Are fish sensitive to trawling recovering in the Northeast Atlantic?

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37 1. Abstract

38

39 1. The protection of sensitive species from overfishing is a key aspect of the ecosystem
40 approach to fisheries management.

41 2. We use life history parameters and knowledge of fish shape and habitat to estimate the
42 sensitivity of 270 species in the Northeast Atlantic to demersal trawling and compare
43 sensitivity to the most recent IUCN categorization. Species classified as threatened were
44 on average significantly more sensitive to trawling than other species. Using trawl
45 surveys in European Atlantic waters from 36°N to 62°N, we estimated indicators of
46 abundance of 31 highly sensitive species and compared changes in abundance to
47 sensitivity, management measures and value of landings.

48 3. The abundance of 23 of the 31 sensitive species increased after year 2000 with 14 of the
49 species showing increases significant at the 5% level. The increases were not due to

specific management measures, as less than half of the species were covered by catch limits. Further, sensitivity or value of landings were not related to trends in abundance.

4. Three species (Atlantic wolf-fish, tusk and starry ray) declined significantly. These species are all at their southern distributional limit in the North Sea.

5. *Synthesis and applications.* We recommend monitoring the development of sensitive species to identify species under pressure and allow rapid management actions before species enter the IUCN threatened category. Further, we recommend taking precautions where species are under combined pressure from climate change and fishing.

Keywords: Sensitive fish, abundance indices, species recovery, IUCN categories, fisheries management, life history traits, fish distributions

62 2. Introduction

63 A key aspect of the ecosystem approach to fisheries management is the protection of species
64 from overfishing (CBD, 2014). However, managing every species in large marine ecosystems
65 is impractical and, therefore, approaches such as risk-based assessments (Hobday et al., 2011)
66 have been proposed to ensure that the most sensitive components are the focus of
67 management. A scoping process identifies priority objectives (Hobday et al., 2011), and a
68 subsequent Population Susceptibility Analysis (PSA) or similar is used to identify the most
69 susceptible species. In Europe, priority objectives stated in the Marine Strategy Framework
70 Directive (MSFD) aim to support ‘halting biodiversity loss, ensuring the conservation and
71 sustainable use of marine biodiversity’ (European Commission, 2008). These objectives have
72 been confirmed in various large-scale scoping exercises (Rindorf et al., 2017).

73 The Minimum Viable Population concept is often used in viability analysis of terrestrial
74 populations (Beissinger & McCullough, 2002) and for marine fish populations, the minimum
75 spawning stock per recruit concept plays a similar role. Basically, fishing should not reduce
76 the spawning stock per recruit of a fish population below the minimum level necessary for
77 replacement. For fish, this level is typically in the order of 20 to 40% of the unexploited
78 population (Brooks et al., 2010). Large, slow growing, late maturing fish species with a low
79 level of natural mortality are likely to reach the minimum level at a lower level of fishing
80 mortality than small, fast growing, early maturing species with higher levels of natural
81 mortality (Jennings et al., 1999; Fernandes et al., 2017). Life history characteristics such as
82 asymptotic length L_{∞} , growth rate K , the length at which 50% of the individuals have reached
83 maturity L_{mat} , and natural mortality M are therefore often used to indicate the sensitivity of
84 different species to fishing (Hobday et al., 2011; Greenstreet et al., 2012). When species-
85 specific information is missing, an estimate of the maximum length L_{max} of a species can be

used to infer asymptotic length, growth rate, natural mortality, and proportion mature at length (Walker et al., 2019).

Following this approach, Le Quesne and Jennings (2012) used a life history model and asymptotic length to predict the sensitivity of different fish species in the Celtic Sea to fishing by estimating the fishing mortality required to reduce the stock to a specific level of spawning stock biomass per recruit relative to the unfished status, using a general relationship between size of the individual and the size selectivity in the fishery. However, in a subsequent study, gear efficiency expressed as the probability of being retained by a particular gear, was shown to have a larger effect on the estimated reference points than the uncertainty associated with general life history relationships (García-Carreras et al., 2015). Gear efficiency depends on the habitat, individual size, body shape and behavior of the fish (Table S1), as well as the properties of the gear (Reid et al., 2007). In 2010-2012, bottom trawl and beam trawl fisheries accounted for 98% of the discards in EU member countries (Catchpole et al., 2017). Hence, while bycatches taken in other fisheries may be important for particular species, the probability of being retained in, or killed by, the bottom trawl and beam trawl fisheries is likely to be most important for demersal fish.

The objective of this study is to identify species sensitive to fishing in the Northeast Atlantic and provide an overview of changes in their abundance in the light of recent effort changes and current management. To achieve this aim, we ranked fish species according to their sensitivity to bottom and beam trawling in the Northeast Atlantic using gear efficiencies estimated by Walker et al. (2017). We then investigated whether species sensitivity was related to IUCN species status (Nieto et al., 2015), and whether management measures are in place to limit the impact of fishing on sensitive species. Finally, we examined the temporal development in the abundance of sensitive species in survey catches throughout the Northeast

Atlantic and compared changes in abundance to sensitivity, current management measures, the decreases in fishing effort from 2000 onwards and market value of the species.

