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LETTER

Fish distributions reveal discrepancies between zonal attachment and quota allocations

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PF conceived the idea for the paper, including the formulation of zonal attachment, and wrote the manuscript; NF conducted the simulations, produced the figures and tables, and wrote the Materials and Methods.

Tweetable abstract: We define and provide empirical estimates of Zonal Attachment–an objective basis for allocating fish quota in transboundary fish stocks.

Tweetable image: supplied as 2011_Q1_NS-IBTS_Cod_stops.gif.

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Abstract

The oceans' fisheries contribute to human wellbeing by providing essential nutrients, employment, and income. Changes in fish distribution, due to climate change or stock expansion, jeopardize conservation objectives because fishers catch more than is allocated as quota. Quotas, or catch shares, should, therefore, correspond to the share of the fish stock biomass present within a country's Exclusive Economic Zone, a concept known as Zonal Attachment. Here, we assess the Zonal Attachment of transboundary fish stocks present in northern Europe, in the waters of the United Kingdom, the European Union (without the United Kingdom), and Norway. In 12 of 14 important fish stocks, estimates of Zonal Attachment to the United Kingdom were significantly higher than current quota allocations, explaining the country's substantial discard problem. With environmental change, and stock recovery under improved fisheries conservation, scientific evidence should be used not only to set catch limits, but also to re-examine catch shares.

KEYWORDS

Common Fisheries Policy, discards, distribution, fish, quotas, zonal attachment

1 | INTRODUCTION

The global contribution of fish to the provision of food and livelihood for human societies is recognized under the United Nations' Sustainable Development Goal 14: "conserve and sustainably use the oceans, seas and marine resources for sustainable development" (FAO, 2018). The conservation of fish stocks is gradually being achieved (Costello et al., 2016; Fernandes & Cook, 2013; Worm et al., 2009), but only in jurisdictions with adequate resources to determine and enforce catch limits based on scientific advice (Fernandes et al., 2017). In northern Europe, catch limits, or Total Allowable Catches (TACs), are set annually for the major fish stocks which occur in the Exclusive Economic Zones (EEZs) of European Union (EU) member states and coastal states such as Norway. Between EU member states, the TAC is then apportioned into national quotas using a fixed allocation key under the "relative stability" (RS) concept, based, largely, on their catches from over 40 years ago. These catches reflected what nations' fishing fleets were targeting at the time, rather than what resources were present: the United Kingdom, for example, had a large distant water fleet operating outside its current EEZ. Fish distributions have also changed, due to expansion (Baudron & Fernandes, 2015), or climate change (Pinsky et al., 2018), so fishers now encounter and catch more than their allocated quota, leading to overfishing (Spijkers & Boonstra, 2017) or discarding (Fernandes et al., 2011). Discarding was a particular problem in Europe, so the latest reform of the EU's

Common Fisheries Policy (EC, 2013) introduced a discard ban, aka the Landings Obligation (LO). Here, we analyze distributions of fish showing that quota shares based on RS bear little relevance to the resources available within national jurisdictions, which is a significant impediment to reducing discards.

In assigning quota, or more generally fishing rights, neither the United Nations Convention on the Law of the Sea (UNCLOS, 1982), nor the subsequent United Nations Straddling and Highly Migratory Fish Stock Agreement indicate what the distribution principles might be. Various allocation mechanisms are applied throughout the world (Bailey, Ishimura, Paisley, & Rashid Sumaila, 2013). In Pacific tuna fisheries, Parties to the Nauru Agreement allocate fishing days amongst fishing nations according to the distribution of biomass and catch history (Aqorau, 2009). Similarly, Pacific halibut and sablefish quota is shared between the United States and Canada according to regional biomass estimates (Cox, Ianelli, & Mangel, 2013). On the east coast, catch shares of cod, haddock and yellowtail flounder are largely apportioned according to the distribution of biomass in the United States and Canada, with 10% based on catch history (Gavaris & Murawski, 2008). In Europe, the allocation of quota for certain stocks between Norway and Iceland (Ásgeirsdóttir, 2007), and Norway and the EU (Hannesson, 2013), apply a similar concept, termed Zonal Attachment (Z_a). Z_a is an estimate of what percentage, on average, of a transboundary stock is found within each EEZ of associated coastal states. However, there is no consensus on the estimation of Z_a, and EU/Norway agreements refer to the "Nantes report" (ICES, 1978), which just lists criteria for long-term proportional allocation. So here, we also propose a new mathematical formulation of Z_a, and base it on percentages of biomass in coastal state waters derived from a geostatistical analysis of survey data. Although this work was prompted by the potential exit of the United Kingdom from EU (and UK ambitions to become an independent coastal state), the concept is applicable more generally to provide an objective basis for negotiations of the allocation of quota in transboundary fish stocks. The EU might also consider it to help comply with the LO and contribute to more effective fisheries conservation.

