The Spatial Distribution of Commercial Fish Stocks of Interest to Scotland in UK Waters

A report prepared by the University of Aberdeen for the Scottish Fishermen's Federation

January 2017

Executive Summary

1. This report presents analyses of the spatial distribution of 17 selected commercial fish stocks of interest to Scotland. With the exception of mackerel, the data were taken from fishery independent surveys. In most cases these were trawl surveys co-ordinated by the International Council for the Exploration of the Sea.

2. Comparisons were made between the percentages of fish contained within the UKs Exclusive Economic Zone (EEZ) - the estimated spatial percentage (incorporating survey uncertainty), and the percentage of Total Allowable Catch (TAC) allocated to the UK – the quota. The estimated spatial percentages were reasonably stable throughout the analysis periods of three and five years.

3. For most stocks the percentage of TAC allocated (quota) to the UK is much lower than the estimated average percentage of the spatial distribution in the UK. The comparison between the estimated average spatial percentages and quota are given in the following summary table.

Summary Table. Comparison of the UK's quota allocation (%TAC) of stocks of importance to Scotland with the estimated spatial percentage, expressed as the average percentage of the stock in UK waters over 5 years. Stocks are ordered by the magnitude of the difference between these two percentages (red indicates quota is less than the average percentage in UK waters, blue indicates quota is more than the average).

Region	Species	UK quota (% TAC)	Average percentage in UK EEZ (%) over 5 years	Difference from average
North Sea	Herring (mature)	15	88	-73
	Hake	18	60	-42
	Saithe	8	46	-38
	Cod	39	60	-21
	Whiting	62	79	-17
	Haddock	65	80	-15
	Anglerfish	73	61	12
	Herring (immature)	-	10	
West of Scotland	Hake	18	79	-61
	Saithe	46	84	-38
	Cod	60	93	-33
	Herring	60	87	-27
	Whiting	57	83	-26
	Haddock	76	87	-11
	Anglerfish VIa & VIb	31	68	-37
Other	Mackerel	23	36	-13
	Rockall Haddock	78	56	22

4. When the uncertainty associated with the survey data is taken into account, there were two stocks where the UK quota is in line with the amount of fish in the UK EEZ: haddock, in both the North Sea and west of Scotland. In both of these cases the quota allocation (%TAC) lies within the bounds of uncertainty of the estimated spatial distribution percentages. Mackerel is also likely to have a quota allocation in line with the estimated spatial distribution percentages, but no uncertainty estimates were available for this stock.

5. Two stocks have quota allocations that are in excess of the estimated spatial distribution percentages: North Sea anglerfish and Rockall haddock. The quota allocations (73% and 78% of the TACs, respectively) were 6% and 7% greater than the maximum estimates of spatial distribution percentages of these stocks (67% and 71%) respectively.

6. All other stocks have quota allocations that are less than the ***minimum*** estimates of spatial distribution percentages. The largest discrepancies were for North Sea herring, west of Scotland hake, anglerfish in VIa and VIb, west of Scotland herring, cod, saithe and whiting, and North Sea hake (all with differences between the quota allocation and minimum estimates of spatial distribution percentage greater than 10%). Smaller but significant discrepancies were found in North Sea whiting, cod, saithe, and haddock (all with differences of less than 10%).

7. With the exception of haddock, all of the stocks on the west of Scotland considered here, have quota allocations that are at least 15% less than the minimum estimates spatial distribution percentages in UK waters.

Contents

Introduction

European Union (EU) fisheries are currently managed in accordance with the Common Fisheries Policy (CFP), established in 1983. A Total Allowable Catch (TAC) is set annually for each fish stock, and a portion of this TAC is then allocated to each member state as a national quota. Quotas are apportioned according to the relative stability key which reflects historical catch percentages in each fishery (Bellanger *et al.*, 2016). TACs are set according to scientific advice in order to maximise catch and ensuring long-term sustainability (Carpenter *et al.*, 2016).

Brexit and the CFP

In the 2016 United Kingdom (UK) European Union referendum, a majority of British voters expressed a lack of support for the United Kingdom's continued membership of the EU. No definitive timetable has been outlined for Britain's exit ("Brexit") from the EU, but the process is likely to involve extensive negotiations regarding the UK's commitment to various pieces of EU environmental legislation (Boyes and Elliott, 2016) including the CFP. It is also unclear at the time of writing what type of fisheries agreements will be in place in the event of UK leaving the EU.

Spatial Distributions of Fish Stocks

Regardless of how Brexit negotiations unfold, it is worth considering the spatial distribution of fish stocks which occupy UK waters, with future negotiations surrounding changes to European fisheries agreements in mind. The best available understanding of actual fish spatial distributions can be obtained from scientific fish survey data. Fishery catch data is a result of the activity of commercial fishing operations whereby cost-effectiveness is maximised in terms of overall expenditure per catch. Fisheries will thus tend to routinely operate in areas of higher fish density, and so any information on spatial distributions of fish obtained from catch data will be biased. Scientific surveys, on the other hand, aim to capture an unbiased estimate of the entire distribution of fish stocks across the areas they occupy through appropriate sampling schemes (Gunderson, 1993). Nevertheless, scientific surveys have their limitations in terms of survey frequency and sample coverage. The outcomes of scientific surveys are thus subject to uncertainties arising from these logistic limitations. Conditional geostatistical simulations (CGS) may be used to evaluate spatial sampling error in fish survey data, providing estimates of density across the survey domain with associated uncertainty measures (Woillez *et al.*, 2009).

The following work was undertaken by request of the Scottish Fishermen's Federation. The objective of the analysis was to determine the percentage of various commercial fish stocks within the Exclusive Economic Zone (EEZ) of the United Kingdom from survey data where available.

Methods

Data Sources

Unless otherwise specified below, data were downloaded as International Bottom Trawl Survey (IBTS) exchange data from the International Council for the Exploration of the Sea (ICES) DATRAS online database, for years spanning 2011-2015. Swept-area densities (kg km^{-2}) per haul for each species considered were calculated by dividing the weight caught by the product of distance trawled, and either door spread, wingspread or beam length, of each gear type, as appropriate. Anglerfish data (*Lophius piscatorius* and *L. budegassa* survey catches combined) were provided by Marine Scotland Science's (MSS) joint industry-science anglerfish survey, from which swept-area bottom trawl densities (kg km^{-2}) were derived for years spanning 2012-2016. Data for herring stocks was in the form of estimated numbers of immature and mature individuals per ICES statistical rectangle from 2010-2014, obtained from acoustic surveys carried out by the ICES Working Group of International Pelagic Surveys (WGIPS). Mackerel data was in the form of total catch (t) per ICES statistical rectangle from 2010 to 2014, obtained from the ICES Working Group on Widely Distributed Stocks (WGWIDE). Spatial extents of EEZs were obtained from the Marine Regions online database (Claus *et al.*, 2016).

Stock Definitions

The areal extent of each fish stock was aligned as closely as possible with the stock management units outlined in EU council regulations (EC 2016; Table 1) as the analysis would allow. For herring the spatial extent of each stock was assumed to encompass all ICES statistical rectangles within the ICES areas outlined in the stock definitions in Table 1. The mackerel catch dataset was considered in its entirety, with percentages calculated for the UK EEZ, the combined EEZs of other EEA countries, non-EEA EEZs and international waters. For anglerfish, the areal extent of the stock was assumed to encompass the shelf within the ICES areas outlined in the stock definitions to a depth of 1000 m. For all other stocks, their areal extents were assumed to encompass the shelf within the ICES areas outlined in the stock definitions to a depth of 300 m.

Conditional Geostatistical Simulations (CGS)

Where trawl survey data were available, CGS were implemented to generate 500 realisations of the spatial distribution of each stock (see Woillez *et al.*, 2009 for a description of methods). Trawl swept-area density (kg km^{-2}) was the variables simulated, calculated from the weight of each species caught as a function of the area trawled (horizontal door spread multiplied by distance trawled). The first step in CGS involves characterising the spatial structure of fish density using variography (Rivoirard *et al.*, 2000): i.e. the calculation and modelling of variability in density as a function of sample separation distance. Variogram models were implemented as follows:

- Where density data contained both zero values and a small proportion of extreme high density values (these were the conditions observed in the majority of all stocks), data was transformed using an empirical Gaussian anamorphosis before calculation of experimental variograms on the truncated Gaussian-transformed variable. Haul densities with a value of zero were simulated in the Gaussian-transformed variable using a Gibbs sampler.
- Where density data contained extreme high density values but no zeros, the empirical Gaussian anamorphosis transformation was performed and the variograms calculated from the resulting normal distribution.
- Where a random spatial structure was observed in the experimental variogram, an average variogram was calculated on standardised data for all other surveys of the same stock where a spatial structure was detected, and used as a proxy (as per Fernandes and Rivoirard, 1999).

