)***	−0.021 (0.0139)
VBAS _{ji} × DUM ₃	−0.025 (0.001)***	−0.011 (0.0102)
VBAS _{ji} × DUM ₄	0.0015 (0.009)	0.007 (0.00954)
VBAS _{ji} × DUM ₅	−0.0886 (0.013)***	−0.070 (0.0126)***
VBAS _{ji} × DUM ₆	−0.0080 (0.007)	−0.003 (0.0076)
VBAS _{ji} × DUM ₇	−0.0390 (0.007)***	−0.029 (0.0073)***
VBAS _{ji} × DUM ₈	−0.094 (0.017)***	−0.093 (0.0202)***
<i>Random parameter</i>		
SDCAT _j	−3.140 (0.952)***	−3.143 (0.8323)***
DIS _j		−0.4128 (0.0633)***
SD of SDCAT _j	9.200 (1.12)***	10.288 (0.9848)
SD of DIS _j		0.556 (0.0722)
Number of observations	8,000	8,000
LR χ^2 (1)	1602.15	1720.78
Prob > χ^2	0.00	0.000
Log likelihood	−773.529	−714.21

Table 4.
Random parameters
logit model 3 and 4

Model 1 in Table 3 introduces the calculated expected catch and distance as covariates. The standard deviation of catch is treated as the random variable. Importantly, the expected catch in an area is positively related to the likelihood that it is fished while the negative sign of the coefficient of the distance variable shows that the probability of choosing an area falls with distance from a fisher’s homeport. This is consistent with studies such as Curtiss and Hicks (2000), Mistiaen and Strand (2000) and Eggert and Tveteras (2004). The random parameter ($SDCAT_j$) has a negative coefficient and is statistically significant ($p < 0.01$). The negative coefficient is an indicator that fishers are typically risk-averse, i.e. the likelihood that an area will be fished falls with the variability of catches in it. The standard deviation of the variability of catch is also statistically significant supporting the hypothesis that the sensitivity of the catch variability varies among fishers. The most commonly used goodness of fit measure is the likelihood ratio test, with the null hypothesis that all parameters are equal to zero; the results show that this can be rejected at 99% confidence.

Model 2 in Table 3 adds the covariate $DEPTH_j$. The coefficient is negative and is again statistically significant ($p < 0.001$). Deeper waters outside the reef that bounds the lagoon are regarded as riskier by artisanal fishers in small boats, consistent with Smith and Wilen (2005), Stelzenmüller *et al.* (2008) and Watson *et al.* (2018). The biophysical features of the ocean influence fishers’ behaviour.

If fish density is given, two important determinants of the catch per trip are the number and size of the traps used. Accordingly, fishers’ location choice is also influenced by these two factors. Table 4 shows the regression results after including the number of traps and the volumes of traps as attributes of individual fishers. The construction of individual-specific attributes follows Hoffman and Duncan (1988). Consider an attribute, W_i , of fisher, i , which is invariant across choices. Let DUM_2, \dots, DUM_8 are the dummy variables for area 2–8, respectively. The attribute enters in the RPL model as follows: $W_2DUM_2, \dots, W_8DUM_8$, respectively, for the eight fishing areas. Area 1 is the base category. The coefficients give the effect of each attribute in each area relative to the omitted category.

Table 4 shows the results. The coefficient of “expected catch” remains positive and statistically significant in all models, i.e. a rise in expected catch increases the likelihood that a site will be fished. Model 4 treats distance as the random variable. From the lower part of the table, the coefficients of $SDCAT_j$ and DIS_{ij} are highly statistically significant with the expected signs. The standard deviation of the two variables is also statistically significant, justifying their treatment as random variables in the regression.

To gauge the model’s predictive ability, the estimated percentage of fishing effort in each fishing area is compared to the actual percentage shares (Table 5). The RPL estimates in Table 4 (model 4) are used for estimating the expected effort distribution. The shares differ by less than 0.03 points in 7 of the 8 fishing areas.