3. Materials and methods

Species sensitivity

Species sensitivity to trawl generated mortality was estimated by applying a length-based Spawning stock per Recruit model (Beverton & Holt, 1957; Gislason et al., 2008) to species recorded in the DATRAS survey database covering the Northeast Atlantic from the coast of Portugal to the North Sea and from the Baltic Sea to west of Scotland (<http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx>). The maximum length of the species, L_{max} , the asymptotic length, L_{∞} , the von Bertalanffy growth rate parameter, K , length at first maturity, L_{mat} , and the length at which the individuals entered the sensitivity model (length at birth for chondrichthyan and length at metamorphosis for bony fish), L_{min} , were derived from the literature whenever possible (Tables S2 and S3), thereby minimizing the variation induced by using one parameter to predict the remaining parameters whenever possible (Thorson et al., 2014).

General relationships between life history parameters and species lengths were used to provide missing values whenever information could not be found in the literature (Table 1). When no growth parameters were available, L_{∞} was estimated from L_{max} using the equation provided by Froese & Binohlan (2000), K was estimated from a regression of $\ln(K)$ versus $\ln(L_{\infty})$ based on the species in the dataset for which K and L_{∞} estimates were available ($p < 0.0001$, $\text{adj.}R^2 = 0.43$, $\text{df} = 186$). When L_{mat} was missing, a regression of $\ln(L_{mat})$ versus $\ln(L_{\infty})$ ($p < 0.0001$, $\text{adj.}R^2 = 0.91$, $\text{df} = 155$) based on species for which estimates were available was used to derive the missing value. For chondrichthyans, regressions of $\ln(L_{min})$ versus $\ln(L_{\infty})$ differed significantly between egg-laying and live-

bearing species (ANOVA, $P(>F) = 0.0004$, $n = 21$). Separate regressions of $\ln(L_{min})$ versus $\ln(L_{\infty})$ were therefore used for egg-laying ($R^2 = 0.68$, $df = 8$) and live-bearing species ($R^2 = 0.81$, $df = 10$). For bony fish, insufficient information about length at metamorphosis was available and an overall L_{min} of 2 cm was adopted. The life history relationships were entered into the model of Spawning Stock Biomass per recruit. The model was insensitive to changes in the value of L_{min} as long as L_{min} was below the length at which the species is either exploited or mature.

Bottom and beam trawls retain a variable proportion of the fish found in the path of the gear. Some species, such as shallow water or reef-associated species, are difficult to catch because their habitat is not consistently sampled during trawl surveys, while pelagic species, such as Atlantic herring *Clupea harengus* are found in the water column and may pass above the headline of the gear without being caught. Furthermore, among the individuals that enter the mouth of the gear, the smaller individuals and species may escape through the meshes. Towed gears will therefore generate species and size specific fishing mortalities in the area where they operate. Walker et al. (2017) estimated the relative efficiency by which different species groups and sizes of fish were retained by the major towed commercial fishing gears operating in the North Sea. Dividing the species according to their body shape and typical vertical position in the water column, catch efficiency at length (exploitation pattern) was calculated for seven groups (Table S1). We allocated the species to these groups and used the average efficiency of small and large meshed commercial beam trawls and otter trawls estimated by Walker et al. (2017) to provide the relative catch efficiency for each cm of length for each of the seven groups. The resulting exploitation pattern was used to estimate the relative efficiency of towed gears for each of the species and size groups and provided the relative fishing mortality at size by which they would be affected for a given level of overall effort.

As a measure of the sensitivity of each species to fisheries generated mortality, we used the relative level of effort needed to reduce the biomass of mature individuals (the spawning stock biomass) to 25% of its unfished level, $F_{25\%SSB}$, (Table S2). Sensitive species can only tolerate relatively low levels of fishing mortality before their spawning biomass is reduced to 25% of the unfished level. The lower the $F_{25\%SSB}$, the higher the sensitivity. The exact percentage (25%) is of little consequence to the subsequent ranking, as the different F indicators are highly correlated (Le Quesne and Jennings, 2012). To distinguish between sensitive and non-sensitive species, we used the $F_{25\%SSB}$ of the most sensitive of the commercial target species which has shown sustained high catches. Less sensitive species may also be severely impacted by a targeted fishing effort, but here we concentrated on species which are mostly bycaught in mixed fisheries rather than targeted directly. Ana- and catadromous species were excluded from the study.