Once a satisfactory variogram model was obtained, 500 realisations of each stock unit were generated using turning band simulations (Woillez *et al.*, 2009) for each survey in a three and five year time-series. The resulting distributions of density realisations were spatially partitioned to give percentages of each stock inside and outside the UK EEZ with upper and lower 95% quantiles for each survey. These distributions were then combined to give percentages of each stock inside and outside the UK EEZ over periods of three and five years.

Percentages per ICES Statistical Rectangle

Where data to facilitate CGS were not available (i.e. herring and mackerel), the percentage of each ICES statistical rectangle lying inside the UK EEZ was calculated using the EEZ shapefile. Catch or assessment data could then be partitioned to percentages inside and outside the UK EEZ, and averaged over periods of three and five years.

Table 1. Stock definitions as outlined in EC (2016).

Region	Species	Stock Definition	Analysis area
North Sea	Cod	IV; Union waters of IIa; that part of IIIa not covered by the Skagerrak and Kattegat	Union waters of IIa, part of IIIa not covered by Skagerrak and Kattegat, IV – to a depth of 300m
	Haddock	IV; Union waters of IIa	
	Hake	Union waters of IIa and IV	
	Herring	Union and Norwegian waters of IV north of 53° 30′ N and IVc & VIId	Union waters of IIa, IV and VIId
	Anglerfish	Union waters of IIa and IV, Norwegian waters of IV	Union waters of IIa, part of IIIa not covered by Skagerrak and Kattegat, IV – to a depth of 1000m
	Saithe	IIIa and IV; Union waters of IIa, IIIb, IIIc and Subdivisions 22-32	Union waters of IIa, part of IIIa not covered by Skagerrak and Kattegat, IV – to a depth of 300m
	Whiting	IV; Union waters of IIa	
Rockall	Haddock	Union and international waters of VIb, XII and XIV	Union waters of VIb down to 300m
	Anglerfish	VI; Union and international waters of Vb; international waters of XII and XIV	Union waters of VIb down to 1000m
West of Scotland	Cod	VIa; Union and international waters of Vb east of 12° 00′ W	VIa shelf to a depth of 300m
	Haddock	Union and international waters of Vb and VIa	
	Hake	VI and VII; Union and international waters of Vb; international waters of XII and XIV	
	Herring	Union and international waters of Vb, VIb and VIaN	Statistical rectangles covered by the assessment which fall within the areas defined for TAC allocation
	Anglerfish	See Rockall, above	VIa shelf to a depth of 1000m
	Saithe	VI; Union and international waters of Vb, XII and XIV	VIa shelf to a depth of 300m
	Whiting	VI; Union and international waters of Vb; international waters of XII and XIV	
Other	Mackerel	IIIa and IV; Union waters of IIa, IIIb, IIIc, and sub divisions 22-32; VI, VII, VIIIa, VIIIb, VIIId and VIIIe; Union and international waters of Vb; international waters of IIa, XII and XIV.	Total Northeast Atlantic fishery

Results

For each stock, the 500 realisation distributions of fish density from CGS were reasonably symmetrical, and were thus equally well represented by the median or the average. Figures 1-3 outline example results from each area analysed. Tables 2 and 3 contain the derived estimates of spatial percentages (with 95% quantiles, where available) inside the UK EEZ for each stock unit considered: estimates are provided as averages over 5 years (Table 2) and 3 years (Table 3). The quantiles represent the minimum (lower 95% quantile) and maximum (upper 95% quantile) percentages of fish that occur in the UK's EEZ. The interval between these minimum and maximum percentages reflects the uncertainty in the survey data from the spatial (sampling locations) and temporal (sampling frequency) coverage. These minimum and maximum values can then be compared to the percentage of TAC allocated to the UK (quota) for each stock unit (Table 2).

There was very little difference between the 3 year and 5 year average percentages. This is evident in the individual survey percentages (Figures 4-20) which were largely stable over time. This reflects some stability in the distribution of fish from year to year. The only case where there was a slight difference between the time periods considered was in North Sea hake, where the 5 year average had a slightly higher lower quantile (31%, Table 2) than the 3 year average (26%, Table 3); but in either case these lower quantiles were higher than the 18% TAC allocation. The North Sea hake estimates were the most variable (Fig. 6) reflecting the potential for the stock to be distributed across the various EEZs. Given this variability, it is better to consider the longer term (5 year) average (Table 2). The estimates of the spatial percentages of saithe were also quite variable (Fig. 10).

The comparison between the average estimated spatial percentages and quota are given in the summary table in the Executive Summary. For most stocks the average percentage of the spatial distribution in the UK is much higher than the percentage of TAC allocated (quota). However, in order for some confidence to be ascribed to any difference between the quota allocation (%TAC) and the [spatial] distributional percentage of the stock in UK EEZ, the upper and lower 95% quantiles (minima and maxima respectively) of the spatial distributions need to be taken into account. Three cases need to be considered:

i) The %TAC is lower than the minimum (lower 95% quantile) estimate of spatial percentage. This indicates that the UK quota is lower than it should be relative to the amount of fish in the UK EEZ.
ii) The %TAC is higher than the maximum (upper 95% quantile) estimate of spatial percentage. This indicates that the UK quota is higher than it should be relative to the amount of fish in the UK EEZ.

iii) The %TAC falls between the minimum and maximum estimates of spatial percentage. The spatial percentage 95% quantile interval includes the quota allocation, so there is no significant difference between the two. This indicates that the UK quota is in line with the amount of fish in the UK EEZ.

There was only one stock where the UK quota is just in line with the spatial distribution of fish in the UK EEZ (case iii above). This was for haddock in the west of Scotland: the allocated quota is 76% of the TAC and the 95% quantiles of the spatial percentage lie between 76% and 96% over 5 years. In all but two of the other cases (North Sea anglerfish, and Rockall haddock) the UK TAC allocation was lower than the minimum estimate of spatial percentage of the stock within the UK EEZ.

In the North Sea, herring, hake, whiting, cod, saithe and haddock, all have %TACs which are lower than the estimated spatial percentages in the UK EEZ (case i above, and see the last column of Table 2 which shows the difference between the %TAC and the minimum estimate of spatial percentage). The biggest difference is in herring, where the UK is allocated 15% of the TAC, but on average, 88% of adult herring are in the UK EEZ. When considered as its immature and mature components, the North Sea herring stock presents an interesting case. The majority of the immature component of the herring stock consistently occurred outside the UK EEZ, whereas the majority of the mature component occurred inside the UK EEZ (Table 2). However, no uncertainty was estimated for this stock, due to the nature of the data. Applying the largest uncertainty interval in the analysis (68% - 12% = 56% for North Sea saithe which is ±23%), would indicate that the herring minimum estimate of spatial percentage would be 65%, which is still very much higher (47%) than the %TAC of 15%. The next largest discrepancy in the North Sea is for hake. The %TAC is 18% yet the minimum estimate of spatial percentage (over 5 years) is 31%, representing a difference of 13%. Whiting is allocated 62% of the TAC, yet the minimum estimate of spatial percentage (over 5 years) is 69%, representing a difference of 7%. Cod, saithe and haddock all have %TACs which are lower than the minimum estimated spatial percentages, but with differences of less than 5%. North Sea anglerfish is the only case in the North Sea where the %TAC (73%) is higher than the **maximum** estimate of spatial percentage of 67% (case ii, above). This indicates that the UK quota for North Sea anglerfish is higher than it should be relative to the amount of anglerfish in the UK EEZ.

With the exception of haddock, all of the stocks in the West of Scotland have %TACs which are lower than the estimated spatial percentages in the UK EEZ (case i above). This outcome was somewhat expected as the majority of the shelf area(s) of the West of Scotland stocks (81% and 82% of the shelf area at 300 m and 1000 m, respectively) are within the UK EEZ. The biggest discrepancy is, once again for hake: the quota is set at 18%

of the TAC and the minimum estimate of spatial percentage was 62%, a difference of 44%. Cod, saithe and whiting stocks on the west of Scotland all had large differences between the quota (%TAC) and the estimated spatial percentage (differences of 19%, 16% and 16% respectively). The herring quota is 60% of the TAC and the average estimated spatial percentage was 87%, without estimate of uncertainty. Using the same largest value of uncertainty as above (±23%), this indicates a potential minimum estimate of spatial percentage of 64%, so the %TAC is still lower, with a difference of 4%, assuming that level of uncertainty. Anglerfish on the west coast encompasses both the west of Scotland and the Rockall bank. The %TAC for this component of the stock is 31%, whereas the minimum estimate of spatial percentage was 65%. So anglerfish, like hake, has much less (34% less) allocated to it as a percentage of the TAC than would be inferred from the spatial distribution in the UK EEZ.