Table 5.
Effort distribution
actual versus
simulated

	Actual distribution of trip	Simulated distribution of trip
Area 1	0.04	0.04
Area 2	0.06	0.04
Area 3	0.03	0.05
Area 4	0.27	0.30
Area 5	0.08	0.05
Area 6	0.27	0.21
Area 7	0.14	0.17
Area 8	0.12	0.15

Elasticities of changes in expected catch and variability

Table 6 shows the sensitivity of decisions regarding location to a 1% increase in expected catch in each fishing area. The italic figure in the table shows the elasticity of own effort to rising catch rate expectation; thus, a 1% increase in the expected catch rate in fishing areas 1, 2 and 3 (the adjacent to the MPA) leads to increases of 1.8, 1.4 and 1.9%, respectively, in the probabilities of fishers moving to these areas.

Effort in the remaining fishing areas also respond positively to rises in their own expected catch rate but the calculated elasticities are lower than those in the adjacent of the MPA. These effort elasticities warrant further explanation.

Areas 1, 2 and 3, being adjacent to the MPA, are also close to the shore, and only 10% of fishing effort is directed to them. Those who fish in these regions travelled at a distance of 5–6 km (Table 7). Why then, does the model suggest that fishing patterns are so responsive to yields in these areas? A plausible explanation can be obtained by referring to the remaining fishers who fish in the northern part of fishing ground. Most of these fishers have their homeports situated in the north of the fishing ground (refer to Figure 1) and have to travel long distances to reach areas 1, 2 and 3. Since the travel cost has to be incurred before any catch is made, it is only when fishers are sure that they can cover the travel cost then they will decide to go to a particular site. Hence, a site may be highly preferred as soon as there is a slight increase in expected catch rate, which allows fishers to cover the travel cost. The estimates also suggest that effort at a site, which is easily accessible (for example area 4), will be less responsive to a change in the expected catch rate than the effort expended on a site where access entails high travelling costs.

The survey found that fishing area 4 attracted almost 27% of fishing effort. It has relatively lower travel cost compared to all areas with the exception of area 1 (see Table 7) because many fishers have their homeport to the north of the MPA and access is easy. It is observed that fishing effort is less sensitive to changes in the expected catch. This may be

Table 6.
Elasticities of
probability of location
choices with respect to
expected catch

1% rise in expected catch in	% of change in probability that area will be selected							
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8
Area 1	<i>1.79</i>	-0.17	-0.12	-0.06	-0.11	-0.08	-0.05	-0.02
Area 2	-0.18	<i>1.35</i>	-0.11	-0.06	-0.05	-0.09	-0.04	-0.06
Area 3	-0.18	-0.14	1.89	-0.01	-0.11	-0.06	-0.01	-0.24
Area 4	-0.34	-0.30	-0.05	<i>0.54</i>	-0.14	-0.31	-0.44	-0.07
Area 5	-0.17	-0.09	-0.15	-0.05	<i>1.34</i>	-0.13	-0.07	-0.12
Area 6	-0.34	-0.37	-0.18	-0.26	-0.30	<i>1.22</i>	-0.31	-0.23
Area 7	-0.17	-0.11	-0.03	-0.28	-0.14	-0.24	<i>1.11</i>	-0.08
Area 8	-0.13	-0.31	-0.94	-0.07	-0.34	-0.28	-0.13	<i>1.06</i>

Table 7.
Average distance
travelled to fishing
grounds

	Average distance travelled (km)	Standard deviation	Minimum	Maximum
Area 1	4.81	2.88	1	12.5
Area 2	6.44	2.57	3	14
Area 3	6.52	2.71	1	10.7
Area 4	5.05	1.26	2	10.5
Area 5	7.96	3.69	2.1	17.8
Area 6	7.37	1.81	1	12
Area 7	6.33	2.15	2	12.8
Area 8	10.01	3.01	1.1	16.8

caused by congestion externalities given that fishers in the area are already many. The effects of such congestion on effort displacement are well documented (e.g. [Curtis and Hicks, 2000](#); [Poos et al., 2010](#); [Girardin et al., 2017](#)).

As the expected catch in one area rises, ceteris paribus, the probability of fishing in other regions will fall. The cross-elasticities are low, varying between 0.1 and 0.2, indicating that a rise in the expected catch rate does not lead to a significant fall in fishing effort in other fishing areas. However, there is a certain degree of substitutability between areas 1, 2 and 3, all of which are adjacent to the MPA.