Comparison of sensitivities and IUCN ratings, L_{∞} and taxonomy

The estimated values of $F_{25\%SSB}$ were analysed to determine if $F_{25\%SSB}$ differed significantly between IUCN ratings (ANOVA) and if there was a linear effect of asymptotic length (L_{∞}) and a categorical effect of taxonomy (Chondrichthyes, Agnatha and Actinopterygia) in a generalized linear model with a linear effect of L_{∞} and a categorical effect of taxonomy. The natural log of $F_{25\%SSB}$ was taken prior to analyses as variance increased with the mean of $F_{25\%SSB}$.

Management of sensitive species in the EU and value of landing

Current management measures for EU fleets were derived from the latest available decisions on fishing opportunities (European Commission, 2018a, b). Price per kg was derived from the European Market Observatory for Fisheries and Aquaculture Products (www.eumofa.eu,

accessed August 12th 2019) and supplemented where prices were lacking with prices from Hanstholm Auction (www.hanstholmfiskeauktion.dk/prices, accessed August 12th 2019). Species were ranked as high value if their value exceeded that of Atlantic cod *Gadus morhua*, medium value if their value was between 50% and 100% of that of Atlantic cod, and low value if their value was not listed or was less than 50% of that of Atlantic cod.

Development in abundance of sensitive species

Species abundance indices were derived from average survey catch rates in the ICES coordinated international bottom and beam trawl surveys in the area in which the species has historically been reported. Data were downloaded from the ICES DATRAS database (<http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx>) on July 9th 2019. The time-range for each survey are given in Table S4.

For the Baltic Sea, North Sea and west of Scotland, only hauls in which all fish species caught were recorded were analysed. Catch rates of beam trawls in the North Sea, where several beam widths are used, were standardised to a beam width of 4 m. In the Baltic Sea, catches with the large and small versions of the trawl were considered as two different surveys.

Species which were not accurately identified to species were joined in species groups. Among the sensitive species, this affected the common skate complex (comprising records for *Dipturus* spp., *D. batis*, the invalid synonym *D. flossada*, and *D. intermedius*) and smooth-hounds (*Mustelus asterias* and *M. mustelus*). Annual estimates of mean catch rates were estimated for species observed in at least 50% of the years. The estimated mean included only hauls taken in realised habitat defined as all ICES statistical rectangles in which the species had been recorded during a survey at any time in the data. Consequently, the total number of hauls varied between species.

To provide integrated species indicators, two types of difference between surveys were considered: differences in mean catch rate and differences in interannual variation in catch rate. Differences in mean catch were accounted for by scaling all survey catches to a mean of 1 in the years from 2009 onwards. Species-level indicators were derived by estimating the weighted average of all indicators for the given species. As the study was focused on population abundance indicators for long lived species, we expect a smooth development of the underlying population size over the years. Survey catches may appear more or less smooth, depending on the consistency of the catchability and relative local abundance of the species in the particular survey. To ensure that more weight was placed on surveys showing consistent population development, the combined indicators were weighted with the reciprocal variance around a Loess smoother in time fitted to the logged non-zero catch rates of each species in each survey. Further, to ensure a minimum precision level for the derived indicators, combinations of surveys and species for which the CV of the residuals from the Loess smoother exceeded 0.75 were excluded. Years in which the catch rates exceeded five times the long-term mean were excluded in the analysis of integrated indicators. This removed occasional very large hauls, which occurred for some of the species (e.g. *Raja clavata* and *Squalus acanthias*). Indicators were integrated by region and across all regions. After a period of increasing or stable high fishing pressure, demersal fishing effort in the Northeast Atlantic area has decreased since the 2000s (ICES, 2018a, b, c). We therefore estimated the trends in species abundance from 1980–2000 and from 2000 onwards as the linear trends in log-transformed species-level indicators. In addition, the number of surveys showing positive trends in the two periods was investigated (regardless of significance level). The categorical effect on trend in abundance of value (low, medium or high) and management (species TAC, group TAC or no TAC) was investigated in an ANOVA.

