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Original Article

Comparisons of landings to scientific advice indicate overshooting within the common TAC for skates and rays in the Northeast Atlantic

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Abstract

The International Council for the Exploration of the Sea (ICES) typically provides advice on fishing opportunities on a stock-by-stock basis. Nevertheless, levels of total allowable catch (TAC) are sometimes set for a collection of stocks and species (i.e. a common TAC). An explicit expectation of these is that landings will scale with ICES advice, especially when ICES advice is used to calculate the common TAC. This expectation is tested for skates and rays in the Northeast Atlantic, spanning 26 stocks, 8 species, and 3 ecoregions. Using ICES landings and ICES advice data from 2016 to 2022, we show that landings of several stocks and species have overshot their respective ICES advice, whereas others have undershot. Specifically, some stocks of blonde ray (*Raja brachyura*) in North Sea and Celtic Seas ecoregions are being landed at a rate that often exceeds double its ICES advice. By collating species based on their ICES assessment category and life-history traits, we find that those considered data-poor and potentially most vulnerable to fishing are consistently landed at higher-than-expected rates in the Celtic Seas. This study questions the appropriateness of a common TAC for skates and rays and calls for shifts towards the use of single-stock catch allocations and the application of advanced stock assessment methodologies.

Keywords: advice; fisheries management; Rajiformes; skates and rays; total allowable catch

Introduction

The exploitation of commercial fish stocks is generally managed on a single-stock or multiple-stock basis. In the latter, stocks with shared characteristics are often grouped together, and total allowable catch (TAC) is set as part of a common TAC. These characteristics likely include shared species identity or taxonomic families, similar life-history traits, or comparable susceptibility and/or catchability to specific fishing gears. Additionally, common TACs might apply to species subject to misidentification during landings, such as spotted ray (*Raja montagui*) and blonde ray (*R. brachyura*). They are also commonly used for nontarget species or those that are considered data-poor due to insufficient catch, abundance, and biological information. Examples of management by common TAC occur across the globe. For instance, in the Alaskan groundfish fishery, several species of sculpin (the Bering Sea and Aleutian Islands Sculpin Complex) and skates (the Gulf of Alaska Skate Complex) are managed using common TACs, with annual catch limits set for each complex (Reuter et al. 2010). Similarly, in the Northeast Atlantic, the European Commission (EC), in line with the European Union's (EU) Common Fisheries Policy (CFP), and the United Kingdom (UK) apply common TACs to manage the exploitation of nontarget species such as turbot (*Scophthalmus maximus*) and brill (*Scophthalmus rhombus*), as well as lemon sole (*Microstomus kitt*) and witch flounder (*Glyptocephalus cynoglossus*) [Council Regulation (EU) 2022/515].

Since 1999, the EC has also used a common TAC for skates and rays in the North Sea. This was extended to three ecoregions in 2009 and is now applied in the Celtic Seas [International Council for the Exploration of the Sea (ICES) subarea 6 and divisions 7.a-c and 7.e-k; SRX/67AKXD], Bay of Biscay and Iberian coast (ICES subareas 8 and 9; SRX/89-C), and Greater North Sea (ICES subarea 4 and divisions 2.a, 3.a, and 7.d) (STECF 2022). The latter has been separated into three TAC areas: Union waters of ICES division 3.a (SRX/03A-C); UK and Union waters of ICES division 2.a and subarea 4 (SRX/2AC4-C); and UK and Union waters of ICES division 7.d (SRX/07D). In total, these common TACs include 29 stocks of at least 10 species. Note, however, that within the ICES's framework for stock assessment and advice, certain stocks may also encompass species without individual stock assessments. For instance, the sailray (*Rajella lintea*) and Arctic skate (*Amblyraja hyperborea*), among other rays and skates in ICES subarea 4 and divisions 3.a and 7.d, fall into this category and often form an unknown part of these stocks.

Table 1. Skate and ray species/stocks considered in the analysis.

Species (Latin name)	Species (common name)	ICES stock code	Ecoregion	ICES category (3, 5, or 6)
Raja clavata	Thornback ray	rjc.27.3a47d	GNS	3
Raja clavata	Thornback ray	rjc.27.6	CS	3
Raja clavata	Thornback ray	rjc.27.7afg	CS	3
Raja clavata	Thornback ray	rjc.27.7e	CS	5
Raja clavata	Thornback ray	rjc.27.8	BI	3
Raja clavata	Thornback ray	rjc.27.9a	BI	3
Raja microocellata	Small-eyed ray	rje.27.7de	CS/GNS	5
Raja microocellata	Small-eyed ray	rje.27.7fg	CS	3
Leucoraja fullonica	Shagreen ray	rjf.27.67	CS	5
Raja brachyura	Blonde ray	rjh.27.4a6	GNS	5
Raja brachyura	Blonde ray	rjh.27.4c7d	GNS	3
Raja brachyura	Blonde ray	rjh.27.7afg	CS	5
Raja brachyura	Blonde ray	rjh.27.7e	CS	5
Raja brachyura	Blonde ray	rjh.27.9a	BI	3
Leucor*aja circularis*	Sandy ray	rji.27.67	CS	5
Raja montagui	Spotted ray	rjm.27.3a47d	GNS	3
Raja montagui	Spotted ray	rjm.27.67bj	CS	3
Raja montagui	Spotted ray	rjm.27.7ae-h	CS	3
Raja montagui	Spotted ray	rjm.27.8	BI	3
Raja montagui	Spotted ray	rjm.27.9a	BI	5
Leucoraja naevus	Cuckoo ray	rjn.27.3a4	GNS	3
Leucoraja naevus	Cuckoo ray	rjn.27.678abd	CS/GNS/BI	3
Leucoraja naevus	Cuckoo ray	rjn.27.8c	BI	3
Leucoraja naevus	Cuckoo ray	rjn.27.9a	BI	3
Raja undulata	Undulate ray	rju.27.7bj[a]	CS	6
Raja undulata	Undulate ray	rju.27.7de[a]	CS/GNS	3