There were two other stocks to consider. Rockall haddock is allocated a quota which is 78% of the TAC, whereas the maximum estimate of spatial percentage was 71%. This indicates that the UK quota for Rockall haddock is higher (by at least 7%) than it should be relative to the amount of haddock in the UK EEZ. Finally, the mackerel stock represented a case where quota (%TAC) was less than the average estimate of spatial percentage, but no uncertainty estimates were available. Given the likely spatial and temporal variability of the other stocks, the mackerel quota seems likely to be in line with the spatial distribution, although at 23% it is 13% lower than the average estimate of spatial percentage of 36%.

Table 2. Average percentage of stocks (%) inside the UK EEZ with 95% quantiles where available over 5 years. Percentage of 2016 TAC (unless alternative year is specified) allocated to the UK for each area (EC 2016) is included for comparative purposes. Percentages are colour-coded according to whether: the allocated TAC is 0-5% less than the lower quantile or fixed value (*) of the spatial distribution, 5-10% less than the lower quantile or fixed value (*), or >10% less than the lower quantile or fixed value (*) [%TAC are significantly lower than the distribution implies]; or the allocated TAC is 5-10% more than the lower quantile or fixed value (*) [%TAC are significantly higher than the distribution implies]; or no shading, which indicates that the quantiles overlap the TAC allocation [%TAC are in line with the spatial distribution]. Diff is the difference between %TAC and the lower quantile of the spatial distribution (for negative values, indicating the %TAC is too low by at least this percentage) or between %TAC and the upper quantile of the spatial distribution (for positive values indicating the %TAC is too high by at least this percentage), unless indicated* which are differences from average values.

Region	Species	UK quota (% TAC)	Average percentage in UK EEZ (%) over 5 years	Upper 95% Quantile	Lower 95% Quantile	Diff from quantile
North Sea	Herring (mature)	15	88	-	-	-73*
	Hake	18	60	84	31	-13
	Whiting	62	79	89	69	-7
	Cod	39	60	74	43	-4
	Saithe	8	46	68	12	-4
	Haddock	65	80	93	66	-1
	Anglerfish	73	61	67	56	6
	Herring (immature)	-	10	-	-	
West of Scotland	Hake	18	79	91	62	-44
	Anglerfish VIa & VIb	31	68	73	65	-34
	Herring	60[2]	87	-	-	-27*
	Cod	60[1]	93	99	79	-19
	Saithe	46	84	98	62	-16
	Whiting	57	83	93	73	-16
	Haddock	76	87	96	76	0
Other	Mackerel	23[3]	36	-	-	-13*
	Rockall Haddock	78	56	71	27	7

[1]EC (2011): Council Regulation (EU) No 57/2011

[2]EC (2015): Council Regulation (EU) No 2015/104

[3]Based on UK 2015 allocation of 247,296 t from total of 1,054,000 t coastal states total catch limitation.

Data sources: percentages of herring stocks were calculated from WGIPS stock assessment abundance estimates (numbers of fish); percentages of the mackerel stock were calculated based on commercial catch weight data; all other percentages were calculated based on survey swept-area density (kg km^{-2}) data.

Discussion points

- CGS provides density surfaces for each survey with uncertainty estimates which may be used to evaluate the spatial sampling uncertainty in the survey data. Combining these over multiple surveys within and over years, provides a measure of the uncertainty in the time domain.

- The outcomes of the turning band simulation are dependent on the spatial structure of the survey data, as defined by the variogram. An automatic fitting algorithm was used to fit model variograms in the above analysis (Desassis and Renard, 2013). This makes the process objective and repeatable, but the resultant models were quite variable in terms of autocorrelation range depending on the characteristics of the data. Simulated spatial distributions ranged from being highly structured to noisy, even for the same stock.

- Where the spatial structure was noisy (a variogram from a single survey with no detected structure) an average variogram was used to describe the spatial structure of a stock. This assumes that the spatial distribution of the stock is persistent from survey-to-survey (or from year-to-year). Although this assumption is commonly applied in similar analyses (see Fernandes and Rivoirard, 1999), it may not be wholly justifiable in light of evidence that some stocks are collapsing or recovering, and shifting their distribution in space (e.g. Baudron and Fernandes, 2015).

- Each unique realisation from the CGS procedure presents a patchily distributed variable, where high density areas are aggregated and infrequently encountered in space. The median realisation thus provides a more plausible representation of the spatial distribution of the stock than a smooth kriged map does, or than the average density surfaces derived here from each distribution of realisations (Figures 1-3).

- The area boundaries used in the CGS did not exactly align with the areas as specified for the allocation of TAC. Scientific surveys are limited to reasonable domains within which it is expected that most of the stock will occur, according to the biology of the species and observations across the survey time-series. In addition, CGS was limited to a single, spatially continuous area polygon in each case, meaning that stocks such as anglerfish where TAC is allocated across the entirety of ICES VI (as well as Union and international waters of Vb; international waters of XII and XIV) were simulated separately for shelf areas of ICES VIa and VIb.

- The mackerel catch data used in calculating percentages per statistical rectangle is biased in terms of its representation of the actual spatial distribution of the stock, because fishery activity is concentrated on areas of high fish density. However, given the regular migratory pattern exhibited by the stock and the tendency of the fishery to operate according to it, the catch data should give a reasonable representation of the stock distribution across a given year. However, the percentage share of the total catch has also been affected by the fact that some countries increased their own catch allocation unilaterally.

Acknowledgments

With thanks to the crews, fishers, and scientists from whom data was obtained. This work was funded by the Scottish Fishermen's Federation.

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Table 3. Average percentage of stocks (%) inside the UK EEZ with 95% quantiles where available over 3 years. Percentage of 2016 TAC (unless alternative year is specified) allocated to the UK for each area (EC 2016) is included for comparative purposes. Percentages are colour-coded according to whether: the allocated TAC is 0-5% less than the lower quantile or fixed value (*) of the spatial distribution, 5-10% less than the lower quantile or fixed value (*), or >10% less than the lower quantile or fixed value (*) [%TAC are significantly lower than the distribution implies]; or the allocated TAC is 5-10% more than the lower quantile or fixed value (*), [%TAC are significantly higher than the distribution implies]; or no shading, which indicates that the quantiles overlap the TAC allocation [%TAC are in line with the spatial distribution]. Diff is the difference between %TAC and the lower quantile of the spatial distribution (for negative values, indicating the %TAC is too low by at least this percentage) or between %TAC and the upper quantile of the spatial distribution (for positive values indicating the %TAC is too high by at least this percentage), unless indicated* which are differences from average values.

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North Sea	Herring (mature)	15	85	-	-	-70*
	Hake	18	60	84	26	-8
	Whiting	62	78	88	67	-5
	Cod	39	59	73	41	-2
	Saithe	8	43	67	10	-2
	Haddock	65	77	89	66	-1
	Anglerfish	73	61	67	56	6
	Herring (immature)	-	9	-	-	
West of Scotland	Hake	18	79	91	60	-42
	Herring	60	88	-	-	-28*
	Anglerfish VIa & VIb	31	65	73	57	-26
	Cod	60	93	99	78	-18
	Whiting	57	80	87	71	-14
	Saithe	46	82	96	59	-13
	Haddock	76	85	91	75	1
Other	Mackerel	23	37	-	-	-14*
	Rockall Haddock	78	65	71	60	7

[1] EC (2011): Council Regulation (EU) No 57/2011

[2] EC (2015): Council Regulation (EU) No 2015/104

[3]Based on UK 2015 allocation of 247,296 t from total of 1,054,000 t coastal states total catch limitation.

Data sources: percentages of herring stocks were calculated from WGIPS stock assessment abundance estimates (numbers of fish); percentages of the mackerel stock were calculated based on commercial catch weight data; all other percentages were calculated based on survey swept-area density (kg km^{-2}) data.

