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# MANAGEMENT OF SUSTAINABLE FISHERIES ALONGSIDE MARINE RENEWABLES: MODELLING THE SPATIAL INTERACTIONS

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## ABSTRACT

Extracting energy from waves and tides is seen as crucial to the achievement of ambitious national targets for meeting energy demands from renewable sources (e.g. 100% of electricity demand by 2020 in Scotland), but the requirements of this new industry must be balanced against the needs of traditional users of the sea, particularly marine fisheries. Whilst previous studies have indicated relatively little overlap between hydrodynamic energy resources and exploited marine fish stocks at national scales, there appears to be greater potential for locally-significant interactions involving inshore fisheries. Although interactions are expected to differ according to marine renewable energy development types and technologies, and to involve spatial scales ranging from devices and individual fish to regions and fish stocks, the first concern for fisheries is likely to centre on spatial occupancy of fishing areas by developments. Whilst exclusion from portions of traditional fishing grounds can be seen as a loss of fishing opportunity, it is also relevant to consider that spatial measures can be an important tool for fisheries management. We develop a spatial model of yield and spawning potential for inshore fisheries, demonstrating the sensitivity of sustainable management criteria to spatial exclusion of fisheries activities at scales relevant to marine renewable energy developments. We show that the sum effects of multiple exclusion zones depend on the interaction between spatial turnover of fish populations and the size and shape of these zones. Fish mobility is a primary factor in determining sensitivity to spatial management measures, but this factor is mediated by the ways in which patterns of individual movement and site fidelity determine spatial turnover at a population level. Managed sensitively with respect to potential impacts and opportunities, there appears to be considerable scope for positive working relationships between the marine renewable energy and fishing industries, but this depends to a large extent on the development of effective frameworks for marine spatial planning.

## INTRODUCTION

The renewable energy sector is a relative newcomer to the marine environment, and marine planners face a considerable challenge in integrating this new industry alongside existing sea users. Particularly in the case of wave and tidal energy, important and accessible energy resources occur in inshore areas which already provide highly important revenues to local communities from the catching and processing sectors of the fishing industry. The process of selecting leasing areas for marine renewable energy has in the past been criticised for failing to include the views of fisheries interests. More recently the renewable energy and fisheries sectors have started to work more closely together to provide the evidence to inform marine consenting and planning processes. Particularly given moves towards increased regionalisation of fisheries management, it is apparent that there may be opportunities for synergies.

This paper considers the issue of spatial occupancy of fishing areas by marine renewable energy developments. Displacement of fishing from areas of traditional grounds is qualitatively similar to the use of closed areas as part of a spatial management strategy. We use a modelling approach to examine the consequences of such displacement for fisheries yield and the conservation of spawning stock biomass.

## METHODOLOGY AND SUMMARY OF RESULTS

Mathematical models are frequently used to support decision making by fishery managers.‘Per recruit’ models are commonly applied to project the consequences of management actions for biological and economic sustainability of fisheries, providing criteria for sustainable exploitation based on the concept of maximum sustainable yield (MSY) – a guiding principle for fisheries management worldwide. Yield per recruit (Y/R) estimates relative yield under a given fishing scenario based on trade-offs between fishing mortality, natural mortality and growth in body size over the lifetime of a cohort; similarly, spawning stock biomass per recruit (SSB/R) considers the same trade-offs to estimate relative spawning potential. It is straightforward to extend this modelling approach to include spatial management measures such as closed areas. Based on Bell *et al.* (2010)[1], we use a matrix-based model that, in addition to fishing and biological processes of mortality, growth and sexual maturity, incorporates movement of the target species between areas open and closed to the fishery and allows definition of closed areas differing in size and habitat quality.