2 | MATERIALS AND METHODS

2.1 | Data selection and biomass distributions

We selected 14 of the most important transboundary fish stocks occurring in the waters of the United Kingdom, EU, and Norway. Details of the stocks and selection process are given in Supporting Information. We used fishery independent survey data from the International Council for the Exploration of the Sea (ICES). Data for most stocks were taken from the International Bottom Trawl Survey for years spanning 2011–2015. Anglerfish data (*Lophius piscatorius* and *L. budegassa* combined) were provided by Marine Scotland Science from their joint industry-science anglerfish survey. Data for the North Sea herring were based on acoustic surveys obtained from the ICES Working Group of International Pelagic Surveys.

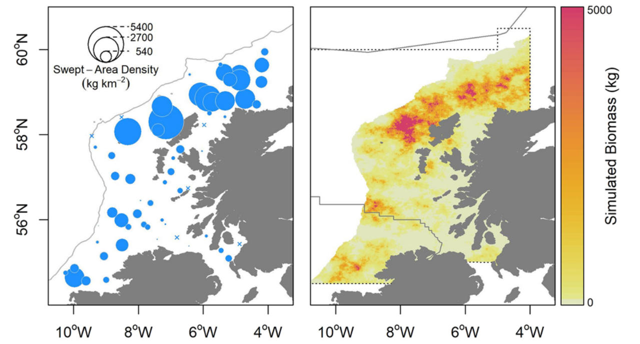

FIGURE 1 Maps of the West of Scotland showing: international bottom trawl survey swept-area density estimates (filled blue circles, kg/km^2, x indicates zero) of adult haddock from the 2012 Quarter 1 survey (left), with 300 m bathymetry contours in grey. These were used to generate 500 conditional geostatistical simulations: the realization corresponding to the median biomass estimate (in kg at 1 km^2 resolution) is shown on the right. The European Union and United Kingdom Exclusive Economic Zones are delineated with a solid grey line, and International Council for the Exploration of the Sea Area VIa with a dotted black line

We used conditional geostatistical simulations to generate estimates of fish stock biomass (Woillez, Rivoirard, & Fernandes, 2009) at high spatial resolution (1 km^2, e.g., Figure 1). These provide statistical distributions of estimates which account for natural autocorrelation in the populations (Rivoirard, Simmonds, Foote, Fernandes, & Bez, 2000), as well as the variability due to spatio-temporal coverage (see Supporting Information). The resulting biomass distributions of each stock were spatially partitioned to give mean percentages $\bar{P}$, within the EEZs a, by life stage s, and time period t, ($\bar{P}_{a,s,t}$), of the territorial waters of the EU (excluding the United Kingdom), Norway, and United Kingdom, with upper and lower 95% quantiles. Where data were not available for simulations (i.e., North Sea herring), biomass was apportioned according to the percentage of each ICES statistical rectangle lying inside the respective EEZs.

2.2 | Definition of zonal attachment

Zonal attachment (Z_a) should be based on the spatial distribution of both adults and juveniles (ICES, 1978), best obtained from fishery-independent survey data. Biomasses of all life stages of the stock are not always available from the surveys (due, for example, to age- or length-specific survey selectivity): these are best obtained from a stock assessment, which integrates multiple data sources. We define zonal attachment (Z) for a particular EEZ a, within the total area A (where $\Sigma a = A$), as

$$Z_a = \sum_s \sum_t \bar{P}_{a,s,t}.T_t.\bar{W}_s, \quad (1)$$

where s is the life stage (which can be ages, length classes, or, in the present case, simply adults and juveniles), and t is a particular time period in the year (e.g., quarter) for when $\bar{P}$, the mean spatial percentage of fish biomass, is estimated (such that $\Sigma\, \bar{P}_a = 100$ for each s and each t). T is the proportion of the year spent in a given area ($\Sigma T = 1$) measured at time t, and $\bar{W}_s$ is the mean proportion of total population biomass for a given life stage ($\Sigma\, \bar{W}_s = 1$). W_s were taken from the equivalent stock assessments as the numbers at stage s multiplied by the mean weights at s. In the present case we used arithmetic means, $\bar{P}$ and $\bar{W}$, of 5 years, in keeping with fishery management plans which are reviewed every 5 years in the EU. Z_a is, therefore, an estimate of the mean of the spatiotemporal biomass percentages of fish at a life stage and time period, weighted by the proportions of the best estimates of the total weight of that life stage. Examples of the estimation of Z_a based on the above equation are provided in Tables S2 and S3, with the latter being a conceptual example population which migrates seasonally across five EEZ's.