Ecoregions are listed as the Bay of Biscay and Iberian coast (BI), the Celtic Seas (CS), and the Greater North Sea (GNS). ICES category indicates the type of dataand assessment model used to provide scientific advice on fishing opportunities for the years 2016–2022.
[a]Not included in the common TAC.

An explicit expectation when using a common TAC is that exploitation rates should approximately scale with stock status and fisheries advice. This is especially true for skates and rays in the Northeast Atlantic, whereby the method used to calculate the annual common TAC emerges as a function of the single-stock advice provided by ICES (ICES 2022a, STECF 2022). The exact method used to calculate the annual common TAC has changed through time, but generally involves an annual mean change in ICES advice or a summed total of ICES advice at the species or assemblage level. Independent of these changes, in a simplified case of two species, A and B, with advice of 1000 and 100 tonnes, respectively, it is generally expected that species A (the more abundant species) will make up a large majority (∼90%) of the catch. In fact, we would argue that achieving this expectation is critical to ensuring sustainable exploitation.

Past studies have shown that skates and rays are particularly vulnerable to exploitation (Frisk et al. 2005, Ellis et al. 2008b, McCully Phillips et al. 2015). They are slow-growing and have relatively low fecundity, which results in low intrinsic growth rates at the stock level; and implies that sustainable exploitation is only possible at low to moderate fishing mortality rates (King and McFarlane 2003). Further, census population numbers are typically smaller than those in teleost fish stocks (Ellis et al. 2010). Consequently, it is widely accepted that special consideration needs to be given to their exploitation, including regular evaluation of the appropriateness of current management actions (STECF 2017).

Here, we investigate the appropriateness of a common TAC for skates and rays in the Northeast Atlantic from 2016 to 2022. Specifically, we explore whether the explicit expectation of the common TAC is met and evidence instances of landings either overshooting or undershooting single-stock advice. In doing so, we highlight a direct mismatch between scientific advice and current levels of exploitation, whereby those species and stocks currently classified as data-poor and potentially most vulnerable to fishing are being landed at much higher rates than suggested by ICES.

Materials and methods

Data

Three primary data sources were used in this study: ICES estimated landings data, ICES scientific advice, and annual common TAC values. Landings data for the period 2016–2022 were sourced from the dataset collated by the ICES Working Group for Elasmobranch Fishes (WGEF; ICES 2023a). Landings data are stock-specific and are provided to WGEF in tonnes per ICES division or subarea. Here, landings by stock have been summarized by year and are assigned to ecoregions (Greater North Sea, Celtic Seas, or Bay of Biscay and Iberian coast) as listed in Table 1, and Supplementary Tables S1 and S2. ICES estimated discard data are also collated by WGEF but were not considered here as for most stocks discard estimates are highly uncertain (ICES 2023a). Stock-specific ICES advice for 2016–2022 was collated from ICES advice in tonnes per year (Supplementary Table S3) and are assumed to pertain to landings and not total catch (including discards). Annual common TAC values, in tonnes per ecoregion, were taken from the EU Council Regulations and are detailed in Supplementary Tables S4 and S5.

In 2016, representatives of ICES and ICCAT (International Commission for the Conservation of Atlantic Tunas) collaborated in a special workshop (ICES 2017) to examine the landings and stock identity of elasmobranchs assessed by the

WGEF. This expert group assigned all reported landings of each assessed species to appropriate stock units. Rules were drafted to correct for known errors, such as frequent species misidentifications or the use of different common names in different regions. This therefore allowed for the automatic reassignment of incorrectly assigned landings or discards to their correct stock units. These stock units were first used for advice by WGEF 2016 (ICES 2016) and have seen minimal modifications since then. However, despite advancements, landings prior to 2015 are not believed to be as accurate as those used after this point. Moreover, in 2014, ICES implemented staggered advice, issuing 2015 advice for skates and rays in the Celtic Seas and Bay of Biscay and Iberian coast ecoregion followed by 2016 advice for the Greater North Sea ecoregion and Azorean waters for 2016. Consequently, 2016 was used as the starting year for this analysis.

ICES stock assessments are performed in different categories (i.e. 1–6), depending on the availability of data and the levels of confidence in the available data. These categories range from well-documented stocks allowing comprehensive analytical assessments and forecasts (category 1) to those relying solely on landings or discard data (categories 5 and 6). For ICES category 3 stocks (which is used for 17 of the stocks considered here), ICES advice is produced using a biomass or abundance trend, catch index measured in landings per unit effort (LPUE) or catch per unit effort (CPUE), derived from scientific surveys or commercial catches. In comparison, the advice for category 5 and 6 stocks (9 stocks) stems from catch (including discards) or landings data over time. For almost all skate and ray stocks, ICES applies a precautionary approach (PA), which is designed to account for uncertainty in estimates of stock status, and aims to prevent or reduce potential risks to the sustainable exploitation of fish stocks. However, a substantial shift occurred in 2022, where ICES moved away from employing the PA approach to adopting a maximum sustainable yield (MSY) approach, utilizing length-based empirical models for all category 3 stocks (Fischer et al. 2020).