Simulation of the movement patterns of individual fish or shellfish (not reported in this

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extended abstract) allows exchange rates between open and closed areas to be scaled between closures of differing size and configuration. In the case of directed movements, for example, modelling shows that residence time is much greater for closed areas orientated with rather than across the dominant movement direction. Here we consider just the example of closing access to 20% of the fishing grounds. This scale is plausible for the spatial occupancy of marine renewable energy in a local inshore fishery area. We consider the case of a stock resembling Scottish brown crab (*Cancer pagurus*) in its biological and fishery attributes[2]. Y/R and SSB/R outcomes are examined at different levels of fishing effort, compared between the following scenarios:

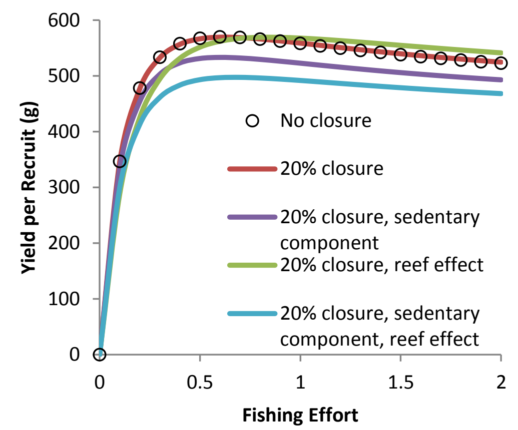
1. Baseline of no closure, i.e. unrestricted access to the fishing grounds.
2. 20% of the grounds closed, with a daily crab emigration rate of 1% from the closed area.
3. 20% closure, with the same overall average closure rate but distinguishing between sedentary (daily emigration rate 0.01%) and mobile (emigration rate 1.99%) components of the stock.
4. 20% closure, emigration rate 1%, but with the closed area having twice the crab carrying capacity per unit area as the open area – i.e. closed areas having a reef effect
5. 20% closure, mobile and sedentary components, *and* reef effect considered together.

Comparison of the first two scenarios shows that curves of both Y/R and SSB/R in relation to fishing effort are virtually identical (Fig. 1, compare open circles and red lines). An emigration rate from the closed area of just 1% in each day is sufficient to provide average levels of exposure that are the same as for an unrestricted fishery. This effect is comprised of (a) increased fishing intensity outside the closed area, and (b) sufficient passage of crabs from closed to open areas to compensate for loss of grounds.

A crucial element of the second scenario is that all crabs are treated as behaving identically. If, more realistically, we assume that, for the same overall average movement rate, some crabs are more sedentary than others (scenario 3), changes in both curves are seen (Fig. 1, purple lines): relative yield (Y/R) peaks at about 6% lower than for the unrestricted fishery, whilst the closure results in 50% higher spawning potential (SSB/R) at a fishing effort of 1, this benefit increasing at higher effort levels.

If we consider the possibility that the infrastructure associated with marine renewable energy developments may actually increase the habitat value within closed areas – i.e. a reef effect, here modelled as an increase in carrying capacity within the closed area (scenario 4) – we can see that this confers additional benefits (Fig. 1, green lines). For homogeneous movement rates, relative yield is more robust to increasing fishing effort, a result of a greater pool of crabs partially protected within the closed area but still emerging to be available to the fishery. Less protection of spawning potential at higher effort levels is evident compared with scenario 3, but the combined effect of both movement heterogeneity and the reef effect in the model (scenario 5) is to provide greatly enhanced protection of spawning potential at the expense of losses of around 12% in relative yield (Fig. 1, blue lines).

(a)




(b)

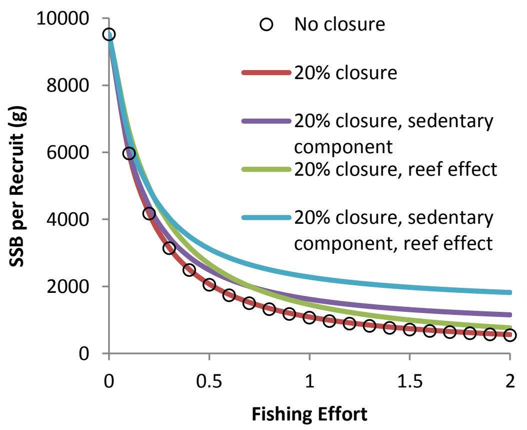



**Figure 1 Results of spatial per recruit modelling, showing (a) relative yield and (b) relative spawning potential as a function of fishing effort under scenarios of area closure, stock movement patterns and enhanced carrying capacity (reef effect) of closed area.**