3 | RESULTS

The confidence intervals of spatial percentages of the biomass of juveniles and adults overlapped in most cases (Figure 2), but there were examples where percentages of juveniles were higher than those of adults, particularly in EU waters, for example, North Sea plaice (*Pleuronectes platessa*), whiting (*Merlangius merlangus*) and herring (*Clupea harengus*). So it was important to weight the different life stages appropriately in the estimation of Z_a. Across all stocks there were large differences between the estimates of Z_a and the current quota shares ($\%TAC_a$). We assumed that these differences were statistically significant when $\%TAC_a$ fell outside the confidence limits of the respective mean adult biomass spatial distribution. This is because the current quota shares, based on RS, relate to historic catches, which were mainly of adults. In all 14 cases, quota shares allocated to the EU were higher than the Z_a of stocks in the EU (i.e., $\%TAC_{EU} > Z_{EU}$): 12 of these were statistically significant. In one case, North Sea herring, we did not have access to the raw data to determine the statistical significance of the difference, but $\%TAC_{EU}$ was 16% higher than Z_{EU}. In the remaining case, west of Scotland haddock (*Melanogrammus aeglefinus*), $\%TAC_{EU}$ was also higher than Z_{EU} (by 13%) but the mean spatial percentage of adult biomass was not significantly different (Figure 2a).

The largest discrepancy was in the case of northern hake (*Merluccius merluccius*) in the North Sea: 2% of the stock in the North Sea was in EU waters, but the EU is allocated 82% of the catch; Norway had 40% of the stock in their waters, yet it gets no quota; whereas the United Kingdom, which had 58% of the stock in its waters, only gets 18% of the catch. Conversely, in all but two cases, $\%TAC_{UK} < Z_{UK}$. In addition to hake, North Sea cod (*Gadus morhua*), haddock, plaice, saithe (*Pollachius virens*) and whiting all had $\%TAC_{UK}$ which were significantly lower than Z_{UK} (Figure 2b). In the case of North Sea herring, $\%TAC_{UK}$ was 36% lower than Z_{UK}. North Sea anglerfish is the only case in the North Sea where $\%TAC_{UK}$ (74%) was significantly higher than Z_{UK} (65%), indicating that the UK quota for North Sea anglerfish is 9% higher than it should be relative to the amount of anglerfish present in the UKs EEZ. Similarly, in the West of Scotland, $\%TAC_{UK}$ was significantly lower than Z_{UK} for all stocks (Figure 2a) except haddock, which was lower but not significantly so, and Rockall haddock which, like North Sea anglerfish, was significantly higher (by 15%). As for Norway, 3 stocks had significant differences between Z_{NO} and $\%TAC_{NO}$, and in each case (anglerfish, cod and hake) $\%TAC_{NO} < Z_{NO}$.

4 | DISCUSSION

As a new independent coastal state, the United Kingdom would have the sovereign rights to exploit, conserve and manage the natural resources in its EEZ (UNCLOS Article 56.1.a), although it must exercise these rights with due regard to those of other states (UNCLOS Article 56.2). This represents an opportunity for new allocation mechanisms as fish distributions change (House of Lords, 2008). Like Norway and other coastal states, the UK government now advocates for quota allocations based on Z_a (DEFRA, 2018), but it has only started to explore how to do this (DEFRA, 2018). Using catches would give a biased representation of Z_a, because catches are restricted by current quota allocations (base of the arrows, Figure 2). The current dilemmas experienced by the Indian Ocean Tuna Commission (Andriamahefazafy, Kull, & Campling, 2019) illustrate the problems with using catch, as local coastal states do not have the catch history of the industrialised distant water fleets. Catches also reflect high fish density, not high biomass, and the two are not always equivalent.