2. Results

Species sensitivity

The estimated values of $F_{25\%SSB}$ for all 270 taxa are given in Table S2. The sensitivities of species from Greenstreet et al. (2012) and Le Quesne and Jennings (2012) were well correlated with those derived by the present method (Correlations = -0.78 and 0.74 , respectively, on a log-log scale). Some of the difference between the ratings can be attributed to differences in the assumed values of the life history parameters. For example, Greenstreet et al. (2012) assumed L_{∞} of spurdog *Squalus acanthias* to be 90 cm, whereas Le Quesne and Jennings (2012) and this study assumed 120 and 121 cm, respectively. The most sensitive of the commercial target species which has shown sustained high catches was saithe *Pollachius virens*, with a value of $F_{25\%SSB}$ of 0.43. Using this species to define the level below which species can be considered particularly sensitive, 59 species with $F_{25\%SSB} \leq 0.43$ were defined as sensitive species/taxa and used in subsequent analyses. These species were dominated by 33 chondrichthyan taxa, including skates (Rajidae; *Amblyraja hyperborea*, *A. radiata*, common skate-complex, *D. nidarosiensis*, *D. oxyrinchus*, *Leucoraja circularis*, *L. fullonica*, *L. naevus*, *Raja brachyura*, *R. clavata*, *R. microocellata*, *R. montagui*, *R. undulata*, *Rajella bathyphila*, *Rajella fyllae*, *Rajella lintea* and *Rostroraja alba*), squaliform sharks (*Somniosus microcephalus*, *Deania calcea*, *Squalus acanthias*, *Dalatias licha* and *Etmopterus princeps*), catsharks (Scyliorhinidae; *Galeus melastomus*, *Scyliorhinus canicula* and *S. stellaris*), hound sharks (Triakidae; *Galeorhinus galeus* and *Mustelus* spp.) and various other species (*Hexanchus griseus*, *Lamna nasus*, *Torpedo marmorata*, *T. nobiliana*, *Dasyatis pastinaca*, *D. tortonesei* and *Chimaera monstrosa*). The remaining species comprised a variety of gadiforms (*Brosme brosme*, *Coryphaenoides rupestris*, *Macrourus berglax*, *Molva molva*, *M. dypterygia*, *M. macrophthalma*, *Mora moro* and *Phycis blennoides*) and other species (*Conger conger*, *Lophius budegassa*, *L. piscatorius*, *Brama brama*, *Argyrosomus regius*, *Anarhichas*

lupus, *A. minor*, *Dicentrarchus punctatus*, *Ephippion guttifer*, *Epigonus telescopus*, *Sebastes* spp., *Lepidorhombus whiffiagonis*, *Hippoglossus hippoglossus*, *Polyprion americanus*, *Scophthalmus rhombus*, *Scorpaena scrofa* and *Synaphobranchus kaupii*).

Comparison of sensitivities and IUCN assessments, L_{∞} and taxonomy

Comparing $F_{25\%SSB}$ to the IUCN assessments, species sensitive to fishing occurred in all IUCN categories. However, average $F_{25\%SSB}$ was significantly higher for species in the Least Concern category ($P < 0.0001$) (Figure 1) indicating that less sensitive species were, on average, more likely to be categorized as Least Concern. There was no significant difference in the average $F_{25\%SSB}$ between the Critically Endangered, Endangered, Vulnerable and Near Threatened categories ($P = 0.2594$). None of the species in the Critically Endangered and Endangered categories showed an $F_{25\%SSB} > 0.75$ (Figure 2, Table S2). The two species classified as Endangered but not sensitive to demersal fishing pressure were basking shark *Cetorhinus maximus* and thresher shark *Alopias vulpinus*. Six Data Deficient species (*Anarhichas lupus*, *Argyrosomus regius*, *Dasyatis tortonesei*, *Ephippion guttifer*, *Epigonus telescopus* and *Phycis blennoides*) were identified as sensitive species. For the remaining 51 sensitive species, 24 are currently listed by the IUCN as Least Concern.

L_{∞} and taxonomy were significantly related to $F_{25\%SSB}$, together explaining 72% of the variation in $F_{25\%SSB}$, while L_{mat} and K did not have a significant effect ($P > 0.1958$). The predictive function of species sensitivity for Actinopterygia was estimated as:

$$\widehat{F_{25\%SSB,AC}} = \exp(6.99 (0.28) - 1.55 (0.08) * \ln(L_{\infty}))$$

Values in parentheses denote standard deviation of the estimates. The parameter estimates for Chondrichthyes were not significantly different from 0 ($P = 0.08$). While taxonomy and

asymptotic length provided significant information on sensitivity, 28% of the variation was not predictable using linear relationships with taxonomy, L_{∞} , K and L_{mat} and hence, the full model should be used whenever possible. The limit between low and medium productivity (high sensitivity) fish given in Hobday et al. (2011) for maximum length (>300 cm and 100–300 cm, respectively) and length at maturity (>200 cm and 40–200 cm, respectively) were insufficient to describe the current sensitive species, as 24 sensitive species had values of asymptotic length <100 cm and six additional species had maximum length <100 cm. Five species had a length at maturity <40 cm.

Management of sensitive species and value of landings

Among the 59 sensitive taxa, landings of four species (6.8%) were subject to species-specific quota management for defined management units, and a further five taxa (8.5%) by genus or family-based quota management (Table S5). Additionally, 13 species of skate (22.0%) would be included within quotas largely set for the complex (Rajiformes). Whilst 13 (22.0%) of the taxa were subject to conservative management (e.g. a combination of prohibited listings and near-zero bycatch TACs), the remaining 24 species (40.7%) are not currently subject to any management measures.