Stocks were only considered in this analysis if they had reported landings or ICES advice and were part of the common TACs. In summary, a total of 26 stocks were considered, including 8 species (Table 1). Two stocks of undulate ray, *R. undulata*, in the south and southwest of Ireland (rju.27.7bj) and in the English Channel (rju.27.7de) were included in our analysis; however, neither are currently included in one of the common TACs. That said, ICES catch advice for the years 2021 and 2022 for these two stocks was 0 (rju.27.7bj; ICES 2020a) and 2552 tonnes (rju.27.7de; ICES 2020b), respectively, and such large differences mean it is of interest to include them in our analysis.

Advice by ecoregion

ICES advice is provided by stock, and stocks often straddle multiple ecoregions. To compare landings per ecoregion to ICES advice, a correction was required to split advised catches into ecoregions. To do this, we calculated the annual proportion of landings per ecoregion for each stock and used this proportion to split the annual ICES advice. For example, for small-eyed ray, *R. microocellata*, in the English Channel (rje.27.7de), landings occur in both the Greater North Sea and Celtic Seas ecoregions. In 2017, 22 (0.6) and 15 (0.4) tonnes were landed in the Greater North Sea and Celtic Seas, respectively. The ICES advice in 2017 was 36 tonnes and was therefore split into advised landings of 22 tonnes in the Greater North Sea and 14 tonnes in the Celtic Seas. This process was repeated for all stocks across all years and ecoregions (Supplementary Table S1).

Table 2. Species-specific life-history traits collated and used in our analysis.

Species (Latin name)	Species (common name)	L_{inf} (in cm)	L_{mat} (in cm)	Fecundity (no of eggs)
Raja brachyura	Blonde ray	125*	82+	42+
Leucoraja naevus	Cuckoo ray	83+	56+	100+
Raja clavata	Thornback ray	114+	74+	76+
Leucoraja circularis	Sandy ray	117*	95#	
Leucoraja fullonica	Shagreen ray	110*	75*	
Raja microocellata	Small-eyed ray	87†	73*	58+
Raja montagui	Spotted ray	79*	58+	65+
Raja undulata	Undulate ray	110+	76+	70Δ

References—*Froese and Pauly (2023); +Villagra et al. (2022); #Du Buit (1974); †Dureuil et al. (2022); ΔSerra-Pereira et al. (2015). L_{inf} refers to length at infinity and is taken from the estimated growth parameters of each species. L_{mat} is the length at which 50% of individuals are considered sexually mature. Fecundity refers to the typical number of eggs produced annually once mature. Blanks represent a lack of data or observations. For sandy ray and shagreen ray, L_{inf} is set at L_{max} (maximum observed length in cm).

Analysis and visualization

A comparison of ICES estimated landings data, ICES scientific advice, and TAC values by ecoregion and year is provided in Supplementary Fig. S1. To compare landings to ICES advice, we have chosen to report differences on the relative (landings divided by advice) and absolute (landings minus advice) scales. Relative values are used to provide an indicative measure of stock-specific exploitation and sustainability, whereas absolute values provide a magnitude and are more likely to be informative to the social, economic, and ecological consequences of fishing. We have also chosen to normalize the relative scale by subtracting by 1 in all instances, therefore ensuring that a value of zero signifies equivalence between annual landings and annual advice on both the relative and absolute scales. It also means that a value above zero indicates that more landings have occurred than advised by ICES, and below zero less landings. In some cases, ICES advice is zero, but landings still occur (e.g. rju.27.7de; 84 tonnes in 2016); in these cases, the relative value has been fixed at one for illustrative purposes and therefore acts to inform our analysis that landings of these stocks/species are occurring but does not overly inflate our estimates. Throughout, we use ‘overshot/overshooting’ when a stock’s landings exceed ICES advice and ‘undershot/undershooting’ when a stock’s landings fall below ICES advice.

To further explore trends of overshooting and/or undershooting, we also aggregated species and stocks by ICES category (category 3 vs. categories 5 and 6; listed in Table 1) and life-history traits. Life-history traits for each of the eight species were sourced from the scientific literature (Table 2). Female traits were prioritized as it is larger and older mature females that ensure the reproductive potential of a stock (Hixon et al. 2013, Griffiths et al. 2023). Nevertheless, this size factor might be weaker in skates than in other commercial fish species; for instance, the relationship between fecundity (F) and total length (TL) was estimated as F = 1.19 ×

TL + 25.1 for female thornback rays between 77 and 105 cm (Holden 1975). If more than one value was available, we used an average and rounded to the nearest whole number. Specifically, we collated information on species-specific length at infinity (L_{inf}), length at maturity (L_{mat}), and fecundity. L_{inf} is the asymptote (in cm) of each species' von Bertalanffy growth model (von Bertalanffy 1938) and therefore provides information on growth and expected maximum size. L_{mat} describes the length at which 50% of individuals are considered sexually mature and is often estimated via logistic regression between size and maturity stage (immature/mature; Schnute and Richards 1990, Chen and Paloheimo 1994). Fecundity is defined as the average total number of eggs produced per year per female. In the absence of L_{inf} estimates for sandy ray (*Leucoraja circularis*) and shagreen ray (*R. microocellata*), we have assumed that L_{inf} is the equivalent to L_{max} (maximum observed length in cm).

