Estimating uncertainty in deriving spatial distribution of blue ling landings from vessel monitoring system (VMS) data and implications for delineating marine protection boundaries to the northwest of the British Isles

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Abstract

Recent years have seen a rapid increase in the development of restricted fishing areas to protect vulnerable marine ecosystems and species-specific fish stocks. The current study focuses on one such area to the northwest of the British Isles where, in 2009, the European Commission (EC) introduced protection areas for spawning aggregations of southern blue ling (Molva dypterygia) in European Union (EU) waters. High-resolution data derived from logbook entries and satellite-based vessel monitoring systems (VMS) are used to estimate spatial and temporal patterns of blue ling fishing activity. However, certain assumptions must be made regarding whether vessels are engaging in fishing activity at any individual monitoring point, leading to uncertainty in estimating activity in the vicinity of protection area boundaries. The study aims to apportion blue ling landings reported by ICES rectangles of 1° latitude × 0.5° longitude inside and outside the protection areas and the data are assessed at different spatial and temporal scales. From the methods evaluated, initial results of the impact of EU conservation measures on fishing activity during the spawning period are inconclusive.

Keywords: blue ling, GIS, marine protection areas, spatial management

1. Introduction

The International Council for the Exploration of the Sea (ICES) has repeatedly advised that blue ling are susceptible to sequential depletion of spawning aggregations, and a large body of evidence has been collated and analysed in support of ICES advice for implementation of measures to restrict the fisheries directed towards blue ling, or where blue ling are caught within mixed fisheries (ICES, 2008; ICES, 2009; Large *et al.*, 2010). Based on these recommendations the European Commission (EC) has, since 2003, introduced total allowable catches (TACs) and a succession of regulations including EC Regulation 43/2009 delineating "measures... to protect spawning aggregations of blue ling in ICES zone VIa" (location shown in Figure 1).
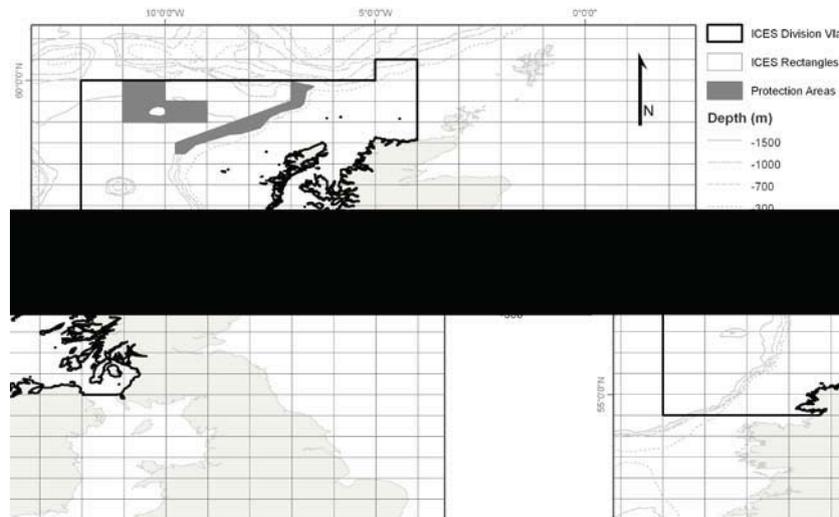
Figure 1: Location of ICES Division VIa and blue ling spawning protection areas.

Designation of marine boundaries within which fishing activity is limited or prohibited is supported by data on various parameters including seafloor topography, marine habitats, spawning times and fishing activity from vessel logbook information (Reed *et al.*, 2005; Hall-Spencer *et al.*, 2009). High-resolution estimates of fishing effort can be derived by combining logbook entries with satellite-based vessel monitoring systems (VMS) data, to estimate spatial and temporal patterns of fishing activity at multiple scales (Mills *et al.*, 2007; Lee *et al.*, 2010; Jennings and Lee, 2012). These estimates are based on vessel speed, direction, types of fishing gear available, etc, but assumptions must be made regarding the actual activity at individual VMS monitoring points. In particular, VMS signals (which are generally recorded two-hourly, but at 30 min intervals while vessels are within restricted fishing areas - EC Regulation 1224/2009) provide a high-resolution grid-referenced location marker, whereas species landings data from the vessels are recorded at the spatial scale of the ICES rectangle (standardised sea areas for statistical analysis, $0.5°$ latitude $\times$ $1°$ longitude in size), so assigning landings to VMS monitoring points relies on some strong assumptions.