Other methods of estimating Z_a, based on bio-economics, have been proposed (Hannesson, 2006, 2013), but these have been theoretical exercises. Extra weighting could also be given to areas where migrating animals feed or reproduce. However, there is no reason to suppose that one particular life strategy is more advantageous than another to the survival of the population. Fish select for the habitat(s), which not only maximize energy gain, but also minimize the risk of mortality (Gilliam & Fraser, 1987). So feeding is no less important

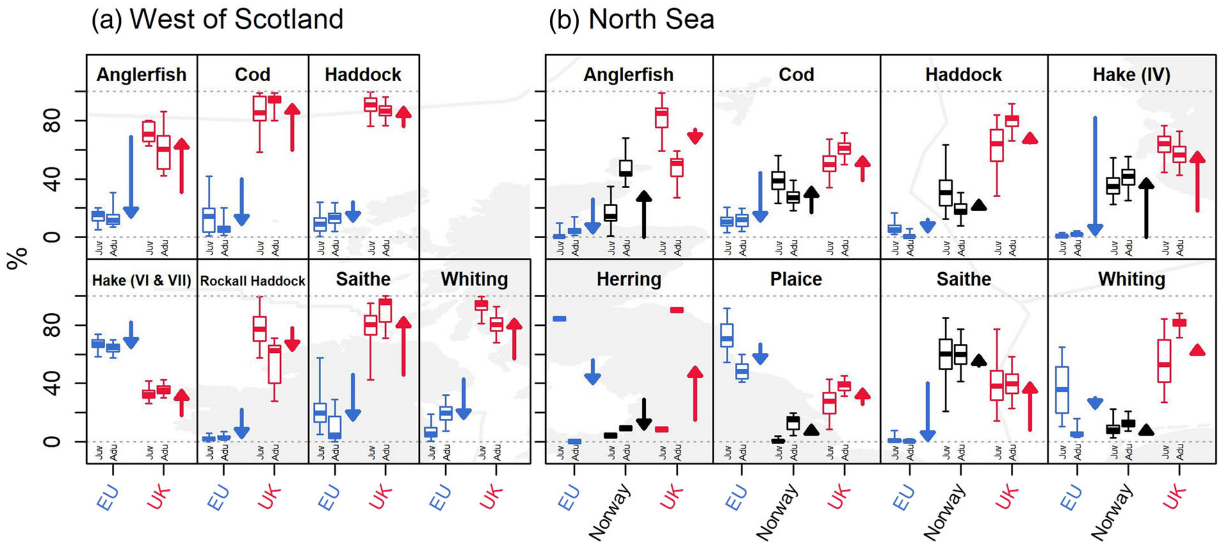

FIGURE 2 Boxplots of percentages of spatiotemporal distributions of juvenile (Juv) and adult (Adu) components of (a) west of Scotland, and (b) North Sea, fish stocks within the Exclusive Economic Zones of the European Union (blue), Norway (black) and the United Kingdom (red). The base of the arrows indicate the value of the current quota share (*%TAC*), and arrow tips are the estimate of zonal attachment: down arrows represent quotas which are greater than zonal attachment; up arrows represent quotas that are less than zonal attachment. Estimates of $Z = 19\%$ for the West of Scotland Anglerfish stock, and of $Z = 34\%$ for the Rockall haddock stock were calculated for high seas areas, outside of national EEZs

than predator avoidance (Brönmark, Skov, Brodersen, Nilsson, & Hansson, 2008), recovery from infection (Shaw & Binning, 2016), or seeking optimal oceanographic conditions (Guraslan, Fach, & Oguz, 2017). Most examples of quota allocation amongst transboundary stocks are based on some combination of historical catches and biomass distributions (Bailey et al., 2013), and where surveys exist, the emphasis is on biomass (Cox et al., 2013; Gavaris & Murawski, 2008). The interdisciplinary Nordic Marine Think Tank review (Dankel et al., 2015) concluded that Z_a should be based on the distribution of biomass, by zone, season, and age group, excluding egg and larvae, hence our definition.