By collating rates of overshooting and/or undershooting with species-specific life-history traits, our aim is to determine whether species that are more or less vulnerable to exploitation are being landed in accordance with ICES scientific advice. In general, we expect that a species with a higher L_{inf} will have a larger body size and will mature at a higher L_{mat}, therefore taking longer to reproduce and recover from exploitation and making them more vulnerable to overfishing (Dulvy and Reynolds 2002, Porcu et al. 2015, Pecuchet et al. 2017). We also expect that species with a lower fecundity will have a lower reproductive potential and will therefore also be slower to recover from, and more vulnerable to, overexploitation (Villagra et al. 2022). We fully acknowledge that the vulnerability of a species to exploitation will also be linked to the fishing gear being used and the area of capture; however, due to a lack of complete coverage of productivity susceptibility analyses (e.g. McCully et al. 2013) for skates and rays, we have opted to use only the biological characteristics of each species.

Results

In the Greater North Sea Ecoregion, our findings show that the landings of blonde ray, *R. brachyura* (rjh.27.4a6 and rjh.27.4bc7d), and cuckoo ray, *L. naevus*, (rjn.27.3a4) overshot the advice, in terms of both relative and absolute landings, in almost all years (Fig. 1). For instance, in 2021 and 2022, the landings of blonde rays in the southern and central North Sea and eastern English Channel (rjh.27.4bc7d) were 299 and 328 tonnes compared to an ICES advice of 164 and 191 tonnes, respectively. In comparison, landings of thornback ray, *R. clavata* (rjc.27.3a47d), undershot the advice from 2016 to 2019 and in 2022, whereas landings of spotted ray, *R. montagui* (rjm.27.3a47d), undershot the advice in 2016, 2017, 2020, and 2021.

Landings of both stocks of blonde ray (rjh.27.7afg and rjh.27.7e) also overshot their respective ICES advice in the Celtic Seas, a trend that is consistent in all years (Fig. 1). Thornback ray (rjc.27.6 and rjc.27.7e) and undulate ray (rju.27.7de) were also landed at rates higher than their respective ICES advices in all years, albeit the emergent trend is less pronounced than for the two blonde ray stocks. Few advice for stocks in the Celtic Seas were consistently undershot, albeit landings of thornback ray (rjc.27.7afg) and spotted ray (rjm.27.7ae-h) fell consistently below their respective ICES advice.

In the Bay of Biscay and Iberian coast ecoregion, landings of spotted ray (rjm.27.8) consistently overshot the advice, whereas advice for the two cuckoo ray stocks (rjn.27.8c and rjn.27.9a) were both mainly undershot over recent years (Fig. 1). Landings of thornback rays (rjc.27.9a) also consistently undershot the ICES advice.

When landings and advice are split by ICES category and summarized by species-specific life-history traits, we observed complementary trends. Specifically, we found that landings of categories 5 and 6 stocks overshot their ICES advice in the Celtic Seas, whereas category 3 stocks, in the majority, were undershot (Fig. 2). In fact, combined landings of categories 5 and 6 stocks in the Celtic Seas (20 350 tonnes) have exceeded ICES advice (10 746 tonnes) by ∼9604 tonnes over the last seven years. Both undershooting and overshooting of category 3 stocks also occurred in the Greater North Sea and Bay of Biscay and Iberian coast ecoregions, as has overshooting of categories 5 and 6 stocks in the Greater North Sea, although the trends are less pronounced than in the Celtic Seas. Landings of the potentially most vulnerable species to fishing (i.e. blonde ray, which has the highest L_{inf} and L_{mat} and lowest fecundity) have consistently exceeded ICES advice in all three ecoregions (an overshot rate of 93% across all stocks and years). In comparison, the cuckoo ray, which has the lowest L_{inf} and L_{mat} and the highest fecundity, is both overshot and undershot. When landings are compared to ICES advice and correlated to species-specific life-history traits, we observe a positive relationship between overshooting and L_{inf} and overshooting and L_{mat} on both the relative and absolute scales (Fig. 3). We also observe a negative relationship between rates of overshooting and fecundity on both scales.

Discussion

The majority of ICES advice for skate and ray stocks currently states that the 'management of catches under a common TAC prevents effective control of single-stock exploitation rates and could lead to over-exploitation of some species'. Here, we have shown that this is certainly the case in the Northeast Atlantic. In fact, by comparing ICES landings and ICES advice, we find clear patterns of overshooting of blonde ray, cuckoo ray, and spotted ray in different ecoregions and undershooting of several thornback ray stocks. Moreover, by aggregating stocks by ICES category and species-specific life-history traits, we note that stocks currently considered data-poor and those potentially most vulnerable to exploitation are being landed at higher rates than their respective ICES advice in the Celtic Seas between 2016 and 2022, a finding that contradicts the PA to fisheries management.