Figures

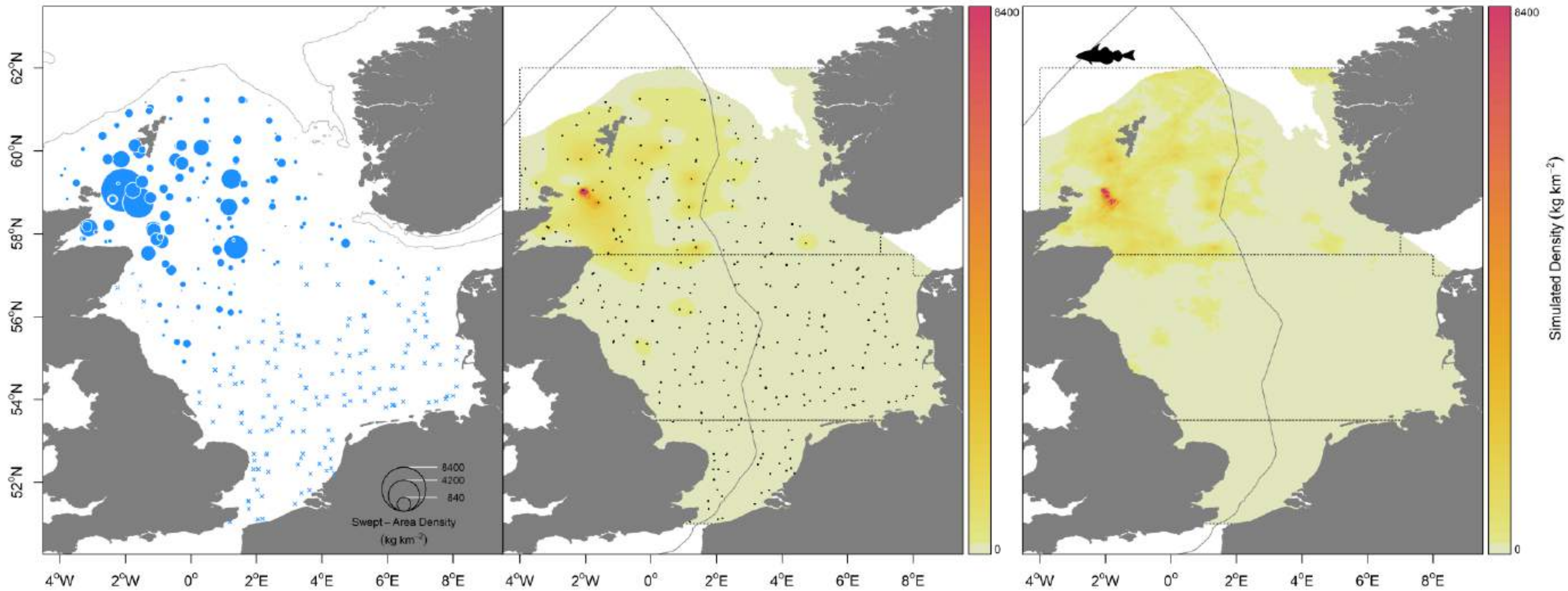

Figure 1. Conditional geostatistical simulation analysis plots for 2013 Quarter 1 North Sea haddock: IBTS swept-area density data used for the analysis (*left*), with 300m bathymetry contours in grey; average density surface calculated from 500 simulated realisations (*centre*) with survey haul locations represented as black points; median density surface of the 500 simulated realisations (*right*). The UK EEZ is delineated with a solid grey line, and ICES areas with dotted black lines (*centre* and *right*).

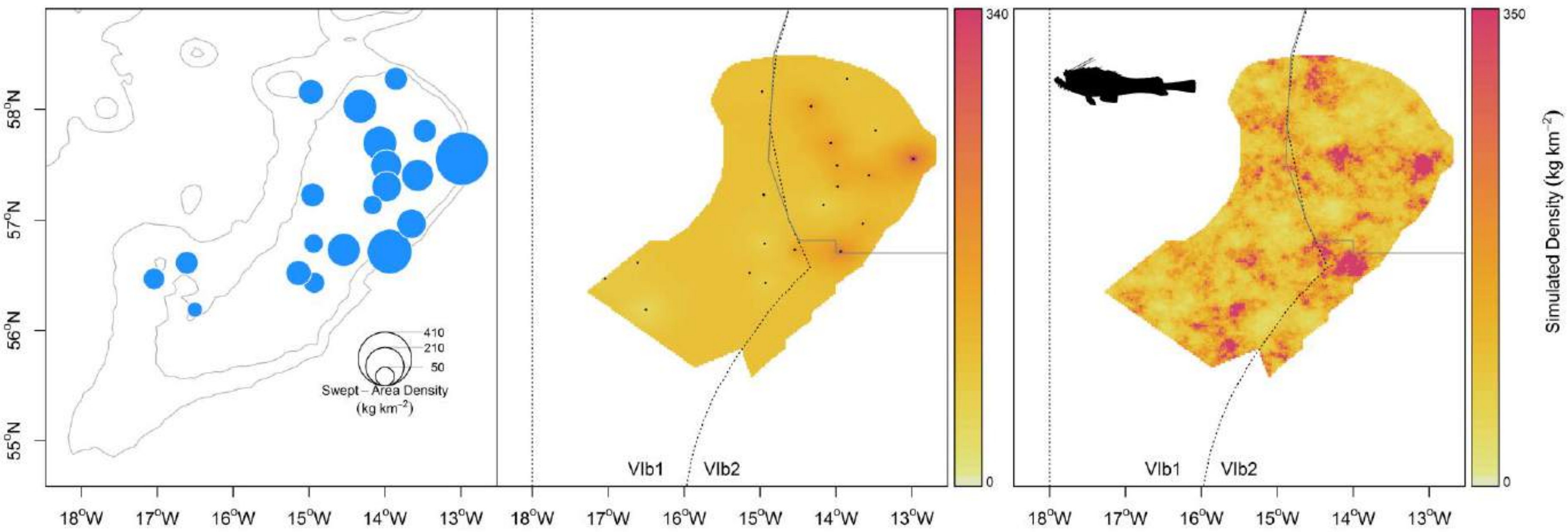

Figure 2. Conditional geostatistical simulation analysis plots for 2014 Rockall anglerfish: Joint industry-science survey swept-area density data used for the analysis (*left*), with 500m and 100m bathymetry contours in grey; average density surface calculated from 500 simulated realisations (*centre*) with survey haul locations represented as black points; median density surface of the 500 simulated realisations (*right*). The UK EEZ is delineated with a solid grey line, and ICES areas with dotted black lines (*centre* and *right*).

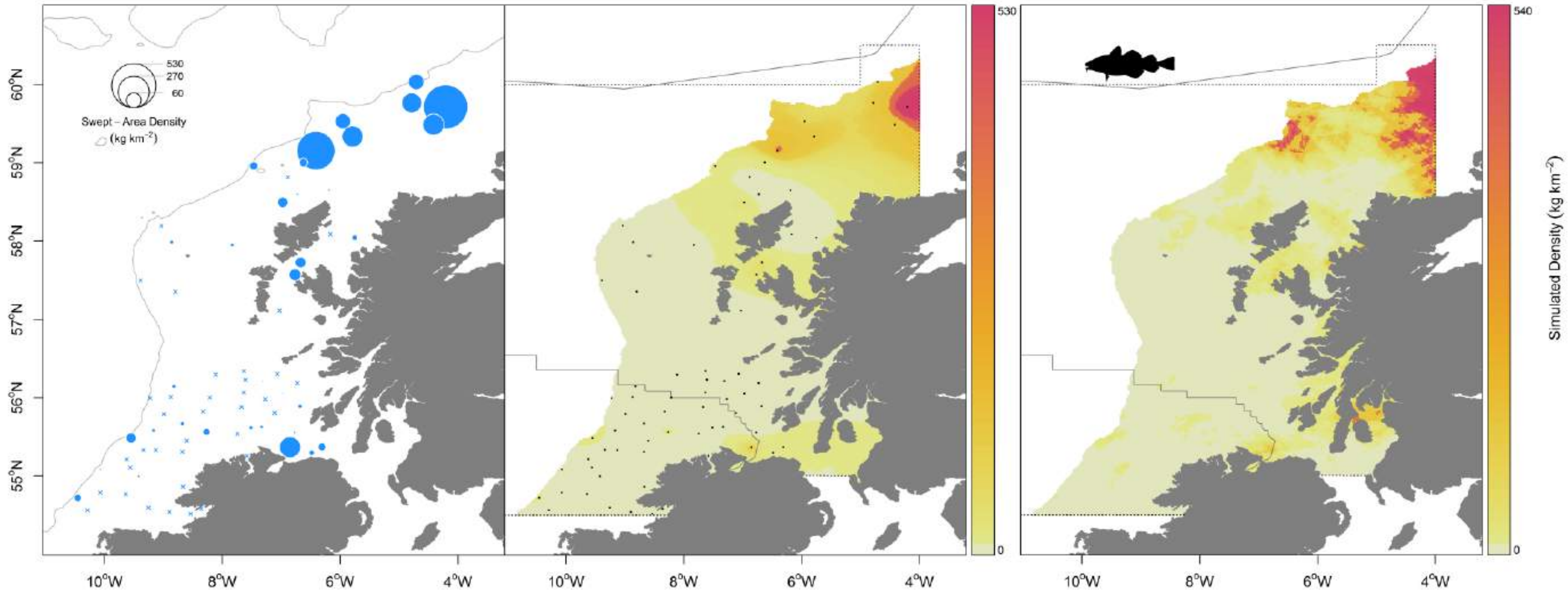

Figure 3. Conditional geostatistical simulation analysis plots for 2013 Quarter 4 West of Scotland cod: IBTS swept-area density data used for the analysis (*left*), with 300m bathymetry contours in grey; mean density surface calculated from 500 simulated realisations (*centre*) with survey haul locations represented as black points; median density surface of the 500 simulated realisations (*right*). The UK EEZ is delineated with a solid grey line, and ICES area VIa with a dotted black line (*centre* and *right*).