The aim of this paper is to analyse the extent to which uncertainty in estimating the spatial apportionment of blue ling landings may affect interpretation of the impact of regulation. The location of interest includes two EC protection zones to the northwest of the British Isles (Figure 1) which have been a focus of research by the Centre for Environment, Fisheries and Aquaculture Science (Cefas, UK), under the EU FP7 DEEPFISHMAN project (Grant agreement no. 227390) - Management and Monitoring of Deep-sea Fisheries and Stocks in NE Atlantic, to assess the impacts of restricting fishing activity within these areas during the annual blue ling spawning season (March-May). The area identified as Protection Area 1 (Figure 2) roughly corresponds with part of the European slope, and Protection Area 2 is delineated by three ICES rectangles enclosing the slopes surrounding Rosemary Bank (the top of which is excluded from the protection area). Detailed analyses of blue ling fishing activity during the spawning periods 2007-2010 were used to investigate changes in magnitude and spatial pattern of landings before and after introduction of the protection areas.
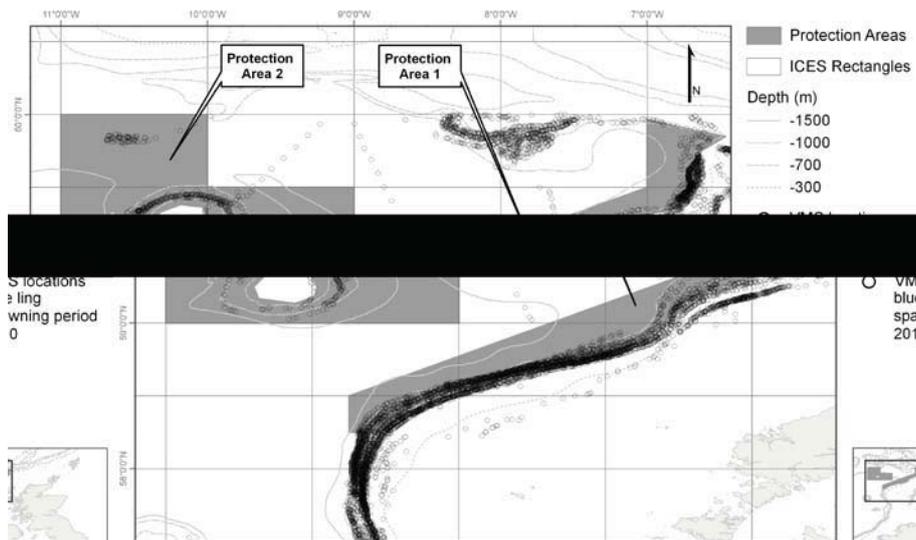
Figure 2: VMS locations in relation to Protection Areas 1 and 2.

2. Methods

Reported landings of blue ling at the ICES rectangle level were apportioned to corresponding VMS activity inside and outside the protection areas during the spawning season. However, the scale of the ICES rectangle is coarse in relation to the spatial distribution of VMS data points (Figure 2), so the apportionment of landings values to VMS point locations does not give a reliable indication of where fishing activity is occurring in relation to the protection area boundaries, especially for VMS points close to those boundaries. Data-flagging vessel entry to, and exit from, restricted fishing areas (as requested for compliance with EC Regulation 1224/2009) would facilitate this apportionment, but these data were not available to the present study. It was, therefore, decided to compare different methods for assessing fishing activity directed towards blue ling in the vicinity of the protection areas during the spawning period. Data were processed and mapped using ESRI ArcGIS v9.3 (www.esri.com/) and the R statistical software package (www.r-project.org/). Three methods used here are described below.

2.1. Method 1: Summation of VMS-apportioned values

Blue ling data at the ICES rectangle level (representing quantities of blue ling landed into UK ports by both UK and non-UK vessels) were collated and assigned to VMS point locations. In summary, a subset of data from the VMS records (i.e. those records containing calculated vessel speeds of 1−6 knots, as a direct indicator of fishing activity; Lee *et al.*, 2010) were identified and matched to records from UK skipper logbooks, or the European fleet register, at the ICES rectangle level to determine gear code, trip and catch information. The total landed weight of blue ling was allocated to the VMS records, based on the fishing time associated with that record as a proportion of total fishing time for the trip. Direct apportionment of blue ling landings values to within, or outside, the protection areas was then achieved by simply summing VMS point values according to whether or not they fell within the protection area boundaries.

2.2. Method 2: Weighted apportionment based on 4-year mean VMS distance from protection boundary

Spatial distribution of blue ling landings by ICES rectangle was weighted according to distance of VMS points from protection area boundaries. The distance calculation was restricted to VMS points within 0.5 decimal degrees of protection boundaries (approximately 56 km at 59°N), to exclude the influence of fishing activity not in close proximity to protection areas; mean and standard deviation values of distance for the entire period 2007–2010 were used to derive weighted buffers within which the ICES-level data could be distributed. The method assumed a normal distribution of VMS points across the protection boundaries (i.e. from inside to outside) and constant mean and standard deviation distance values along all protection boundaries. The weighted values were then apportioned with respect to the protection areas.

2.3. Method 3: Weighted apportionment based on annual mean VMS distance from protection boundary

The method described in Section 2.2 was repeated with three modifications: (i) the distances were used to derive annual weighted buffers for 2007–2010; (ii) the skew of VMS point distribution across the protection boundaries was taken into consideration (but distribution for each year was assumed constant *along* the boundaries); (iii) spatial distribution of blue ling data was weighted by density of VMS points and blue ling quantities associated with those points (as derived in Section 2.1). The data were apportioned to protection areas, as before.