A number of factors could drive the consistent overshooting of ICES advice of certain species and stocks. For blonde ray, stock-specific landings were found to exceed ICES advice by an average of +103%, with a maximum absolute difference of 987 tonnes in 2020 in the Celtic Sea (rjh.27.7afg). Such high values could be linked to market demand and sale prices. A preliminary investigation into the EC's Fisheries Dependent Information database (STECF 2023) showed that blonde ray has the highest ex-vessel price per kilogramme across the species considered (Supplementary Fig. S2). While prices of the different species may differ between seasons and countries (Amelot et al. 2021), the price for blonde ray has been ∼€2.50 kg^{-1} compared to €2.00 kg^{-1} for thornback ray throughout the study period. Blonde ray is also one of

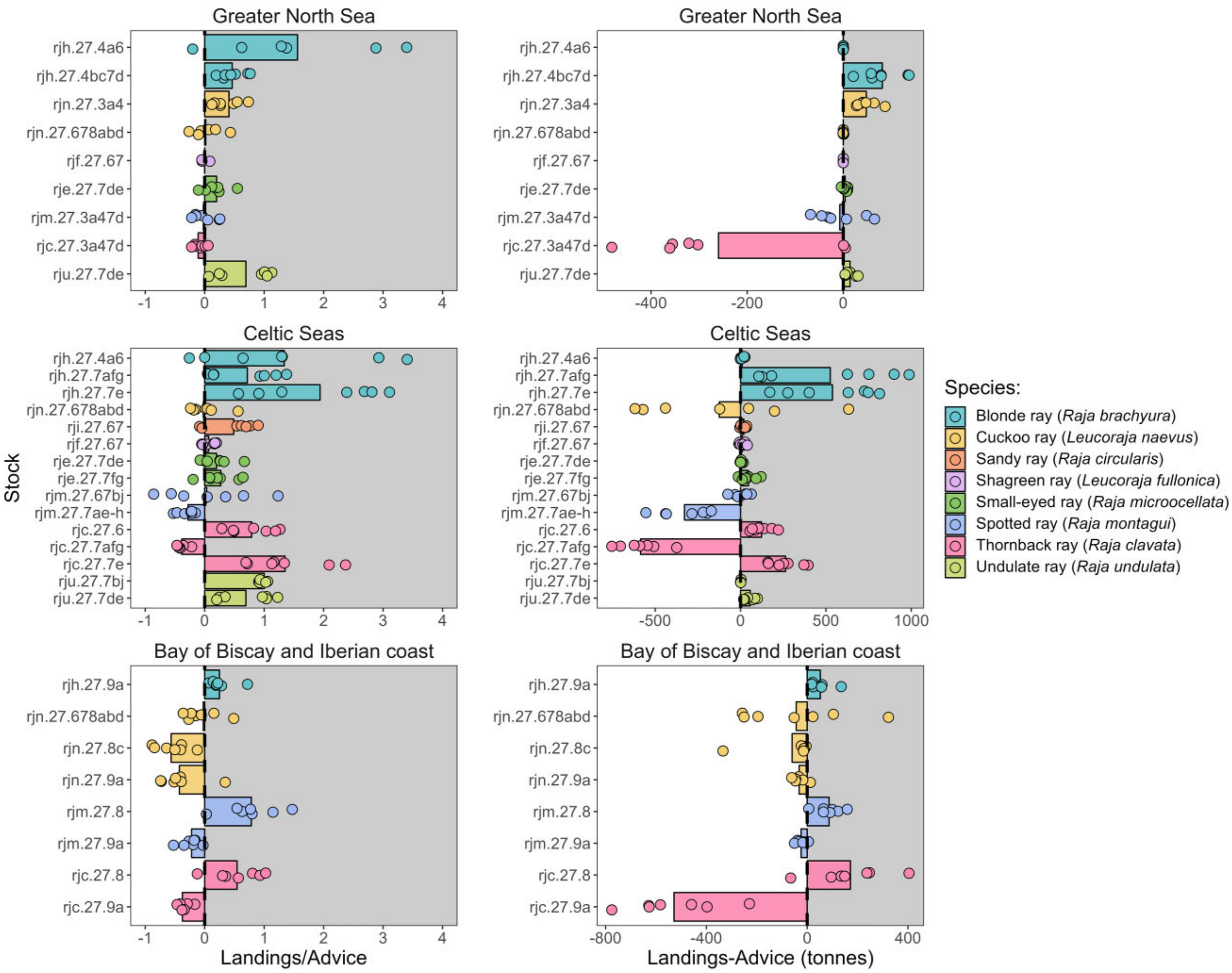

Figure 1 Relative (left) and absolute (right) differences in ICES estimated annual landings and ICES advice for skates and rays in the Northeast Atlantic. Relative values have been normalized by subtracting by one to ensure the scales in all columns are comparable. Bars detail the average difference between the period 2016–2022 and points the annual differences for each stock. The dashed line at zero in each panel signifies equivalence between landings and advice, such that values to the left (in the white section) and right (in the grey section) signify undershooting and overshooting of the ICES advice, respectively. Stocks are detailed using ICES stock codes and by species.

the largest species included in the common TACs (McCully et al. 2012, Thys et al. 2023), meaning that an average specimen will yield significantly more value and is likely to result in 'high-grading', whereby fishers preferentially land certain species (and discard others) in a bid to maximize economic gain (Batsleer et al. 2015).

High landings of other species like cuckoo ray (e.g. in the North Sea, Skagerrak, and Kattegat—rjn.27.3a4) and spotted ray (e.g. in the Bay of Biscay—rjm.27.8) might not necessarily be linked to financial gain. Both of these species have lower average prices per kilogramme than blonde ray ($<$ €1.50 kg^{-1} and $\sim$ €2.00 kg^{-1} for cuckoo ray and spotted ray, respectively; Supplementary Fig. S2). Thus, the overshooting of ICES advice in these species and areas may instead be linked to a tendency for certain life stages to aggregate in shallow coastal waters, possibly increasing catchability (Ellis et al. 2008b).

