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PhD Thesis Chapter

# Examining the impact of spatial closures on the behaviour of a tropical tuna purse seine fleet

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The full thesis "Understanding fleet behaviour to reduce uncertainty in tuna fisheries management" is available from Imperial College London:

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## Introduction

The use of spatial tools in fisheries management, which include marine reserves and temporary closures, has become increasingly popular in addressing problems of sustainability (Gell and Roberts, 2003; Hilborn et al., 2004; Sumaila et al., 2007). As with any other fisheries management tool, it is important to evaluate the performance of closed areas in achieving their objectives. Considerable work has focused on evaluating the conservation benefits to fish stocks and marine habitats within closed areas (Halpern and Warner, 2002; Halpern et al., 2009; Hart, 2006; Lester et al., 2009), as well as the contribution of closures to improving fishery yields (Gaines et al., 2010; Gell and Roberts, 2003; Sale et al., 2005). However, far less attention has been directed at evaluating the wider management implications of closed areas and, in particular, how a closure affects the dynamics of effort allocation in a fishery.

To do this, a promising approach is to build up a counterfactual scenario of fleet behaviour by developing a predictive model of effort allocation that accounts for a broad range of influences on fishery dynamics. In this way, the observed response of a fleet to a closure can be compared to predictions of how the fleet would have behaved if the closure had not been implemented. This approach has been demonstrated by Smith et al. (2006), who showed it was necessary to account for a range of factors influencing catch rate, including the use of multiple gears, heterogeneity in

fisher skill and the seasonal distribution of fish, to reveal the negative effect of two marine reserves on the catch of a Gulf of Mexico reef-fish fishery.

In this study we use a counterfactual approach to examine the policy effect of two closed areas on the behaviour of the tropical tuna purse seine fleet in the western Indian Ocean. The focus of our analysis is understanding the causal effect of closures on fleet spatial behaviour and to characterise the reallocation of effort by the fleet in response to closed areas.

## Methods

### Description of the closed areas

In November 2011 and again in 2012, the Indian Ocean Tuna Commission (IOTC) designated a one-month closure with the objective of restricting the fishing capacity of the fleet and reducing fishing pressure on stocks of yellowfin and bigeye tunas (Resolution 12/13; http://www.iotc.org/English/resolutions.php; accessed 1st June 2013). The closure extended from the Somali coast to 60°E and covered a large part of the productive northwest fishing grounds typically fished by the fleet during August-November.

In late 2010 the British government designated their entire British Indian Ocean Territory (BIOT) a marine reserve. The BIOT reserve is positioned at the eastern periphery of the purse seine fishery area in a region typically fished during November-February characterised by catches of free-swimming schools. Prior to the closure of BIOT, the importance of the area in terms of purse seine fishery production varied considerably from year to year, with the average proportion of total monthly catch taken within the Territory ranging from 0-23% (MRAG Ltd; unpublished data, 1999-2008).

### Statistical model

We used the model described in Davies et al. (in preparation; also presented at IOTC WTPP 2014) to generate predictions of how the fleet would have allocated effort in the absence of the closures. The model was used to predict retrospectively the probability of effort being allocated into a location based on three main drivers; the response of the fleet to the bio-physical conditions of the ocean, practical constraints on movement and inertia in the use of seasonal fishing grounds. To train the model, monthly fishing data were disaggregated by flag nationality and kept at their native spatial resolution of 1° latitude/longitude. Data were split into the periods 2006-2010 for model training and 2010-2011 for prediction.

Given the temporary nature of the IOTC closure and the short period that BIOT has been designated as a reserve, our analysis was focussed on the short-term reallocation of effort rather than higher level investment and fishery participation decisions. For the IOTC closure, we focussed on the behaviour of the fleet during November, the month of the closure, in 2011 and 2012. For the BIOT reserve we focussed on the period December-January when the provision of fishing licences was historically highest (J. Pearce, MRAG Ltd; personal communication). Fishing data were available until December 2012, allowing the analysis of two full fishing seasons.