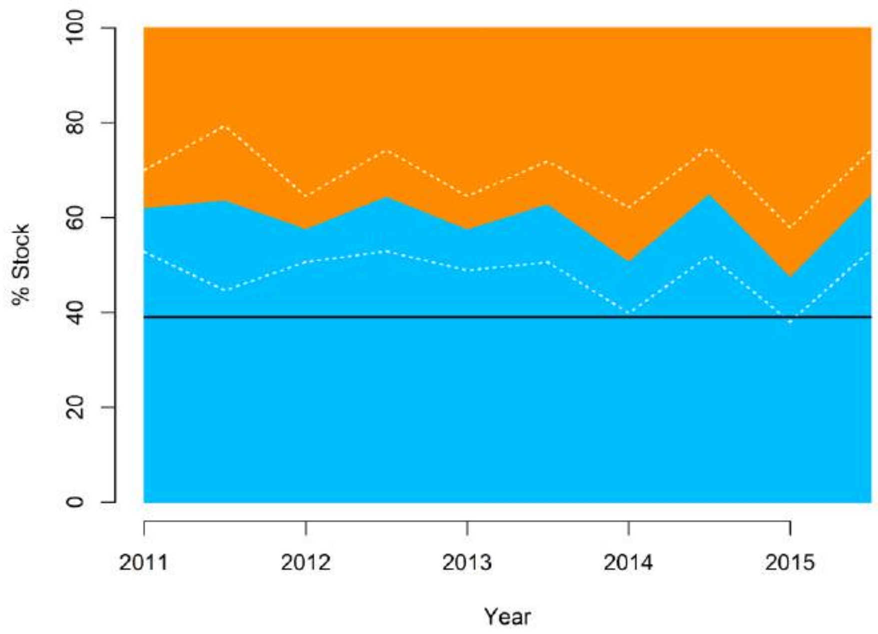

Figure 4. Percentage of North Sea cod stock (%) within the UK EEZ (blue), simulated using Q1 and Q3 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

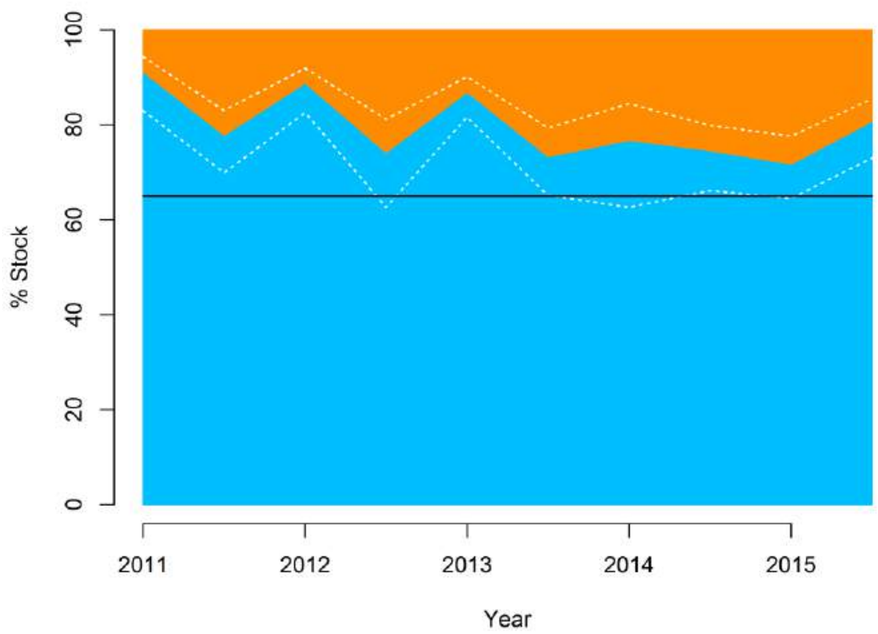

Figure 5. Percentage of North Sea haddock stock (%) within the UK EEZ (blue), simulated using Q1 and Q3 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

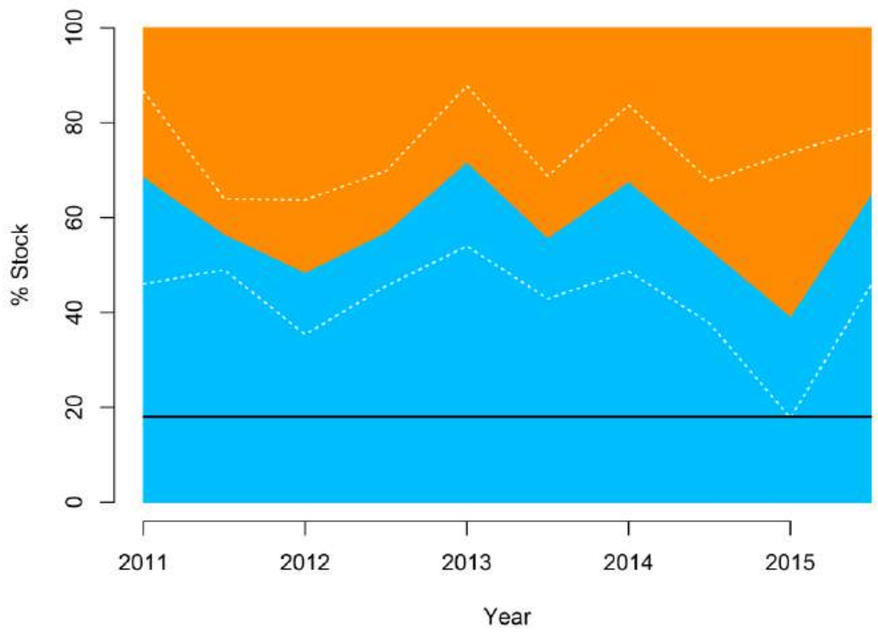

Figure 6. Percentage of North Sea hake stock (%) within the UK EEZ (blue), simulated using Q1 and Q3 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

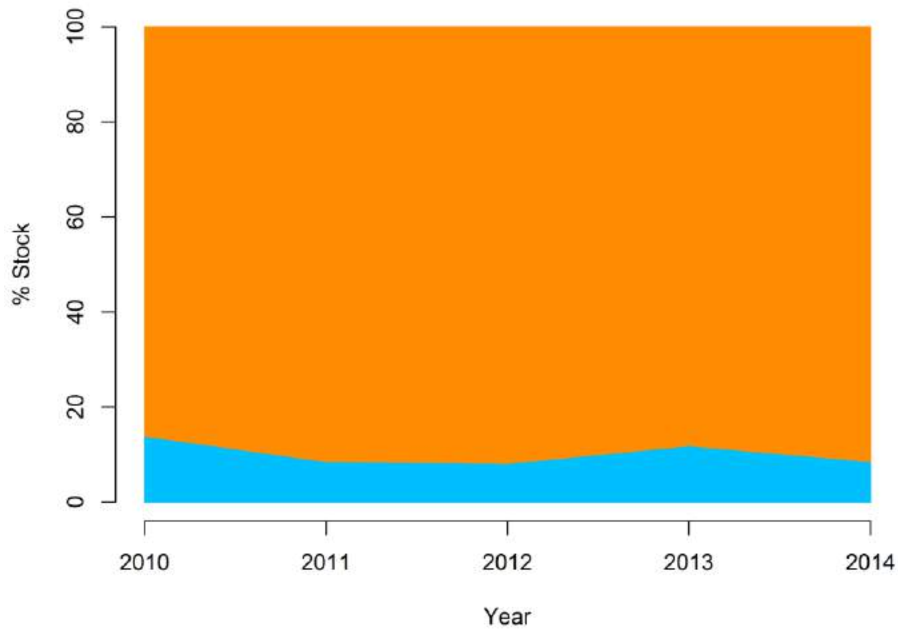

Figure 7. Percentage of the immature component of the North Sea herring stock (%) within the UK EEZ (blue), calculated as the percentage of estimated abundance per ICES statistical rectangle inside the UK EEZ.