In the present case, there are at least three examples which highlight the significance of these results for dealing with the LO within northern Europe. Z_{UK} of West of Scotland cod and whiting were 91 and 84% respectively c.f. $\%TAC_{UK}$ of 60 and 57% respectively. Both stocks are in such a dire condition, that scientific advice has been to set catches to zero (cod) or the lowest possible level (whiting) since the early 2000s. However, these fish are inevitably caught in a mixed demersal fishery, so minimal by-catch limits are permitted. Previously, this still led to high levels of discarding, and under the current LO, this could lead to a closure of the fishery as $\%TAC_{UK}$ is rapidly exhausted. Recent scientific advice (ICES, 2017) includes alternative catch options of cod on the basis of the precautionary approach. If the United Kingdom was allocated its Z_{UK} 91% of the TAC, catches would be in line with the UK 5-year average catch (including discards). Z_{EU} was 9%, which, under the similar catch option would provide EU (Irish and French) fleets with amounts that would cover their expected catch also. This would allow these fleets to comply with LO and under previous catch options, also have allowed spawning stock biomass to increase. In the case of whiting, the situation is more difficult because there have been fewer catch options which would result in a biomass increase. Applying the Z_{UK} estimated here (84%) would nonetheless reduce total unwanted catch to a few tens of tons and subject the stock to a very low fishing mortality ($F < 0.1$).

Hake has been heavily discarded by the UK demersal fishing fleet for several years (Baudron & Fernandes, 2015). In 2011, for example, the United Kingdom was allocated a quota of 348 t of North Sea hake, from a TAC for the area of 1935 t. By acquiring quota from other sources (Hoefnagel, de Vos, & Buisman, 2015), Scottish fleets landed 3035 t of hake, but still discarded 4993 t. Even if they had been allocated the Z_{UK} share calculated here (58%, c.f. 18% quota share given) it would have only accounted for 14% of what was caught. In this case the problem is not only with the allocation of TAC within the management unit (North Sea), but in the distribution of the TAC across the entire Northern hake stock (Table 1). In 2011, the TAC for the entire stock was 55105 t, but only 3% of this was allocated to the North Sea, and only 18% of that was allocated to the United Kingdom. So in the North Sea, the United Kingdom is allocated less than 1% of the total hake TAC, yet over 28% of the total hake stock occurs in UK waters of this area (Table 1). The discard problem also persists, with a total of 4189 t being discarded in 2016 in the North Sea (ICES, 2019). We estimated $Z_{NorthSea}$ to be 48% (Table 1). Applying this share to the 2011 TAC would have meant a North Sea TAC of 26450 t, and applying the Z_{UK} of

TABLE 1 Estimates of zonal attachment (Z_a) for the northern hake stock, by management area and by EEZ within each management area, compared to current quota shares (*% TAC*). Adult spatial biomass percentages were significantly different to current quota shares for all stock management units. Red shading represents quotas that are greater than zonal attachment; green shading represents quotas that are less than zonal attachment

Management area	Z_a	% TAC	Z_{EU}	% TAC_{EU}	Z_{NO}	% TAC_{NO}	Z_{UK}	% TAC_{UK}
III	3	3	56	100	44	0	–	–
IV	48	3	2	82	40	0	58	18
VI & VII	40	57	65	82	–	–	35	18
VIII	9	37	100	100	–	–	–	–

58% would have allocated a UK quota of 15341 t. This would have totally eliminated the discard problem for hake from that fleet. Similar scenarios could be built for North Sea cod and saithe, which were discarded in large quantities (e.g., 9,079 t & 6,478 t discarded respectively in 2017) and have significant imbalances in the allocation of quota compared to where the fish occur.

As a new coastal state, a complete switch to Z_a may be possible for the United Kingdom, but it may be disruptive to current socio-economic structures and international relations. However, the United Kingdom is also committed to an LO, so the status quo is more problematic. Stocks could be considered individually, and only those with large differences between old and new quota allocations (larger arrows, Figure 2) which create problems (i.e., hake) could be dealt with first. A gradual transition could take place, as occurred in northeastern United States and Canada where the ratio of biomass to historical catch weighting increased from 60 to 90% over 7 years (Gavaris & Murawski, 2008). Quota transfers (Hoefnagel et al., 2015) could assist to mitigate for discarding in the interim period. In any case, there are examples where even the largest quotas of the problematic stocks are not even taken, which should make political implementation easier. For example, in 2018, Spain was allocated 31,499 t of Northern hake quota, but only caught 26,078 t; France was allocated 58,274 t and caught 41,260 t (ICES, 2019). Given the improved status of stocks in Europe, there is now ample evidence for a review of relative stability to establish a more scientific basis for setting catch shares in line with current distributions of fish, just as there is a scientific basis for setting catch limits. Zonal attachment should be employed to ameliorate intransigent problems presented by the landings obligation in mixed fisheries (Sobrino & Sobrido, 2017). This applies not only to Europe, but globally, so that the oceans, seas and marine resources can be conserved and used for sustainable development.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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