Five high value species had landing values per kg greater than cod (*Dicentrarchus labrax*, *Hippoglossus hippoglossus*, *Lepidorhombus whiffiagonis*, *Scophthalmus rhombus*, *Lophius budegassa* and *L. piscatorius*). Another 10 medium value species attained values between that of cod and half this value (*Anarhichas lupus*, *Etmopterus princeps*, *Macrourus berglax*, *Molva dypterygia*, *Molva macropthalma*, *Molva molva*, *Scyliorhinus canicula*, *Scyliorhinus stellaris*, *Sebastes* spp. and *Squalus acanthias*). The remaining species were categorized as low value species.

310

311 Development in abundance of sensitive species

312 Of the taxa classified as sensitive, 31 were recorded with sufficient frequency and accuracy in
313 the surveys to allow estimation of trends (Table 2). For some species, indices were highly
314 correlated, whereas for others, the surveys differed in development (Figure 3). The
315 abundance of 24 of the 31 species increased from 1980–2018 (Table 2, Figures 3–4). Among
316 the species showing significant trends, 15 increased and three (starry ray *Amblyraja radiata*,
317 wolf-fish *Anarhichas lupus* and tusk *Brosme brosme*) decreased. These three are at their
318 southern boundary in the surveyed area (Figure 2) whereas this was not the case for the
319 remaining species (except halibut *Hippoglossus hippoglossus*; Figure S1). Starry ray and tusk
320 decreased at a significantly greater rate in the later period than in the period as a whole
321 ($P < 0.0181$ in both cases). Among the 10 species showing a significant change in the trend
322 between 1980–1999 and 2000–2018, six exhibited an increasing trend while four
323 deteriorated. Fourteen species showed no significant change between time periods while the
324 remaining six species had insufficient historical data to test for changes in trends.

325 Categorising the surveys individually according to the trend estimated, trends in 42 of 78
326 combinations of species and surveys from 1980–1999 were positive, whereas the
327 corresponding number after 2000 was 161 of 209, a change from 54% to 77%.

328 Among the species listed by IUCN as Critically Endangered, Endangered or Vulnerable, four
329 taxa increased significantly after 2000 (*Dipturus* spp., *Leucoraja circularis*, *Mustelus* spp.
330 and *Squalus acanthias*) whereas four showed no significant change (*Dasyatis pastinaca*,
331 *Galeorhinus galeus*, *Leucoraja fullonica* and *Hippoglossus hippoglossus*). Among the species
332 assessed as Least Concern, starry ray, tusk and marbled electric ray *Torpedo marmorata* all
333 decreased significantly from 1980 to 2018.

There was no relationship between sensitivity, the presence of a catch limit, the value at landing and the population index trend of the species ($P>0.29$). For example, the two least sensitive of the species (starry ray and wolf-fish) declined whereas the most sensitive (the common skate complex) increased. The three species showing the greatest increase in the past 20 years had very different management measures: the common skate complex (to be returned to the sea unharmed), Smoothhounds (no management) and undulate ray *Raja undulata* (individual species TAC). Starry ray and wolf-fish showed comparable declines, despite the former being required to be returned to the sea unharmed (since 2014) whereas the latter can be landed. High and medium value species included both declining/stable species (wolf-fish and halibut) and increasing species (*Lophius budegassa* and *Squalus acanthias*), and the same was true of low value species (starry ray and tusk declining and smoothhounds and the common skate complex increasing).

3. Discussion

Using life history parameters and knowledge of fish shape and habitat to identify the likely sensitivity for each species, we demonstrated that in general, sensitive demersal marine fish increased in abundance in the Northeast Atlantic since 2000 and in many cases had been doing so since 1980. The analysis identified potentially sensitive species along the Northeast Atlantic shelf, and the trawl survey data integration method allowed the temporal changes in species abundance to be monitored for more than half of these sensitive species. The increase in abundance of most of the sensitive species analysed did not appear to be due to species-specific management measures, as less than half of the species were covered by catch limits and there was no strong evidence of an increase in relative abundance as fishing effort decreased after year 2000. Further, neither sensitivity nor market value appeared to be related to trends in abundance. However, the three species which declined significantly were all at

their southern limit in the North Sea, indicating that conditions in the North Sea may be affecting these species more than others, possibly due to the greater changes in water temperature (Hobday and Pecl, 2014).

The accuracy of the identification of sensitive species depends on the accuracy of the parameters included and the method used to derive sensitivity. Thorson et al. (2014) demonstrated the importance of a proper literature review to derive the best available life history parameter estimates. While we performed a detailed literature review, our focus was on the development of the species across all of the sampled parts of the NE Atlantic, and therefore we did not use local values of life history parameters. If the analysis is repeated for a specific area, local values could be used instead, but as information is often sparse for species identified as sensitive, using local values increases the risk of basing the analyses on very limited data, and hence, it may be preferable to use the values given here for analyses even at a more limited spatial scale. While our results on species sensitivity ranking are in broad agreement with findings from other studies, in that larger, slower growing, late maturing species are the most vulnerable to fisheries generated mortality (e.g. Jennings et al., 1999; Ravard et al., 2014), sensitivities based on the life history model were not well explained by a linear combination of life history parameters causing our results to differ from those of Greenstreet et al. (2012). Our results also differed from those of Le Quesne and Jennings (2012) perhaps as a result of including group-specific catchabilities. The methods used to derive catch efficiencies assumed all individuals within a certain size and habitat group are equally likely to be caught in the trawl (Walker et al., 2017). This assumption may not be appropriate for species with variable behavioural responses to the trawl and species that occur on non-trawlable or deeper grounds, such as rocky bottoms, reefs and wrecks. For example, conger eel *Conger conger* inhabits rocky areas of the continental shelf and shelf