Fishery management strategies based on the MSY principle often use $F_{MSY}$, the level of fishing mortality at which yield is maximised, as a target for a sustainable fishery management. The fishing mortality at the maximum of the Y/R curve, known as $F_{max}$, is a common proxy for $F_{MSY}$. Alternative approaches can be based on a SSB/R curve, taking the value of SSB/R at a fixed proportion of that estimated for an unexploited stock. Table 1 lists values of these candidate biological reference points estimated for all five scenarios. Note that fishing mortality is defined as being 0.5 at a fishing effort of 1 for an unrestricted fishery, so the values in Table 1 can be related to fishing effort axes of the curves in Fig. 1 by multiplying by 2. A value of 20% of unexploited spawning potential was selected for the reference point based on the SSB/R curve, referred to as $F_{20\%}$, resulting in values that are slightly more precautionary than $F_{max}$ for an unrestricted fishery.

**Table 1. Candidate biological reference points for fishery management under spatial and stock movement scenarios. $F_{max}$ is fishing mortality at maximum yield per recruit; $F_{20\%}$ is fishing mortality at 20% of spawning potential of unexploited stock.**

| Scenario | $F_{max}$ | $F_{20\%}$ |
|---|---|---|
| Baseline (no closure) | 0.306 | 0.271 |
| 20% closure | 0.307 | 0.275 |
| 20% closure, sedentary component | 0.302 | 0.380 |
| 20% closure, reef effect | 0.421 | 0.371 |
| 20% closure, sedentary component, reef effect | 0.336 | 0.844 |

As expected from the previous results, in the absence of reef effects or any heterogeneity of movement rates, the candidate reference points for the closure scenario are close to those for the unrestricted fishery. In other words, under scenario 2 the closure has conferred no additional resilience to fishing pressure that could be reflected in revised management targets. In the absence of a reef effect, movement heterogeneity coupled with closure (scenario 3) does not shift the location of the peak on the relative yield curve, but does allow higher fishing mortality for a target level of conservation of spawning potential. Reef effects (scenarios 4 and 5) allow higher targets based on both yield and spawning criteria. The very high value of $F_{20\%}$ for scenario 5 reflects the enhanced resilience of spawning potential conferred by the closure when there is both a reef effect and heterogeneity of movement rates.

## CONCLUSIONS

A simple fishery model shows that closure of fishing grounds at local scales likely to be associated with marine renewable energy developments in inshore areas may have positive implications for sustainable fishery management. These positive implications relate largely to increased resilience of spawning potential to fishing pressure, which may potentially come at the expense of some loss of landings. However, particularly if marine renewable energy infrastructure enhances the value of habitat within the areas lost to fisheries, it is possible that losses in relative yield measured by Y/R may be offset by increases in recruitment made possible by increasing the total carrying capacity of the grounds through the reef effect. This may be particularly relevant for some crustacean fisheries, for which recruitment could be more limited by habitat bottlenecks than by egg production.

It is worth noting that it was necessary to account for movement heterogeneity in the models before the potential losses and gains from this type of *de facto* spatial fishery management became apparent. Data from tagging and telemetry studies show that some commercially important species can show very high levels of site fidelity, especially in relation to structures associated with marine energy developments[3]. It is thus important that future modelling studies addressing fisheries interactions with marine renewables are not over-simplistic in their treatment of fish and shellfish movement patterns. Directed migratory movements, not addressed in this extended abstract, are an important category of movement pattern that may have strong implications for the effectiveness of spatial management.

The marine renewable energy and fishery sectors are two major users of sea space, delivering actual and potential economic benefits to local communities, often in peripheral regions. Irrespective of any potential for marine renewable energy developments to contribute to spatial management of inshore fisheries, it is vitally important that the two sectors work together closely to ensure that marine planning decisions are based on the best possible evidence: the fishing industry to provide evidence on which areas of sea are crucial for their activities; the renewables industry to minimise impacts in placing and operating their developments; both sectors to identify opportunities for synergy, such as incorporating habitat creation with construction of development infrastructure. It is also important, of course, that these activities should continue to be supported by robust science.

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