A tendency to overshoot can also be linked to the ICES advice process. Historically, the advice for many skate and ray stocks was based on species-specific landings; however, since 2012, the precautionary approach has been applied within the ICES framework, such that advised catches might not necessarily track changes in stock status (ICES 2012). For instance, a stock's estimated size may have increased markedly in recent years but the advised catch on that stock may have been capped at an increase of +20% under the ICES stability clause (ICES 2022b). Moreover, if a stock is assessed using category 5 or 6 methods, a default reduction in catch advice of −20% is applied every other advice year (ICES 2012, ICES 2023b) to account for uncertainties stemming from the lack of biological reference points and an absence of robust scientific data for these stocks. Such harvest control rules exist to prevent the overexploitation of data-poor stocks whose true stock status remains unknown; however, they can sometimes result in a mismatch between the likelihood of capture of a species or stock by fishers (which will intuitively increase when stock size increases) and single-stock advice. This is only further confounded by the fact that single-species ICES advice is currently used to calculate the common TAC, but the common TAC provides an inherent degree of flexibility, whereby fishers can opt to land those species they catch and are not necessarily bound by restrictions on certain species or stocks. This flexibility means that our expectation on the application of a common TAC for fisheries management—that fisheries catch will scale with single-stock advice—will not necessarily

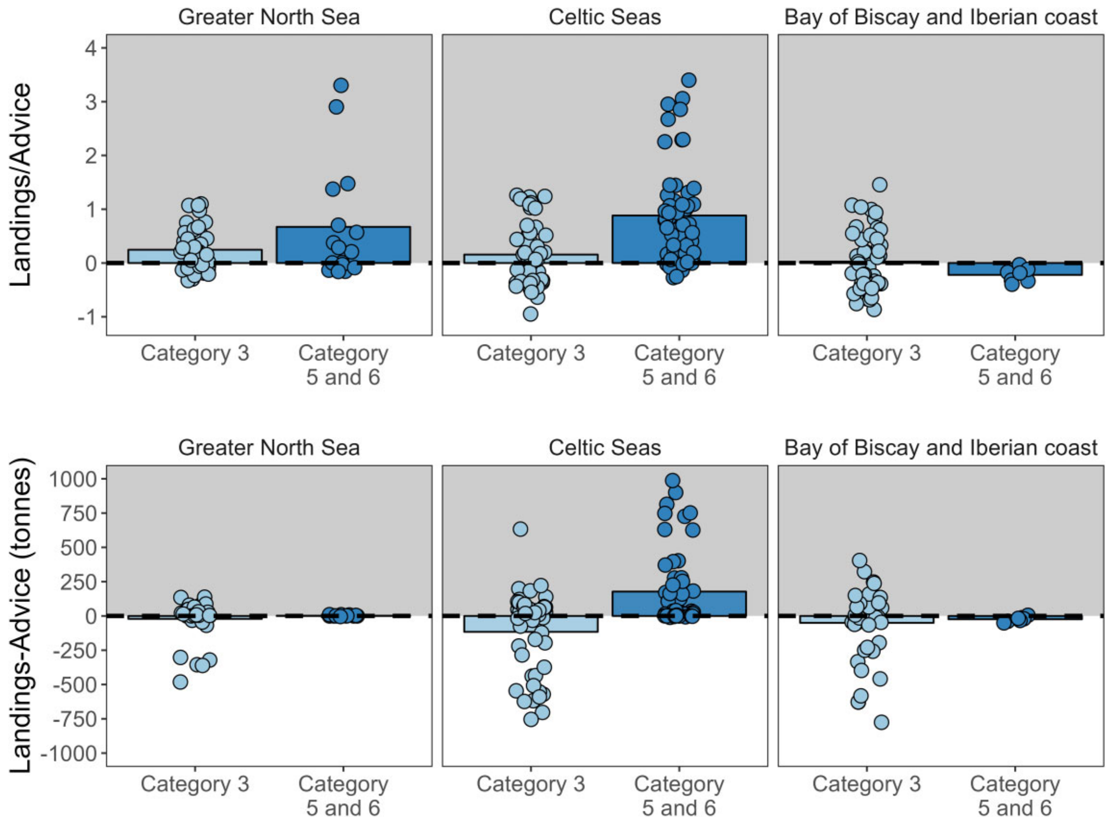

Figure 2 Relative (top) and absolute (bottom) differences in ICES estimated annual landings and ICES advice for skates and rays in the Northeast Atlantic by ecoregion and ICES category. Relative values have been normalized by subtracting by one to ensure the scales in all columns are comparable. Bars detail the average difference between the period 2016–2022 and points the annual differences for each stock. The dashed line at zero in each panel signifies equivalence between landings and advice, such that values below (in the white section) and above (in the grey section) signify undershooting and overshooting of the ICES advice, respectively. The stocks included in each ICES category are detailed in Table 1 and were sourced from ICES single-stock advice.

be met. This is highlighted by thornback ray, which is estimated to be the most abundant skate and ray species in the Northeast Atlantic (Ellis et al. 2008a), and whose single-stock advice makes up a large majority of the common TAC, but for most stocks the advised catch is not taken.