## Results

### IOTC closure

In the observed scenario the fleet complied with the closure in both years of its implementation and fishing effort was allocated to the south and east of the closed area boundaries (Figure 1). There was some similarity in the response of the Spanish and French fleet components, with both nationalities allocating the majority of fishing effort to the south of the closure. This behaviour largely corresponded with counterfactual predictions, suggesting that vessels mainly fished in parts of the seasonal fishing grounds that remained accessible. The major difference in the response of the two flag nationalities was the allocation of effort by Spanish vessels to the east of the closure area, well beyond the eastern extent of the typical seasonal fishing grounds (Figure 1). This allocation of effort is probably explained by skippers searching for floating objects that had drifted eastwards out of the closure area, which would not be considered usual behaviour under typical conditions due to the reduced chance of finding and catching associated schools in this region (skipper; personal communication). This suggests that either fishing opportunities were not satisfactory in the accessible parts of the typical fishing grounds or that skippers were exploring eastern areas in an attempt to test out new fishing opportunities.

### BIOT reserve

In the observed scenario there was a marked difference in the allocation of effort by the French and Spanish components of the fleet in the first year of closure of BIOT. In the case of the Spanish fleet component, effort was mainly allocated in the Seychelles region as predicted, although some effort was allocated in the northwest Somali basin region (Figure 2). This suggest that a number of vessels remained in the main FAD fishing areas out of season, although it is difficult to attribute this as a direct effect of the BIOT closure. The allocation of effort by the French fleet, whilst again mainly concentrated in the southwest Seychelles region, revealed considerable exploration around the BIOT reserve. A number of vessel travelled to the east of BIOT into areas rarely fished by the fleet, either passing through the closure or passing to the south (Figure 2). This fishing behaviour may be explained by poor fishing opportunities experienced elsewhere, prompting French skippers to search in novel areas around BIOT, or may reflect the behaviour of skippers attempting to assess the lost opportunities resulting from the designation of the reserve. In the second year of closure of BIOT the fleet mainly allocated effort throughout Seychelles region (Figure 2). This largely corresponded with predictions of the model and thus suggests little disruption of fishing behaviour caused by the reserve. The observation of more effort than expected in the northwest regions by both fleet components may reflect the late movement of the fleet into the free school grounds due to the perceived unfavourable fishing conditions in the southeast.