A rise in the expected catch in fishing area 4 attracts fishers from adjacent areas 1, 2, 6 and 7. Effort in all fishing areas appear highly responsive to the catch in fishing area 6. One explanation is that area 6 is situated close to most of the other fishing areas. Fishing area 7 is a substitute to neighbouring areas 4 and 6. Efforts in areas 4 and 6 are also highly responsive to catches in fishing area 8, which is adjacent to them. The closer are two areas, the higher the degree of substitutability between them.

The distance from the homeport to a fishing area has a negative effect on the probability that it will be fished. This relationship is consistent with similar studies, such as [Stelzenmüller et al. \(2008\)](#) and [Valcic \(2009\)](#), and is shown graphically in [Figure 3](#).

[Table 7](#) shows the average distances travelled to each fishing area by fishers. The average distance to fishing area 1, which is the nearest to the MPA area (area 1), is 4.8 km. Fishing area 4, which has the lowest catch rates but attract most fishers, has an average distance travelled of 5 km. The difference between the two alternatives can be drawn from the other factors influencing fishing location choices, for example, the variability of catch.

[Table 8](#) shows the change in the likelihood of choosing a particular fishing area with respect to a change in risk as measured by the standard deviation of catch.

Importantly, the effects of risk are not consistent across the eight areas. A rise in catch variability does not necessarily reduce the probability of fishing in that area. For instance, a 1% rise in catch variability in fishing area 1 leads to a fall in effort, not only in that area but also in areas 3 and 8. When the same analysis is conducted for area 2, a reduction in effort in areas 6 and 8 is observed. However, when the standard deviation of the catch widens in areas 2, 3 and 8, the number of fishers to these areas increases.

The explanation for the ambiguous result on the sensitivity of effort to standard deviation comes from the different attitude to risk of individual fishers. From [Table 8](#), it is observed

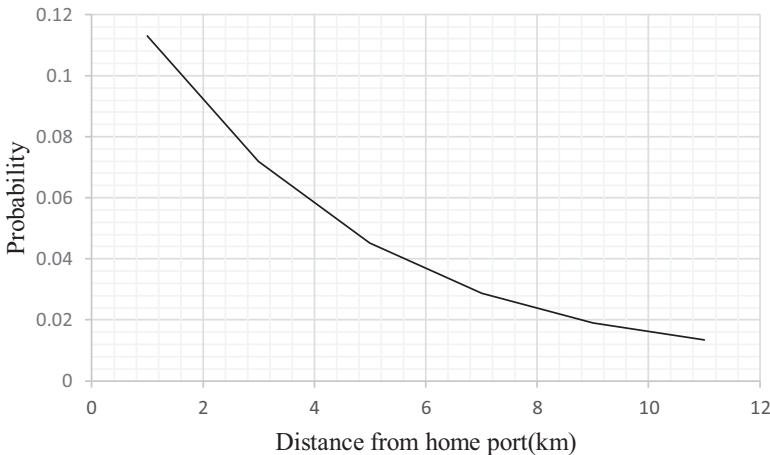


Figure 3.
Distance and location
choices from the RPL
estimates

that, while the other areas attract risk-averse fishers, a 1% rise in the standard deviation of catch increases the probability that fishers will visit areas 2, 3, and 8 by 1.3, 10.6 and 3.4%, respectively. In other words, areas 2, 3 and 8 tend to attract risk-loving fishers. While the other fishing areas are in the quiet waters protected by the Island's fringing reef, these areas are situated outside it, in the off-shore part of the fishing ground, an area that also carries greater physical risk.

Using the RPL model, the coefficient of the standard deviation of the expected catch can be used to differentiate fishers according to their risk preference. Almost 33% of the fishers are classified as risk-loving (Figure 4). The fishers' attitudes have implications for the displacement of effort, since the reactions of risk-averse fishers differ from those of risk-lovers.