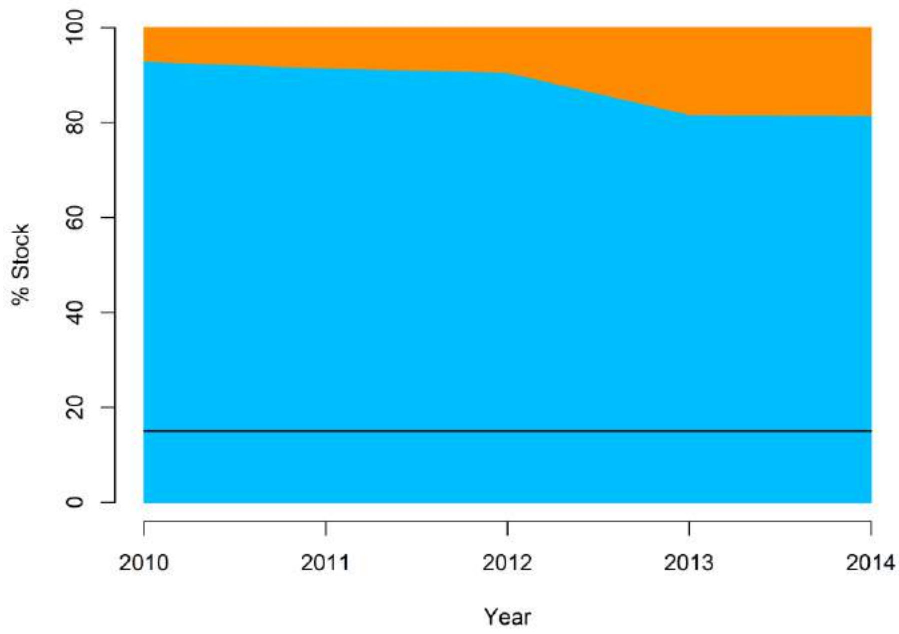

Figure 8. Percentage of the mature component of the North Sea herring stock (%) within the UK EEZ (blue), calculated as the percentage of estimated abundance per ICES statistical rectangle inside the UK EEZ. The solid black line shows the UK TAC allocation as a % of the total allocation.

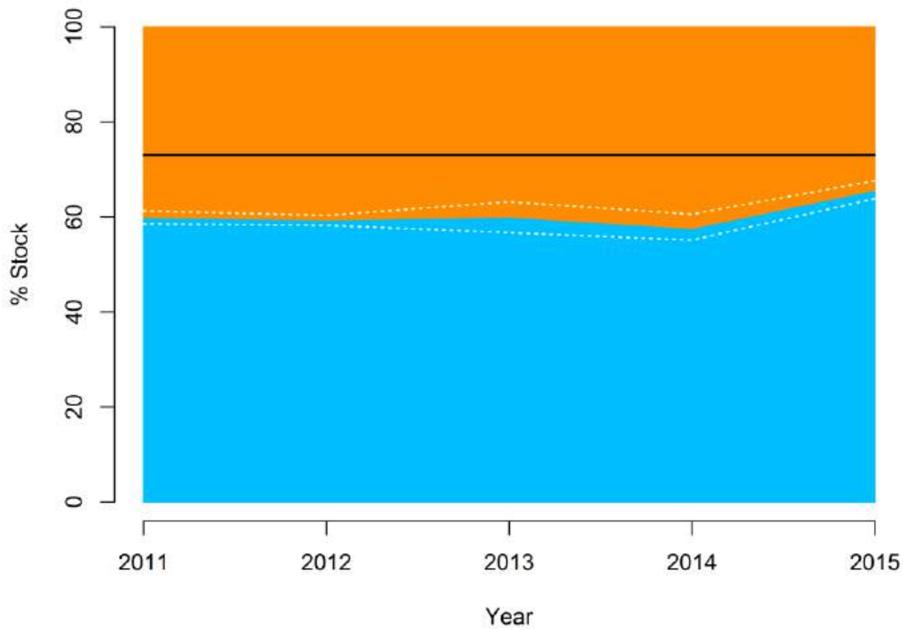

Figure 9. Percentage of North Sea anglerfish stock (%) within the UK EEZ (blue), simulated using Q1 and Q3 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

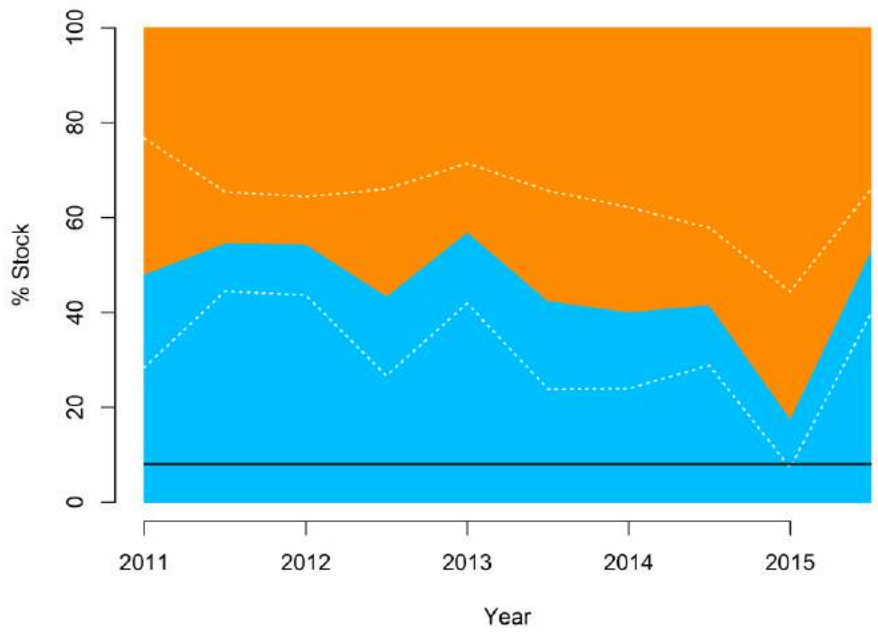

Figure 10. Percentage of North Sea saithe stock (%) within the UK EEZ (blue), simulated using Q1 and Q3 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

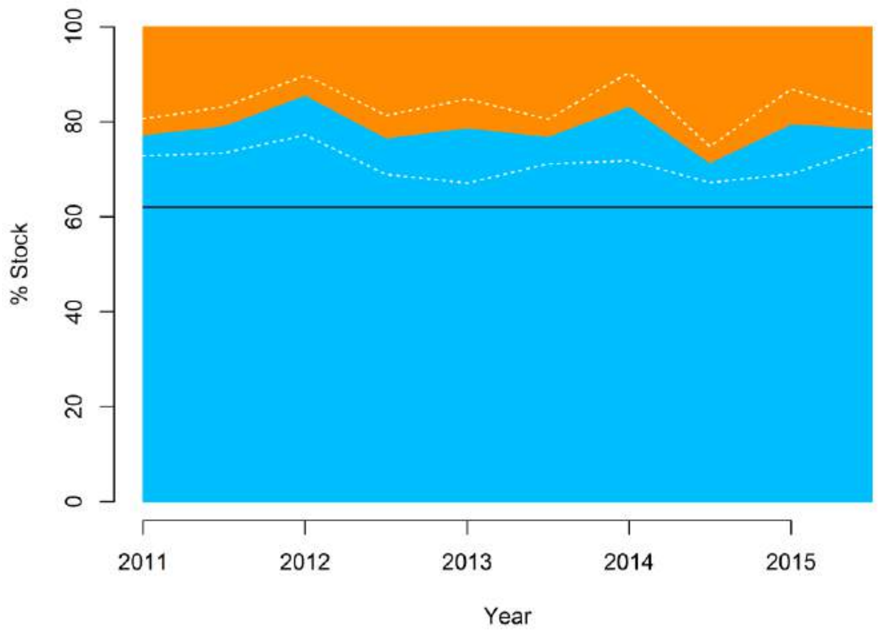

Figure 11. Percentage of North Sea whiting stock (%) within the UK EEZ (blue), simulated using Q1 and Q3 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

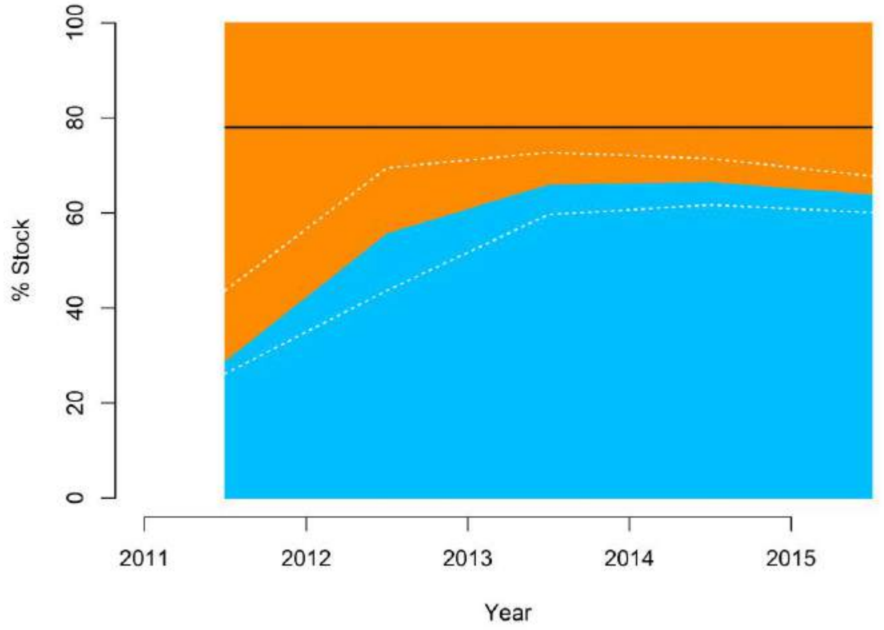

Figure 12. Percentage of Rockall haddock stock (%) within the UK EEZ (blue), simulated using Q3 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