384 slope (Xavier et al., 2010). Once settled, it has a relatively sedentary lifestyle. Walker et al.
385 (2017) assumed conger eel to be caught with the same catch efficiency at size as other eel-
386 like species encountered near the seabed, which may be an overestimate. Similar
387 considerations may apply to other species favouring untrawlable habitats. Furthermore, our
388 study did not consider sensitivity of the species to pelagic fisheries or earlier targeted
389 fisheries. Species like basking shark and thresher shark would owe their current IUCN
390 Endangered status to these factors, rather than demersal fisheries.

391 Information about the survival of individuals that are discarded from different gear types was
392 not available. However, many bycatch species are discarded and, if they survive, their
393 populations may be more resilient to fishing than their life history parameters would indicate.
394 For most fish species, discard mortality will increase with the duration and depth of the tow,
395 the time spent on deck and handling/discarding practices, but survival can also vary in
396 response to size, sex, temperature, catch composition and handling (Ellis et al., 2017). Recent
397 work on capture-release mortality could be used to improve the knowledge of the degree to
398 which released fish survive to reenter the population (Dapp et al., 2016). Needless to say,
399 discard survival will not impact species which are landed.

400

401 Spatially explicit models and management measures are potentially useful alternatives for
402 managing sensitive species (Duggan et al., 2015; Walker et al., 2019). Spatially explicit
403 models may provide indication of whether some species are likely to be at greater risk due to
404 fishing than expected from our analyses and whether catches of sensitive species observed to
405 be in decline can be limited by spatial measures (Shephard et al., 2012). However, such
406 analyses must be based on a reliable distribution of the sensitive species, and this was only
407 available for about half the sensitive species identified here.

408

Le Quesne and Jennings (2012) suggested that significant reductions of fishing effort in the Celtic Sea were required to allow sensitive species such as the common skate complex, spurdog and spotted ray *Raja montagui* to increase. The same conclusion was reached for the North Sea by Walker et al. (2019) for wolf-fish, anglerfish, brill, starry ray, spurdog, smoothhounds, spotted ray and thornback ray (excluding the species not listed here as sensitive). Among these eight species, five were observed as increasing in this study. This may indicate either that these species are less frequently caught outside the heavily fished North and Celtic Sea, providing the possibility for them to increase in less fished areas, or that they are experiencing an increase in productivity due to, for example, warming waters or other ecosystem changes.

The IUCN ratings of the species were in broad agreement with the sensitivity of the species, and species ranked in the Critically Endangered, Endangered or Vulnerable categories were generally classified as sensitive in our analysis. However, the IUCN ranking of different species was not a reliable indicator of the potential for the species to sustain fishing pressure – the Least Concern and Data Deficient species included starry ray, tusk, marbled electric ray and wolf-fish , which were all ranked as sensitive and all decreased significantly from 1980 to 2018, indicating the potential error of assuming that species listed in these categories are not under pressure. Ideally, the status of these species should be updated during the next IUCN assessment cycle using survey data under the IUCN criteria (IUCN Standards and Petition Subcommittee, 2017). On the positive side, just above half of the species listed by IUCN as Critically Endangered, Endangered or Vulnerable increased significantly since 2000, hence providing some confidence that these species may in time move out of these categories.

The lack of a direct management of catches of a large proportion of the sensitive species means that some of the species in decline can continue to be caught. We stress here, that while the assumption that the fishing mortality affecting non-target species is unlikely to exceed the fishing mortality affecting target species (Pope et al. 2000), is likely to hold for many species, this is not necessarily the case for species with restricted distributions. Further, the fishing mortality predicted to generate MSY for the more productive species may not be sustainable for sensitive species. Species experiencing negative effects of other pressures or drivers (e.g. climate change) may also be more sensitive to fishing mortality than their general life history parameters would suggest. Due to these caveats, species like wolf-fish, tusk and starry ray, which are at the southern limit of their distributions in the North Sea, are likely to be more sensitive to fishing than indicated in our sensitivity ranking. We recommend further monitoring of sensitive species and more regular assessments of their status to spur management actions before species enter the Critically Endangered, Endangered or Vulnerable IUCN categories. Further, we recommend taking additional precaution where species are under combined pressure from climate change and fishing.