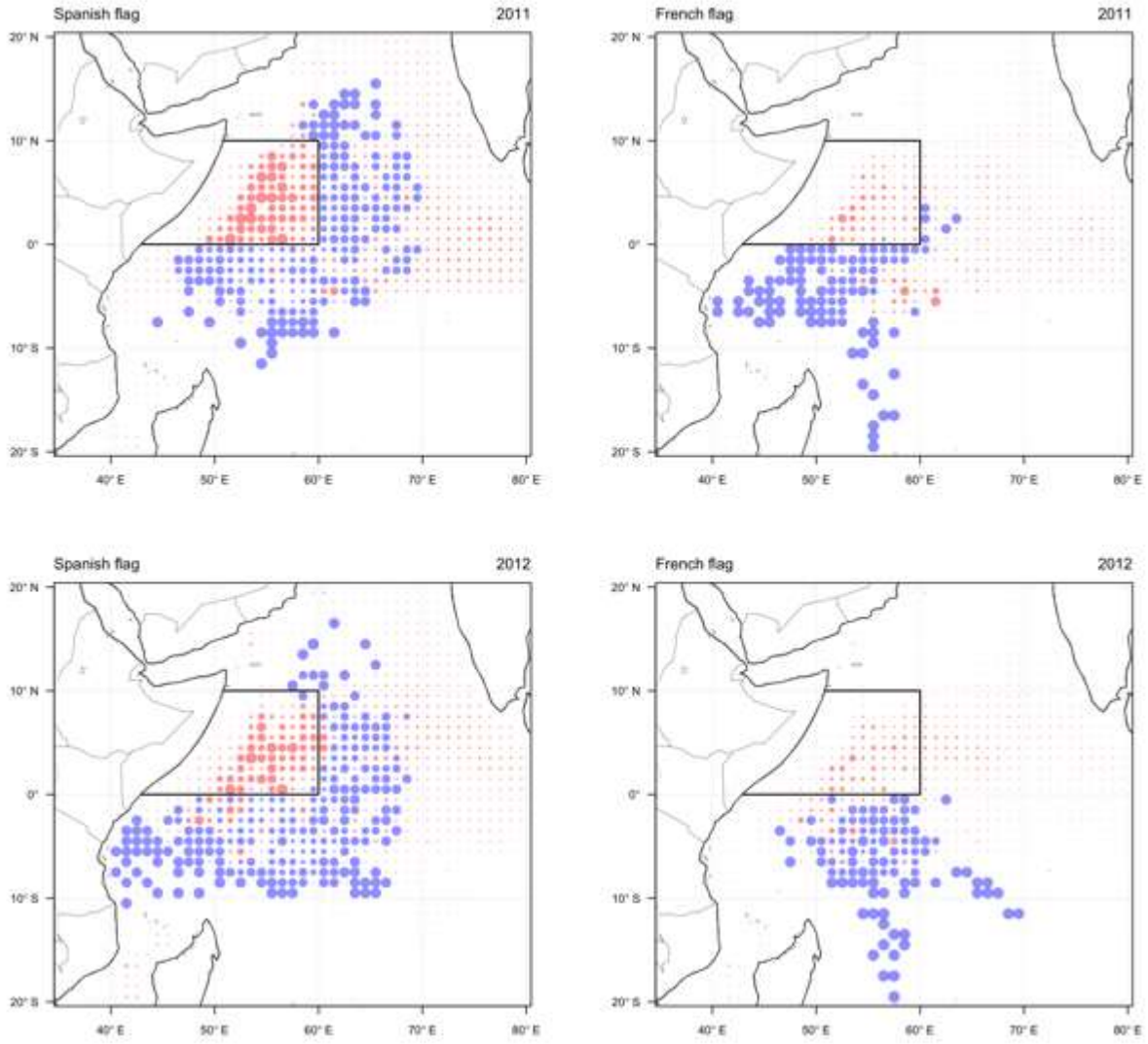


Figure 1 Observed allocation by the Spanish (left) and French (right) components of the fleet in the western Indian Ocean during November 2011 (upper) and 2012 (lower). Observations in each grid cell are shown as the predicted probability of effort minus observed response, where blue circles show more effort than expected and red circles show less effort than expected. Circle size indicates the relative size of the residual. The location of the IOTC area closure is shown by the solid line.