3.   Results

Comparisons between the three methods used to estimate percentage apportionment of blue ling landings between Protection Areas 1, 2 and the unrestricted area (Table 1) indicate that the method used has a marked effect on the final result, particularly in the estimation of blue ling landings for Protection Area 1. The results for Protection Area 2 are similar across all three methods (also indicated by similar values close to 100% in the relevant columns in Table 2, which represents Method 1 estimates expressed as percentages of Methods 2 and 3 estimates, respectively). However, the different methods produce very different estimates for Protection Area 1, with highest estimates produced by Method 1 (Table 1) and correspondingly lower values for landings from the unrestricted fishing areas. Table 2 indicates that the greatest discrepancy for Protection Area 1 estimates arises between Methods 1 and 2, the former estimates being 1.74–4.62 times that of the latter.

These differences can be explained partly by examining the spatial distribution of VMS points in relation to the protection area boundaries (Figure 2). The majority of VMS points in the vicinity of Protection Area 2 fall well inside the area boundary, so all methods produce similar results. However, a large number of VMS points in the vicinity of Protection Area 1 are close to, or straddle, the boundary, introducing a great deal of uncertainty over the apportionment of landings in relation to that protection area.

Table 1: Percentage estimates of blue ling landed* annually from each area using different apportionment methods: VMS summation (Method 1), weighted apportionment (4-yr mean – Method 2) and weighted apportionment (annual mean with skew – Method 3).

Year	Method 1 % Non-protected area	Method 1 % Protection area 1	Method 1 % Protection area 2	Method 2 % Non-protected area	Method 2 % Protection area 1	Method 2 % Protection area 2	Method 3 % Non-protected area	Method 3 % Protection area 1	Method 3 % Protection area 2
2007	64	27	9	82	10	8	74	18	8
2008	56	26	18	73	11	17	67	17	16
2009	73	24	3	84	14	3	76	21	3
2010	71	23	6	82	13	5	76	19	5

*Estimated from VMS points within 0.5 decimal degrees of protection boundaries.

Table 2: Comparison between VMS summation (Method 1) and weighted apportionment (Methods 2 and 3) for estimating annual blue ling landed from each area.

Year	Method 1 estimate expressed as % of Method 2 Non-protected area	Method 1 estimate expressed as % of Method 2 Protection area 1	Method 1 estimate expressed as % of Method 2 Protection area 2	Method 1 estimate expressed as % of Method 3 Non-protected area	Method 1 estimate expressed as % of Method 3 Protection area 1	Method 1 estimate expressed as % of Method 3 Protection area 2
2007	78	262	114	86	151	114
2008	77	244	108	84	153	110
2009	88	174	102	96	116	103
2010	87	180	112	93	123	115

4. Discussion and Conclusion

The results presented in Table 1 do little to suggest that regulatory implementation in 2009 has had a marked impact on the balance of blue ling fishing activity between protected and non-protected areas. Initial results suggest that EC Regulation 43/2009 has produced an overall reduction in blue ling landings during the spawning seasons of 2009 and 2010, but interannual variability in spatial distribution of blue ling landings from VMS signals suggests that additional factors may be affecting fishing activity (e.g. fluctuations in sea temperature or currents which may impact blue ling migrations to spawning grounds). Historical biological evidence and observational reports suggest that most blue ling spawning takes place within the depth range 730−1100 m (Large *et al.*, 2010), and this is supported by findings from the current study, which indicate a mean depth of 750 m associated with maximum blue ling fishing activity (roughly coincident with the southern boundary of Protection Area 1). However, data currently available on spatial and temporal distribution of spawning blue ling (collected in compliance with EC Regulation 43/2009) are too sparse to evaluate the protection boundaries from a biological perspective. Initial findings point to a shift of fishing activity to just outside the protection areas, and this observation, combined with the uncertainty surrounding activity close to the boundaries, highlights the need for close monitoring and robust analysis to support the delineation and possible revision of boundary limits.

The current analysis suggests that Method 3 provides better estimation than Method 2 in marginal locations because the spatial distribution of values is weighted by density of VMS signals in the former method, rather than being spread uniformly across areas where there are few VMS points. A further refinement to

Method 3 would be to account for differences in VMS spread and skew across protection boundaries at the ICES rectangle level, instead of assuming a uniform distribution along the entire length of the boundary.

Tally-book data are recorded on a haul-by-haul basis by French skippers (ICES, 2011; Lorance *et al.*, 2010), but these data were not available for the present study. Such data, combined with a routine increase to hourly VMS signalling frequency outside protection areas, would improve spatial resolution, thereby minimising error in landings allocation. However, the greater the detail, the more work involved, so a balance needs to be struck between accuracy and computational effort. Use of sensors on fishing gear to provide a better indication of actual fishing activity may eventually facilitate more accurate assessment for marine management purposes. Meanwhile, in the absence of direct means of attributing landings data to VMS locations, comparative methods such as those examined here provide a way of determining the likely range of estimates.

Acknowledgements

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