4. Authors' contributions

HG and AR conceived the ideas and designed the analyses; HG conducted the literature review and estimated species sensitivity, AR analysed species abundance and led writing of the manuscript. All authors contributed critically to the development of the analyses and manuscript and approved the final draft.

5. Acknowledgements

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6. Data availability statement

The data used in this work are life history parameters as given in Tables S2 and S3 in the Supporting Information and are available in Dryad as Rindorf (2020) "Life history traits and abundance of Northeast Atlantic fish" (doi:10.5061/dryad.8sf7m0cjd).

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Life history component		Equation	Reference/Assumption/Data
Deterministic relationships			
Asymptotic length, L_{∞} (cm)		$L_{\infty} = 10^{(0.044+0.9841\log_{10}(L_{\max}))}$	Froese & Binohlan (2000)
Von Bertalanffy parameter, K (year ⁻¹)		$K = 1.447 * L_{\infty}^{-0.5132}$	Data from Table S2
Length at first maturity, L_{mat} (cm)		$L_{mat} = 0.6106 * L_{\infty}^{0.9684}$	Data from Table S2
Minimum length, L_{min} (cm)	Egg-laying Elasmob.	$L_{min} = 0.7918 * L_{\infty}^{0.5921}$	Data from Table S2
	Live-bearing Elasmob.	$L_{min} = 0.5399 L_{\infty}^{0.7977}$	Data from Table S2
	Actinopterygians	$L_{min} = 2$	Assumed
Body weight at length L , W_L (g)		$W_L = 0.01 * L^3$	Gislason et al. (2008)
Model equations			
Proportion mature at length, P_L		$P_L = (1 + e^{(5.5*(1-L/L_{mat})})^{-1})^{-1}$	Assuming L75%=1.2* L_{mat}
Natural mortality at length, M_L (y ⁻¹)		$M_L = K * (L_t/L_{\infty})^{-1.5}$	Charnov et al. (2013)
Fishing mortality at length, F_L (y ⁻¹)		$F_L = F_{factor} * Catch\ eff.(L)$	Walker et al. (2017)
Total mortality, Z_L (y ⁻¹)		$Z_{L+\Delta L/2} = F_{L+\Delta L/2} + M_{L+\Delta L/2}$	
Numbers at length $L + \Delta L$		$N_{L+\Delta L}$ $= N_L \left(\frac{L_{\infty} - (L + \Delta L)}{L_{\infty} - L} \right)^{Z_L/K}$	Gislason et al. (2008)

Average numbers in length interval	$\bar{N}_{L,L+\Delta L} = \frac{N_L - N_{L+\Delta L}}{Z_{L+\Delta L/2}}$	Gislason et al. (2008)
Spawning stock per recruit	$\frac{SSB}{R} = \sum_{L=L_{min}}^{L_{\infty}} \frac{P_L \bar{N}_{L,L+\Delta L} W_{L+\Delta L/2}}{N_{L_{min}}}$	Gislason et al. (2008)

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Species	Annual change from 1980 to 2018	Annual change from 2000 to 2018	Probability of same trend from 1980– 1999 and 2000– 2018	Number of surveys with positive trend 1980– 1999/all surveys	Number of surveys with positive trend 2000– 2018/all surveys
<i>Amblyraja</i> <i>radiata</i>	-0.032 (0.008, P=0.0002)	-0.069 (0.009, P<0.0001)	0.0181	1/2	2/5
<i>Anarhichas lupus</i>	-0.070 (0.007, P<0.0001)	-0.081 (0.022, P=0.0019)	0.7383	0/2	1/4
<i>Brosme brosme</i>	-0.025 (0.007, P=0.0010)	-0.078 (0.015, P<0.0001)	0.0042	2/3	2/5
<i>Chimaera</i> <i>monstrosa</i>	0.045 (0.017, P=0.0152)	0.067 (0.015, P=0.0003)	0.1080	2/2	4/5
<i>Conger conger</i>	0.052 (0.008, P<0.0001)	0.000 (0.008, P=0.9936)	0.0786	2/3	5/10
<i>Dasyatis</i> <i>pastinaca</i>	-0.000 (0.027, P=0.9972)	0.006 (0.036, P=0.8714)			2/2
<i>Dipturus batis</i> complex	0.075 (0.012, P<0.0001)	0.092 (0.009, P<0.0001)	0.5196	4/4	5/6

