Ecological Modelling 312 (2015) 77–90

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Modelling abundance hotspots for data-poor Irish Sea rays

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ARTICLE INFO

Article history:
Received 12 February 2015
Received in revised form 6 May 2015
Accepted 9 May 2015
Available online 5 June 2015

Keywords:
Boosted regression trees
Data poor
Elasmobranch
Skates
Rays

ABSTRACT

Skates and rays represent one of the most vulnerable components of fish communities in temperate demersal fisheries such as the Irish Sea. They also tend to be data poor in comparison to commercially exploited teleost fish. Spatial management has been suggested as an important tool to protect these species, but requires an understanding of the abundance distribution, and the relationship the abundance distribution has with the environment at both adult and juvenile life history stages. Here we modelled bottom trawl survey data using delta log-normal boosted regression trees on to derive rays' spatial abundance, and environmental links. The modelling approach allowed the development of high resolution predictive maps of abundance of four skate and ray species targeted by fishing activity: thornback, spotted, cuckoo and blonde rays. The distributions of these species were driven by a general preference for sand and coarser substrates as well as higher salinities, temperatures and currents speeds. Spatial comparisons between abundance distributions and locations of skate and ray commercial landings indicated that the main hotspots for the investigated species are outside of the main commercial fishing areas and overlap with potential MPAs proposed for wider ecosystem protection. The method offers a useful tool for selecting potential MPA's to assist the management and conservation of data-poor species.

1. Introduction

1.1. Managing data-poor elasmobranch stocks

Most elasmobranch species are large-bodied, slow-growing and inherently vulnerable to overfishing, due to their low fecundity and late maturation (Holden, 1974, 1973; Musick et al., 2000). Several factors preclude the use of standard methods for stock assessment of elasmobranchs: data (particularly on age-structure and fecundity) are typically scarce or of poor quality (Ellis et al., 2010; Fahy, 1989; Gallagher, 2000), and landings are often reported for groups of species rather than for individual species. These problems are particularly compelling in Ireland where the actual species composition and age structure of ray catches is masked in bulked landings that are commercially boxed by size and value (Fahy, 1991). Ray catches are often not identified at the species level, or are misidentified (Fahy, 1991; ICES WGEF, 2009, 2010) (e.g. blonde rays (*Raja brachyura*) are often misidentified as spotted rays (*Raja montagui*)).

Long-term, species-specific assessments are impeded by low and variable catch rates of rarer skate species (Ellis et al., 2010; ICES WGEF, 2009, 2010) and by inappropriate survey design (Ellis et al., 2010) leading to errors in abundance estimation (Brander, 1981; Casey and Myers, 1998; Myers and Worm, 2005).

Improved stock assessment for elasmobranchs has been a high priority since the start of the century (Chevolot et al., 2008; Ellis et al., 2005b; Heessen, 2003). The Johannesburg Declaration of 2002 (United Nations, 2002) committed governments to restore fisheries to maximum sustainable yield (MSY) by 2015 (European Commission, 2008). This typically involves managing the total allowable catch (TACs) of individual species. For Irish Sea skates and rays this approach is currently unfeasible, as biologically appropriate management units have not been defined (Ellis et al., 2010). For mainly bycatch species such as skates and rays, single-species TACs are unlikely to be effective as they can often increase discarding (ICES WGEF, 2012). It has been shown that discard mortality of rays from the fishing fleet is already very high (Shephard et al., 2015).

Where management reference points are unknown, as in the case of blonde ray, the International Council for the Exploration of the Sea (ICES) prescribes a precautionary 20% annual TAC reduction (ICES WGLIFE, 2012; NWWRAC, 2012a). Whilst recent ICES advice based on abundance estimates recommended a 36% reduction for thornback and cuckoo ray, a 20% *increase* was recommended for

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http://dx.doi.org/10.1016/j.ecolmodel.2015.05.010
0304-3800/

spotted ray (ICES WGEF, 2012). Such examples highlight the inconsistencies that might arise in a mixed ray fishery managed under singles-species TACs. Precautionary TAC reductions could increase the pressure on the already precarious Irish Sea ray fishing sector which has collapsed from its 1931 peak (ICES, 2014) with only a few Irish vessels currently taking the majority of the landings of thornback (*Raja clavata*), spotted, blonde and cuckoo ray (*R. naevus*) (Gerritsen, H., Marine Institute, pers. comm.).

1.2. Addressing management problems with spatial approaches

Marine Protected Areas (MPAs) are often implemented to achieve conservation goals (Agardy, 2000; European Commission, 2008; Waitt Foundation, 2014), and have been demonstrated to be effective for elasmobranch species (Edgar et al., 2014). The ICES Working Group for Elasmobranch Fisheries (WGEF) recommends that such management interventions be implemented as effort restrictions or closures (spatial or seasonal), particularly to protect nursery and spawning grounds (ICES WGEF, 2012). Consultation with fishers has indicated that spatial management methods are considered to be the most effective approach (Fitzpatrick, M., pers. comm.; NWWRAC, 2013).