Marginal rates of substitution between drivers of fishing location and catch rate expectation

Since the underlying utility function assumed in this study is linear in its explanatory variables, the marginal rates of substitution (MRS) between the drivers of fishing effort appear in terms of the catch rate (Buracam *et al.*, 2013). The MRS for distance quantifies how much catch per trip (in kg) would be needed to maintain the same level of fishing activity if there is an increase in the average travel distance of 1 km. The result shows

1% rise in SD of catch	% of change in probability to choose the respective fishing ground							
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8
Area 1	-2.57	0.02	-0.29	1.40	0.39	0.51	0.70	-0.26
Area 2	0.01	1.30	-0.66	0.42	0.04	-0.26	0.12	-1.09
Area 3	-0.21	-0.69	10.61	-0.17	-0.49	-0.82	-0.09	-6.47
Area 4	0.16	0.06	-0.03	-2.31	0.16	0.62	1.36	-0.09
Area 5	0.25	0.03	-0.36	0.73	-1.14	0.38	0.40	-0.55
Area 6	0.09	-0.08	-0.22	1.04	0.14	-1.03	0.55	-0.71
Area 7	0.17	0.03	-0.03	3.02	0.19	0.68	-3.77	-0.19
Area 8	-0.05	-0.30	-1.87	-0.11	-0.18	-0.68	-0.13	3.35

Table 8.
Elasticities of
probability of location
choices with respect to
catch variability

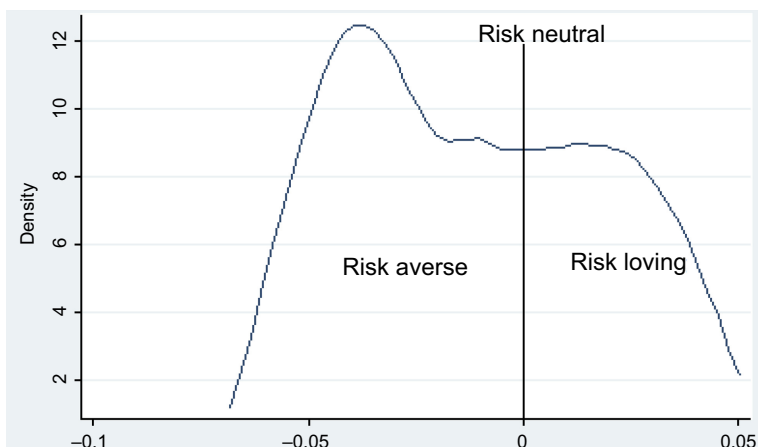


Figure 4.
Risk preference of
fishers

that 1.7 kg is required [3]. The MRS with respect to depth measured in metres stand at 0.8 kg.

When fishers face a one unit increase in standard deviation of catch per trip in a particular location, they will require a compensation of 13.3 kg on average to keep fishing there. However, the rate of substitution is an average that ignores the variation in risk aversion between fishers.

Modelling the impacts of marine closure on spatial effort distribution

A key issue in the design of marine reserves is effort displacement. Where do fishers go when an area is closed to them? Using the estimates from the RPL, it can be shown where displaced fishers would go if any of the eight areas studies were closed to fishing.

Table 9 shows that closing a high fishing intensity area such as area 4 leads to a significant increase in fishing effort in areas 6 and 7, while the closure of area with low fishing pressure (area 1, 2 and 3) leads to a marginal change in other fishing areas.

The analysis shows that expanding the locally reserved area by closing any of the eight areas studied would tend to shift the effort in the direction of the areas closer to the local fishing port inshore, i.e. 4, 6, 7 and 8.

Conclusion

This study attempts to shed light on the fishing the line hypothesis and supports the view that rising catch rates will attract fishers at the border of a Marine Park BBMP. However, the elasticity of fishers' effort with respect to expected catch differs across the areas, including the adjacent of the Park. Importantly, the responsiveness of effort to the catch rate is lowest in areas which are already heavily fished and easily accessible. A probable explanation relates to congestion effects of being accessible. As fishers anticipate the areas would be overcrowded, this acts as a deterrent to respond to rising expected catch rates. In contrast, the adjacent areas of the MPA are less accessible from most fishers whose homeports are located in the northern part of the fishing ground, and therefore the effort exhibits high responsiveness to rising catch rates. Rising expectations on catch rates in this case attract fishers who are more likely to cover their travel costs. The high elasticity implies that even if a reserve is placed in highly inaccessible area, involving high travel cost, as soon as expectations of catch rates rise (through spillovers), it may attract fishers in its vicinity, leading to degradation in the adjacent areas. A small reserve, in this respect, may be desirable as it is more likely to bring about minimal spillovers, and therefore would not attract many fishers. This design would be appropriate if the policy objective of the MPA is to shift fishers to other substitute areas.