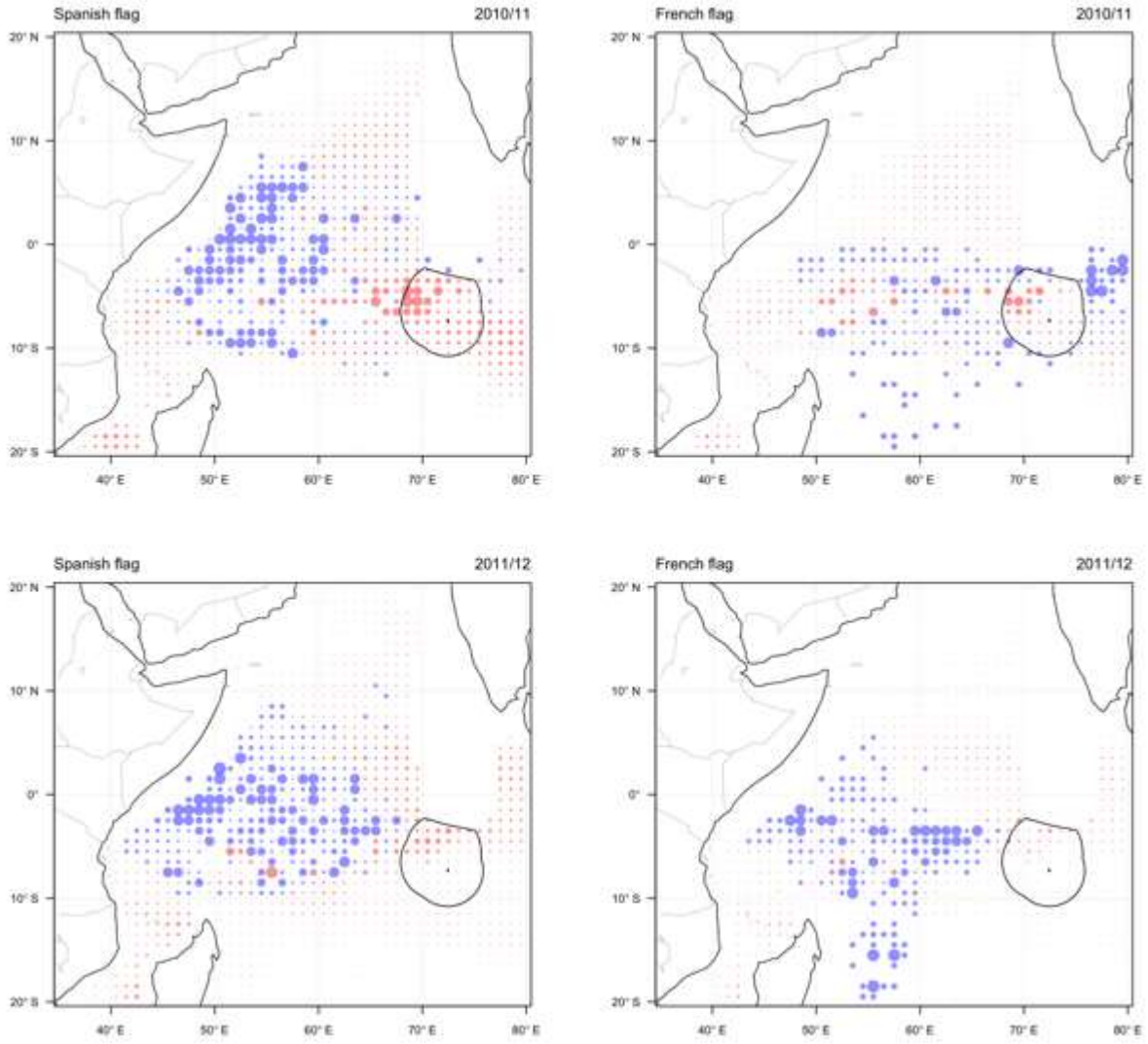


Figure 2 Observed allocation of effort by the Spanish (left) and French (right) components of the fleet in the western Indian Ocean during the months December-January in 2010/2011 (upper) and 2011/2012 (lower). Observations in each grid cell are shown as the predicted probability of effort minus observed response, where blue circles show more effort than expected and red circles show less effort than expected. Circle size indicates the relative size of the residual. The location of the BIOT closure is shown by the solid line.

## Discussion

In this study we examined the impact of two closed areas on the spatial behaviour of the Indian Ocean tropical tuna purse seine fleet, using a counterfactual approach to isolate the policy effect of the closures from other competing influences on fleet behaviour. The construction of a counterfactual scenario proved to be crucial in isolating the policy effect of the closures from conflicting environmental influences on effort allocation and our results showed a mixed and

inconsistent closure effect on fleet behaviour. Our results also demonstrated the flexibility of the fleet in adapting to the closures, particularly it's ability to explore new areas, and furthermore we identified varied responses within the fleet, suggesting that the placement of a closure may have a varying impact on different components of the fleet.

Of particular interest in our results was the inconsistent effect of the BIOT reserve on fleet behaviour. In the 2010/11 season purse seine fishing conditions appeared to be favourable in the BIOT region and some vessels allocated effort around the boundaries of the closures, suggesting that the closure did result in the exclusion of fishing effort that would otherwise have been allocated there. In the following year, anomalous shallowing of the Seychelles-Chagos Thermocline Ridge, which in the past has been linked to an Indian Ocean Dipole event (Marsac, 2008), affected the suitability of purse seine fishing conditions in the region and the fleet was predicted to have a considerably lower probability of fishing within BIOT. This counterfactual scenario coupled with the absence of observed effort close to the boundary of BIOT suggests that the closure in the 2011/12 season had little impact on the behaviour of the fleet. This result serves to highlight the importance of the placement of closures in fishery systems characterised by high variability, where the complex suite of influences on fleet behaviour can make it difficult to predict or evaluate the contribution of a closure to achieving management objectives.

A second key result was the varying magnitude of closure effect on the two fleet components observed for both closures. The varied response observed is largely explained by differences in the seasonal movement pattern of the fleet components linked to fishing strategy, with Spanish vessels typically remaining in the northwest FAD-fishing grounds for a longer period than French vessels, which move into subequatorial free schools regions earlier. A switch in the relative impact on two fleet components was observed for the BIOT closure in 2010/11, when the French component showed a more evident response to the closure with considerable exploratory behaviour around the closure boundaries. This variation in response is probably again linked to company-level strategy and differences in the targeting of free and associated schools, with Spanish skippers belonging to FAD-orientated companies less inclined to search for free schools in the vicinity of the BIOT closure and the opposite true for French skippers.

In this study we focused on the behavioural response of the fleet to spatial management but did not look at overall effect of the IOTC and BIOT closures on catches of tunas or bycatch species and as such we cannot offer a conclusion as to the conservation efficacy of large offshore closures. The effect of closures on fish stocks can take years or decades to be demonstrated (Lester et al., 2009) and, as with fleet behaviour, it can be difficult to isolate the policy effect of a closure in generating reductions in catch or bycatch without accounting for other influences on production dynamics, including ecological processes, technological innovation and consumer pressures. Nevertheless, the development of a catch model that integrates with the model of fleet behaviour we employ here would be a valuable next step in the evaluation of the benefit of area closures in tuna fisheries.

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