Despite such factors, it remains a concern that several species and stocks that are currently considered data-poor and potentially most vulnerable to exploitation are being consistently landed at rates that exceed ICES advice. A possible solution to this might be a wholesale shift towards single-stock TACs. Such a shift might help to establish a clearer link between ICES estimates of stock status, data availability, and current rates of exploitation (a recommendation also made in STECF 2022) and is likely to provide the best opportunity of managing fishing mortality at the stock level. A major problem of this, however, is that several nontargeted skate and ray species are often caught as bycatch to more targeted demersal species like haddock (*Melanogrammus aeglefinus*) or European plaice (*Pleuronectes platessa*). Thus, in the context of the landing obligation regulation (Article 15 of the EU Regulation No. 1380/2013), there is a risk of early closures to fisheries as the quota of one species/stock may be exhausted before the others. Such a species is generally referred to as a 'choke species'. A choke species can be either a target or bycatch species and can be limiting either because of their low productivity and reduced fishing opportunities or because of a discrepancy between historical rights allocations and current abundance (Mortensen et al. 2018). Discarding rates are also high for many of the skates and rays, and although species like thornback ray are estimated to have relatively high discard survival rates (e.g. Enever et al. 2009), facilitating exemptions to the EU landing obligation in several counties and fleets (EU regulation 2018/2035), further work should extend our analysis to incorporate discard data. Unfortunately, much of the discard data (dead or total) provided to WGEF is uncertain (ICES 2023a), and its inclusion may further inflate estimates of overshooting in certain stocks, species, and areas.

Skate and ray populations in the Northeast Atlantic include several small stocks (e.g. thornback ray in the western English Channel—rjc.27.7e), for which quantitative assessment remains challenging. For instance, due to data limitations, many of these small stocks do not receive a recommended catch level, or catches/landings are advised at values of 0 or <100 tonnes (e.g. ICES 2022a). Obtaining sufficient data to improve these quantitative assessments requires a high volume of survey and commercial catch sampling in a relatively small spatial area. Due to budget restrictions and survey design, such data are unlikely to be forthcoming and will be limited by the relatively large size of several skate and ray species and the coastal and often patchy distribution of certain stocks (e.g. undulate ray in Atlantic Iberian waters—rju.27.9a). Consequently, specific assessment and management approaches may be needed.