The study also demonstrates that even if there is evidence that fishers have been fishing the line from the MPA, there are also other factors which affect fishermen choice of fishing

Table 9.
Redistribution of
fishing effort with
marine closure

	Status quo	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8
Area 1	0.04	0	0.04	0.04	0.06	0.05	0.04	0.04	0.04
Area 2	0.05	0.05	0	0.05	0.08	0.05	0.06	0.05	0.06
Area 3	0.04	0.04	0.04	0	0.04	0.05	0.05	0.04	0.10
Area 4	0.32	0.33	0.34	0.32	0	0.33	0.40	0.40	0.33
Area 5	0.06	0.07	0.07	0.07	0.07	0	0.08	0.07	0.08
Area 6	0.18	0.19	0.19	0.19	0.26	0.20	0	0.22	0.22
Area 7	0.15	0.15	0.15	0.15	0.31	0.16	0.19	0	0.16
Area 8	0.16	0.16	0.17	0.18	0.18	0.18	0.20	0.17	0

grounds. Thus, even if the catch rates are high relative to other fishing areas, as only 10% of local fishing trips are in the vicinity. Whilst higher catches do attract fishers, they are only a partial and very restrictive explanation of fishers' behaviour. Fishers evaluate several factors before choosing their preferred fishing sites. Distance from the homeport, variance of catch at a site and fishers' attitudes to risk play an important role in determining fishers' effort should also be considered in the configuration of an MPA.

The RPL model generates the marginal rate of substitution between the drivers of fishers' effort and catch rate expectations. This enables the estimation of costs that fishers would incur following closure. An indifference curve, drawn with distance travelled on one axis and expected catch on the other, would have a positive slope of 1.7, representing the compensation of fishers following a rise in distance, so that they are not worst off.

The study shows that the Blue Bay region has several fishing areas which would be especially sensitive to further marine closure in terms of effort distribution, particularly vulnerable ones being those that provide stable catches and are close to fishers' homeports.

The finding has an important implication on the size of an MPA. The establishment of a MPA has important implications on fishermen relocation of efforts and therefore affects the broader costs and benefits of the reserve. In this respect, the analytical framework and estimation method of this study allow the identification of fishing areas as complements (when fishing in one area increases fishing effort in another) and substitute which is valuable information for both determining the placement and size of an MPA. The analysis suggested that the zones most likely to have suffered from the closure of an area would have been those substitute areas that offered fishers low travel costs, stable catches and a lower potential human risk. If a reserve is placed in a preferred fishing area and is large, the resulting spatial redistribution of fishers may have profound effects on fish populations in other substitute areas. A larger reserve is likely to have more displacement effect in this case than a smaller one. Therefore, a small or a network of a small reserve may be appropriate. The premise to select the site and size of the reserve is to avoid overconcentration of fishers in alternative fishing areas, which can be vulnerable to excessive fishing and unintended effects from fishers.

Limitations of the study

The lack of evidence on fishing the line can also be attributed to limited spillovers when there is no suitable habitat outside an MPA for adult fish or for larvae to settle. Biological and ecological research on spillovers in the study site would supplement the findings of this study. Drivers such as spatial behaviour such as past behaviour, tradition and information sharing were also not treated in this analysis. The analysis can be improved through a much in-depth analysis of fishers' location choice, combining several research designs, quantitative as well as qualitative, that could be replicated in many small scale fisheries.

The simulations of spatial fishery closure in this study used static economic analysis which neither allowed for the dynamic increases or decreases in the fishable stock following spatial closure nor for potential changes in economic factors such as fish prices. The build-up of biomass can take several years, and spillover effect is time dependent. Since the Marine Park has been established for more than three decades ago, the results are sufficiently informative in relation to the distribution of fishing efforts and determinants of fishing location choices.

Notes

1. This technique is used in this study, and further information is provided in the next section.

2. A detailed explanation of RPL can be found in [Train \(2009\)](#)
3. The MRS between expected catch and distance, $\frac{\partial \text{ECAT}}{\partial \text{DIS}}$, is calculated as follows: $-\frac{\partial U}{\partial \text{DIS}} / \frac{\partial U}{\partial \text{ECAT}}$. The coefficient of the covariate DIS (−0.33) and ECAT (0.19) are used. This gives 1.7.

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