Whilst spatial management of skates and rays could be valuable (Ellis et al., 2008; Speed et al., 2010), its application is hampered by incomplete knowledge of specific ecologically important habitats (nursery and spawning areas) (Ellis et al., 2010). Identifying such areas may help resolve the 'choke species' problem, whereby declines of certain species (especially cuckoo and blonde ray (NWWRAC, 2012b)) result in catch limit restrictions being imposed on the entire species group. Protecting the most vulnerable species through spatial management of their nursery or spawning areas could allow catch limits for other species to be relaxed, such that most resilient species could be sustainably harvested.

Various modelling approaches can help identify the best areas to be protected with permanent/seasonal closures or technical measures such as minimum landing sizes. For example, the program Marxan (Ball and Possingham, 2003) finds the smallest areas required to meet its objective (e.g. protect nurseries) but performs badly with poor or absent data (Vincent et al., 2004) leading to over-large MPAs and avoidance of coasts (Loos, 2006) (where rays are often present). Maximum Entropy (MaxEnt) methods (Elith et al., 2011; Phillips et al., 2004) model species distributions from presence-only data, but cannot utilise abundance data, when available. Generalised Linear and Additive Models (GLMs & GAMs) are commonly used in a two-step procedure (e.g. De Raedemaecker et al., 2012, and references therein), first by modelling the presence/absence, then by modelling the presence-only abundance, and finally joining the two models (Guisan and Zimmermann, 2000; Martin et al., 2012).

Boosted Regression Trees (BRTs) could provide more robust predictions than GLMs and GAMs (Lo et al., 1992), with less variance (oversensitivity to noise leading to overfitting/imprecision) and bias (false assumptions in the algorithm leading to underfitting/inaccuracy), with a lower risk of misspecification and the ability to model complex interactions. In addition, BRTs are unaffected by multicollinearity, missing predictor values and outliers (see comparative evaluation in Abeare (2009)). They use machine learning to add increasingly small predictor-response relationships into one model to account for high proportions of variability despite complex multivariate relationships (Elith et al., 2008).

1.3. Ray habitat preferences and the study area

The four rays considered in this study have small distributional ranges (McEachran and Miyake, 1990; Stehmann and Bürkel, 1984). Juveniles remain nearly sedentary (Holden, 1975; Steven, 1936) but adults migrate inshore to feed, and also to mate and spawn in the spring/summer period (Steven, 1932; Walker et al., 1997). Such site-fidelities and habitat preferences make these rays species good candidates for spatial management (Hilborn et al., 2004; Kaiser et al., 2004).

Peak recreational angling landings for all species occur in certain small areas (Fahy and O'Reilly, 1990). Larger specimens have especially localised distributions (Fahy and O'Reilly, 1990), and find shelter in refuges that harbour high biodiversity (Shephard et al., 2012) and allow them to reach their maximum weight (Fahy, 1991; Ryland and Ajayi, 1984). Anglers often catch particularly large rays, partially because they fish where trawlers cannot operate (Ryland and Ajayi, 1984). Commercial landings are highest off the Southeast coast of Ireland (Gallagher, 2000; Hillis and Grainger, 1990) and peak in August–December (Fahy, 1989; Gallagher, 2000).

2. Aims

We present a modelling approach for spatial management of data-poor stocks (cuckoo, thornback, blonde and spotted rays in the Irish Sea), using Boosted Regression Trees to map species abundances in relation to environmental correlates, and to identify ecologically important abundance hotspots. We then investigate how these models can be used to aid in MPA design. Finally, we assess the robustness of this approach by comparing our results with available data on.

3. Methods

3.1. Database selection and processing

The Irish Sea is a well-mixed shallow shelf sea that tapers to a deeper (100 m) central channel, with very shallow (≤5 m) sandbanks running parallel to the coast that create 20–30 m deep channels some 7–12 km from shore (Connor et al., 2006; Vincent et al., 2004). Tidal bed stress is generally low to moderate except off a few particular headlands (Connor et al., 2006). The substrate is largely a sandy/gravel mix, generally coarser at depth, with rocks north west off Anglesey and a large mud bank running parallel to the south east coast of Northern Ireland, corresponding to locally lower bed stresses. Environmental data used in our analysis are described in Table 1.

Depth, substrate and temperature are known to correlate with elasmobranch abundance (Ellis et al., 2005a; Kaiser et al., 2004; Martin et al., 2012) but other potentially pertinent variables were also included in the analysis (the BRT modelling approach, described below, does not penalise for additional variables). QGis mapping software (Quantum GIS Development Team, 2014) was used to interpolate environmental data points to a surface of Voronoi polygons, then to append their values to the highest resolution dataset (depth grids covering the whole Irish Sea (n = 391,568)). Distance to shore was calculated using raster proximity analysis. Substrate categories were converted from descriptive Folk classifications (Folk, 1954, 2013) to median grain size (SearchMESH, 2014), and inputted as a continuous factor to the model.

We downloaded catch per unit effort (CPUE, in numbers per hour) data for all rays caught in ICES area VIIa (Irish Sea) by standardised survey trawls (International Groundfish Survey and Bottom Trawl Survey) from 1993 to 2012 from the ICES Database of Trawl Surveys (ICES, 2012). To maximise the spatial coverage of the analysis, these data were averaged across all years. Cuckoo, thornback, blonde or spotted rays were present in 1645 of the 3341 half-hour trawls, the midpoints of which were used as the map locations for those data. This generated 1447 site locations, many