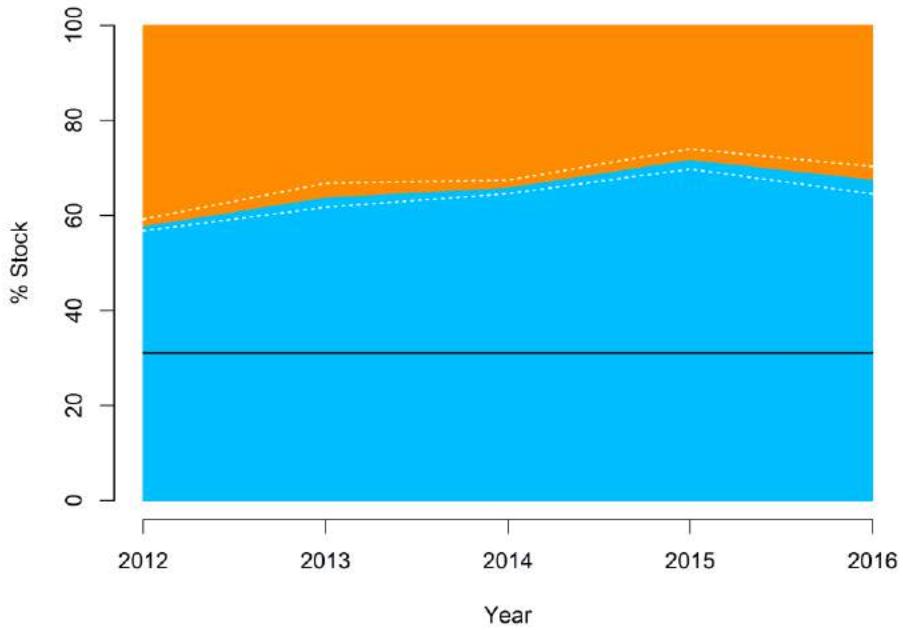

Figure 13. Percentage of anglerfish stock in VIa & VIb (%) within the UK EEZ (blue), simulated using joint industry-science anglerfish survey data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

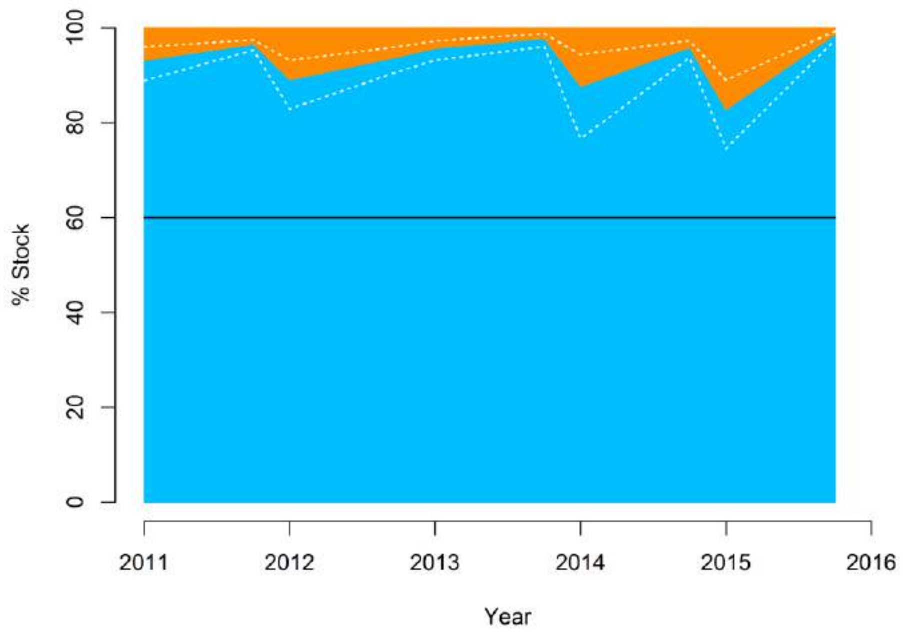

Figure 14. Percentage of West of Scotland cod stock (%) within the UK EEZ (blue), simulated using Q1 and Q4 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

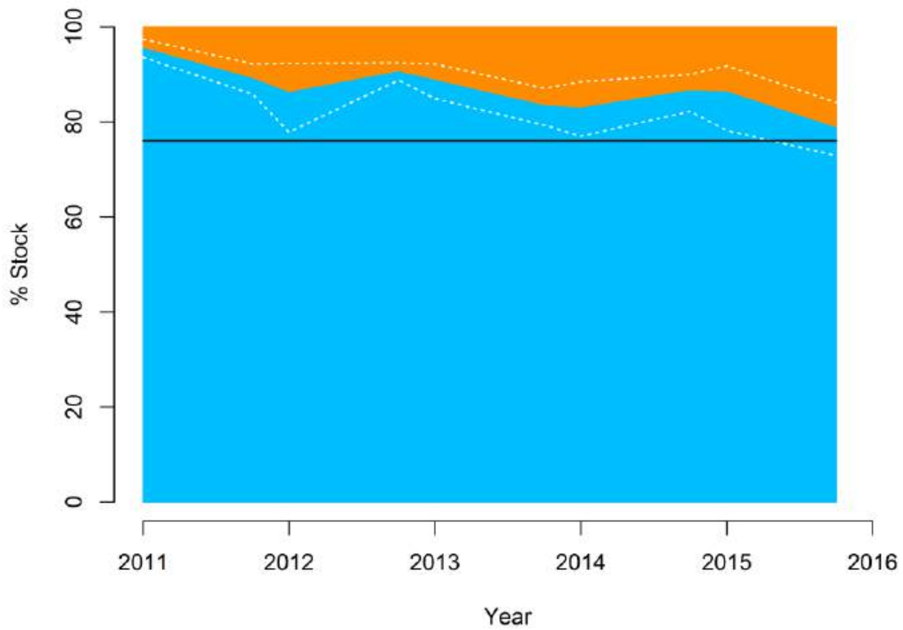

Figure 15. Percentage of West of Scotland haddock stock (%) within the UK EEZ (blue), simulated using Q1 and Q4 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

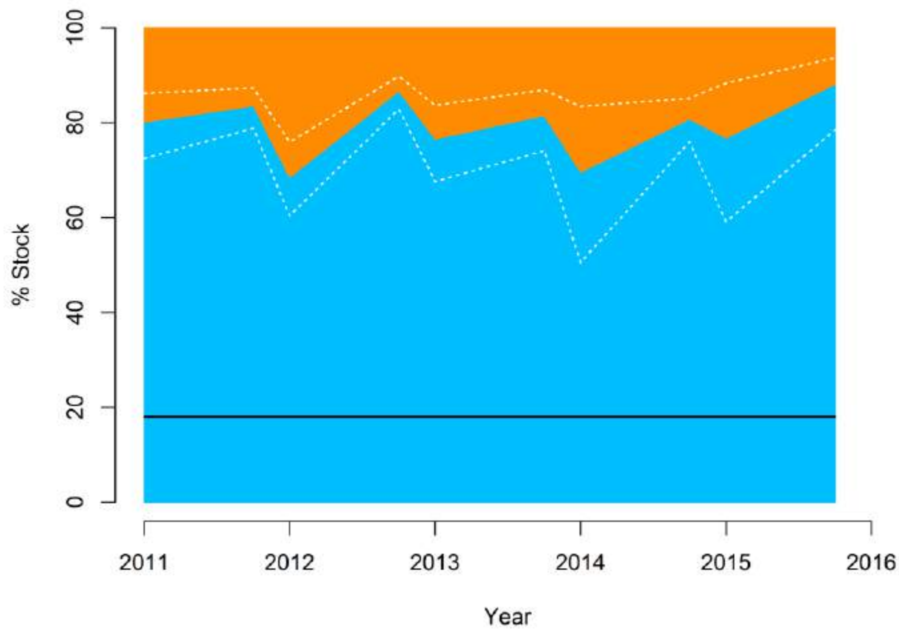

Figure 16. Percentage of West of Scotland hake stock (%) within the UK EEZ (blue), simulated using Q1 and Q4 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