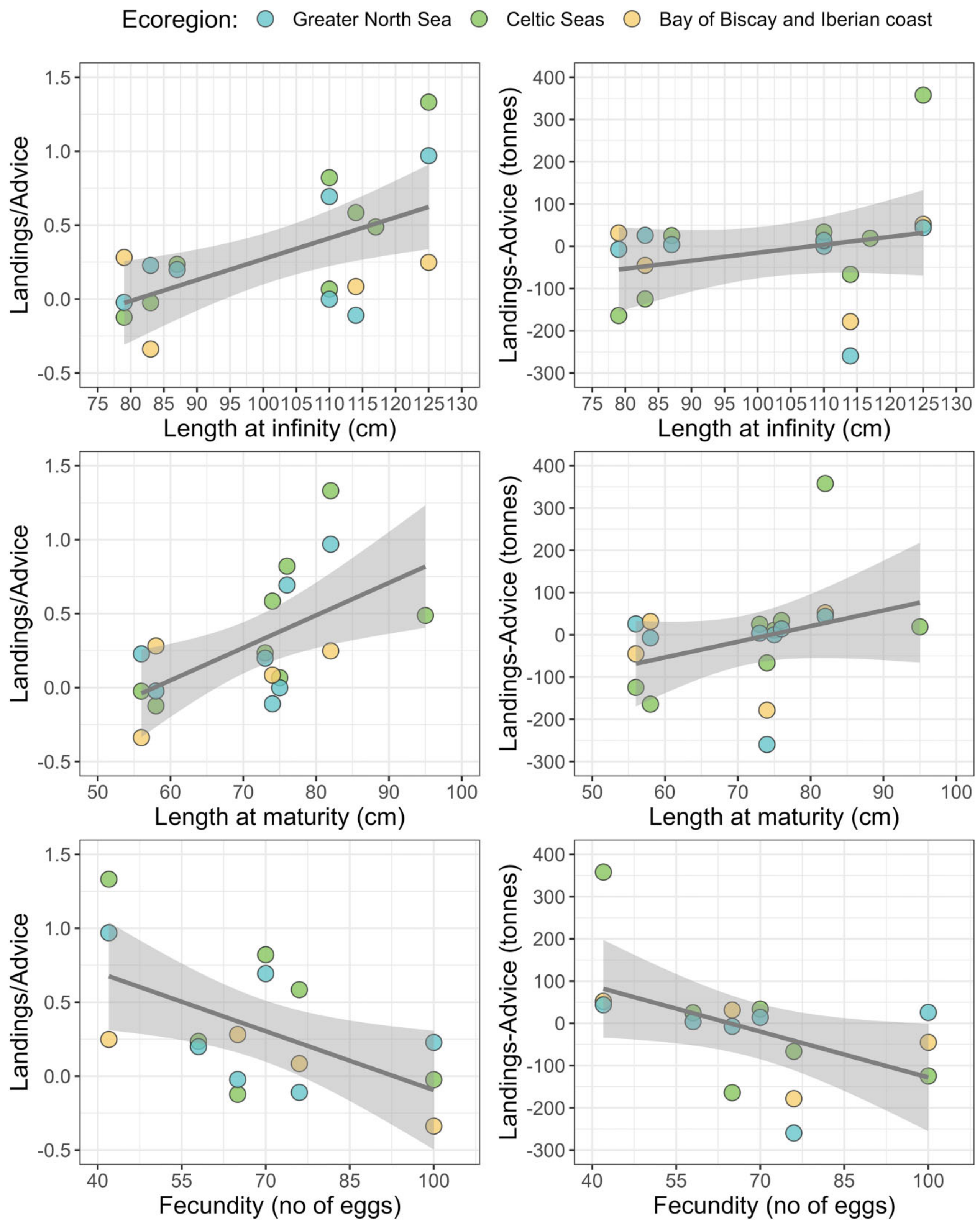

Figure 3 Correlations between life-history traits and differences in ICES estimated annual landings (tonnes) and ICES advice (tonnes) for skates and rays in the Northeast Atlantic. The differences between landings and advice are presented on the relative (left) and absolute (right) scales. Relative values have been normalized by subtracting by one, such that a value of zero in both cases signifies equivalence between landings and advice. Points are shown by ecoregion with each point representing a species-specific average taken across the years 2016–2022. Species-specific values of length at infinity (in cm), length at maturity (in cm), and fecundity (number of eggs) are listed in Table 2. Grey lines with shaded 95% confidence intervals are the product of a linear model and are used to visualize the correlation between a given life-history trait and the difference between landings and advice.

It should also be noted that local management measures outside of the TAC system may limit the exploitation of these stocks. For instance, there is a seasonal closure in May and June in Portuguese waters that prevents the landing of all Rajidae species, and gear restrictions as exemplified by the Azorean Government's measures for demersal and deep-water fisheries in 2009 and Belgium's restrictions on gillnet fisheries in 2018 (ICES 2022a). Additionally, size regulations based on minimum conservation reference sizes (MCRS) have been established, which may vary across countries. For instance, as of 2022, the Portuguese government has imposed a 60 cm TL MCRS for all skates and ray species, while in the North Sea, the UK's Inshore Fisheries and Conservation Authorities enforce a minimum landing size of 40 cm disc width, while other nations utilize an MCRS based on TL, varying from 45 cm in France to 55 cm in the Netherlands (ICES 2022a). These and similar measures that are outside the TAC system may also serve to affect the exploitation of individual species. Increasing the age at first capture has been shown to increase the intrinsic rate of population increase of three skate species in the western Atlantic (Frisk et al. 2002). Further, because survival has been estimated to be relatively high for discarded skates (Enever et al. 2009, Van Bogaert et al. 2020, Schram et al. 2023), an MCRS equal to or higher than the mean length at maturity might ensure a sustainable exploitation level, subject to fishing mortality (F) on adult skates remaining relatively low (e.g. $F < 0.6$, a level unlikely to be reached without significant targeted fishing). Both maximum (protection of mature adults) and minimum (protection of juveniles and subadults) size restrictions might also be a suitable management option and have been shown to be as effective as seasonal spatial closures at recovering the thornback ray population in the Thames Estuary (Wiegand et al. 2011). In a multispecies fisheries context, empirical 'move-on' rules have also been proposed for both target and nontarget species, which require fishing vessels to move away from an area to alternative fishing grounds once a catch threshold has been reached (Dunn et al. 2013).

There is also a growing need for skates and rays to be assessed using more quantitative stock assessment methods, such that the implications of exploitation can be evaluated. This transition has already started; for example, several category 3 stocks are now assessed using length-based empirical methods (e.g. the so-called rfb rule, Fischer et al. 2020, 2021a, 2021b). These methods incorporate life-history traits and length frequency distributions and allow advice to be given in accordance with established reference values and the MSY approach to fisheries management (e.g. ICES 2022c). Six previous category 3 stocks within WGEF are now also assessed using category 2 approaches, whereby a surplus production model (SPiCT; Pedersen and Berg 2017) is fitted to catch and survey data, and catch advice is given as a fractile (e.g. the 35th) of the estimated catch distribution at F_{MSY} (the fishing mortality that results in MSY; ICES 2022b). Initial evidence from these shifts in methodology suggests that TACs for skates and rays might increase (by quite large margins) in the coming years (ICES 2022d), and it remains unknown how this will affect fisheries management measures, fisher behaviour, or levels of exploitation. Another possibility for some key species would be the use of integrated models (e.g. Methot and Wetzel 2013), which allow users to combine several sparse information sources (typical of skates and rays) into one model that can then be used for quantitative stock assessment and advice. Regardless, such advances in stock assessment methodology should signal an increase in the quality of single-stock advice and spur calls for management to move away from common TACs. These methods also call for increasing levels of data, which are severely lacking for certain stocks and species, and significant efforts should be made to align at-sea sampling programmes with data needs.

Managers have acknowledged the deficiency in safeguarding vulnerable stocks under the current combined TAC for skates and rays (STECF 2017, 2022). In this context, science has an important role in guiding managers to choose the best course of action based on scientific facts. As such, transitioning from a combined TAC to a single-stock TAC cannot be done immediately but requires a well-defined strategy that underscores the need of tailored TACs that address the distinct vulnerabilities and conservation requirements of these stocks.

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Author contributions

J.B., C.A.G., G.J., K.B., and P.L.: conceptualization. J.B., C.A.G., P.L., and K.B.: data curation, methodology and formal analysis. C.A.G and K.B.: visualization. J.B. and C.A.G.: writing - original draft. All authors contributed equally to writing - review and editing..

Supplementary data

Supplementary data is available at the *ICES Journal of Marine Science* online..

Conflict of interest: The authors declare no conflicts of interest.

Data availability

All data used in this study are freely available online or are detailed in the Supplementary Information document. All the R code needed to reproduce the analysis and all the figures is freely available on GitHub at https://github.com/cagriffiths/Landings-vs-advice_skates-and-rays.

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