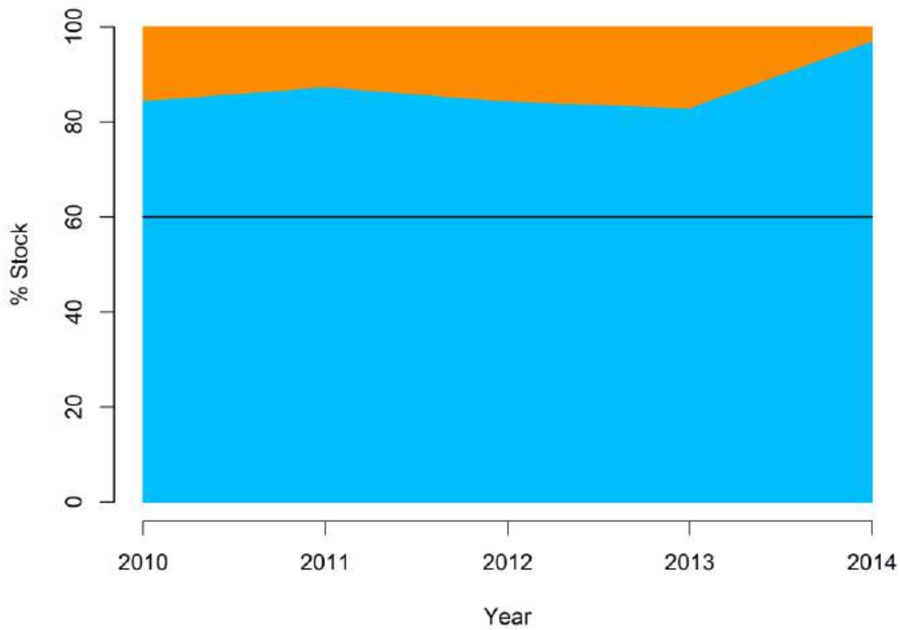

Figure 17. Percentage of West of Scotland herring stock (%) within the UK EEZ (blue), calculated as the percentage of estimated abundance per ICES statistical rectangle inside the UK EEZ. The solid black line shows the UK TAC allocation as a % of the total allocation.

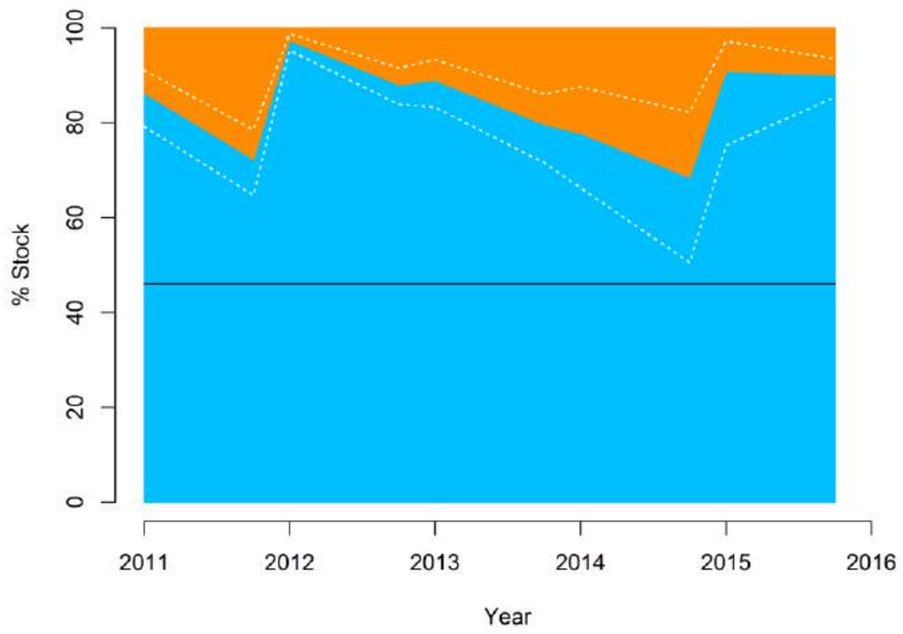

Figure 18. Percentage of West of Scotland saithe stock (%) within the UK EEZ (blue), simulated using Q1 and Q4 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

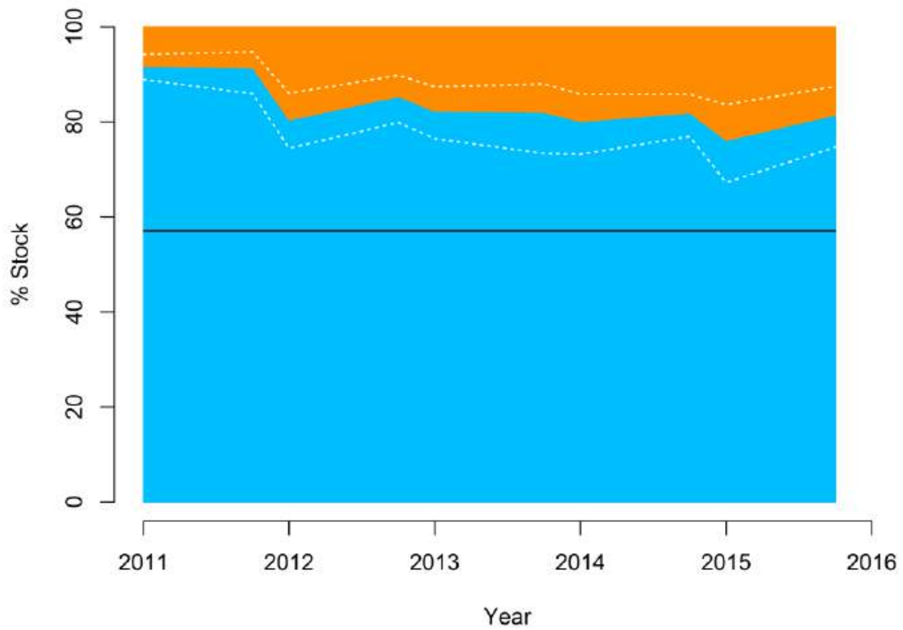

Figure 19. Percentage of West of Scotland whiting stock (%) within the UK EEZ (blue), simulated using Q1 and Q4 IBTS data. The white dotted lines show the upper and lower 95% quantiles. The solid black line shows the UK TAC allocation as a % of the total allocation.

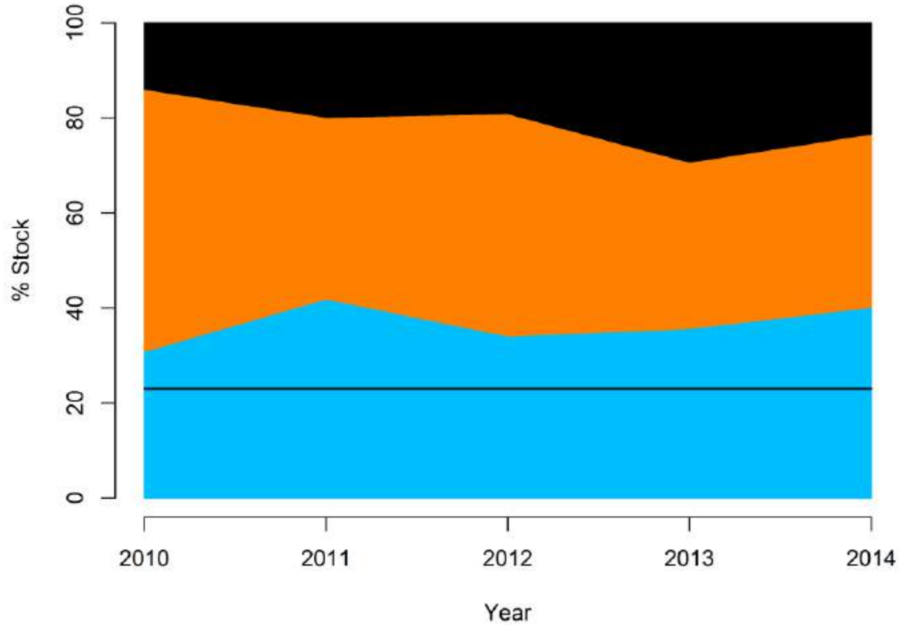

Figure 20. Percentage of mackerel stock (%) within the UK EEZ (blue), within the EEZs of other EEA countries (orange), and outside of the EEA (black), calculated as the percentage of catch per ICES statistical rectangle. The solid black line shows the UK TAC allocation as a % of the total allocation.