<i>Galeorhinus</i>	-0.011 (0.019,	0.039 (0.034,	0.6018	2/3	4/4
<i>galeus</i>	P=0.5632)	P=0.2759)			
<i>Galeus</i>	0.065 (0.012,	0.064 (0.011,	0.5192	2/4	8/8
<i>melastomus</i>	P<0.0001)	P<0.0001)			
<i>Hexanchus</i>	0.028 (0.015,	0.028 (0.015,			1/1
<i>griseus</i>	P=0.0890)	P=0.0890)			
<i>Hippoglossus</i>	0.012 (0.009,	-0.029 (0.027,	0.4556	1/2	0/2
<i>hippoglossus</i>	P=0.2041)	P=0.2940)			
<i>Lepidorhombus</i>	0.023 (0.004,	0.009 (0.008,	0.4411	3/5	14/14
<i>whiffiagonis</i>	P<0.0001)	P=0.2674)			
<i>Leucoraja</i>	0.035 (0.020,	0.074 (0.017,			3/4
<i>circularis</i>	P=0.0959)	P=0.0006)			
<i>Leucoraja</i>	-0.008 (0.013,	0.023 (0.018,	0.9217	1/1	2/3
<i>fullonica</i>	P=0.5550)	P=0.2077)			
<i>Leucoraja naevus</i>	0.030 (0.006,	0.001 (0.007,	0.0551	4/5	8/10
	P<0.0001)	P=0.9004)			
<i>Lophius</i>	0.028 (0.009,	0.048 (0.008,	0.0410	1/3	7/9
<i>budegassa</i>	P<0.0053)	P<0.0001)			
<i>Lophius</i>	0.026 (0.008,	0.002 (0.010,	0.0014	3/5	6/12
<i>piscatorius</i>	P=0.0046)	P=0.8562)			
<i>Molva</i>	0.122 (0.039,	0.054 (0.037,			3/3
<i>macrophthalma</i>	P=0.0054)	P=0.1597)			

<i>Molva molva</i>	0.016 (0.007, P=0.0213)	0.049 (0.012, P=0.0007)	0.0146	1/4	5/8
<i>Mustelus</i> spp.	0.095 (0.010, P<0.0001)	0.122 (0.010, P<0.0001)	0.2205	3/4	8/8
<i>Phycis</i> <i>blennoides</i>	0.059 (0.015, P=0.0006)	-0.017 (0.018, P=0.3785)	0.0010	2/3	4/7
<i>Raja brachyura</i>	0.011 (0.014, P=0.4289)	0.059 (0.012, P<0.0001)	0.0005	0/4	6/7
<i>Raja clavata</i>	0.016 (0.008, P=0.0656)	0.086 (0.007, P<0.0001)	<0.0001	2/6	11/13
<i>Raja</i> <i>microocellata</i>	0.009 (0.009, P=0.3126)	0.000 (0.012, P=0.9995)			1/3
<i>Raja montagui</i>	0.054 (0.009, P<0.0001)	0.050 (0.013, P=0.0015)	0.8078	2/6	10/10
<i>Raja undulata</i>	0.069 (0.019, P=0.0009)	0.099 (0.043, P=0.0339)	0.8856	1/1	3/3
<i>Scophthalmus</i> <i>rhombus</i>	0.046 (0.008, P<0.0001)	0.052 (0.026, P=0.0593)	0.0955	3/5	12/15
<i>Scyliorhinus</i> <i>canicula</i>	0.041 (0.005, P<0.0001)	0.069 (0.005, P<0.0001)	<0.0001	4/6	11/12
<i>Scyliorhinus</i> <i>stellaris</i>	0.039 (0.012, P=0.0027)	0.079 (0.020, P=0.0012)	0.0014	1/1	4/4
<i>Squalus</i> <i>acanthias</i>	0.039 (0.008, P<0.0001)	0.067 (0.021, P=0.0060)	0.6783	0/4	8/11

<i>Torpedo</i>	-0.044 (0.016,	-0.018 (0.018,	1/1
<i>marmorata</i>	P=0.0140)	P=0.3358)	

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577 Figure 1. $F_{25\%SSB}$ for each IUCN category (Critically Endangered (CR), Endangered (EN),
578 Vulnerable (VU), Near Threatened (NT), Least Concern (LC) and Data Deficient (DD)) All
579 values of $F_{25\%SSB} > 2$ are shown as 2. Dotted line signifies the limit between sensitive and
580 non-sensitive species ($F_{25\%SSB} = 0.43$).

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586 Figure 2. Distribution (colour) of selected sensitive species and extent of surveyed area (grey
587 rectangles). Left panel top to bottom: Increasing species - Common skate complex (*Dipturus*
588 spp.), ling (*Molva molva*), and lesser-spotted dogfish (*Scyliorhinus canicula*). Right panel top
589 to bottom: decreasing species - Starry ray (*Amblyraja radiata*), Atlantic wolf-fish
590 (*Anarhichas lupus*) and tusk (*Brosme brosme*). Distribution data are scaled to a mean of 1 in
591 the period 2009 to 2018. The distribution of the remaining species can be found in the
592 supplementary material.

593 Figure 3. Development of species indicators for individual surveys. Each line is one survey
594 annual index.

595 Figure 4. Development of species indicators integrated across surveys and areas. Each point
596 is one survey annual index, black line is a loess fit and grey lines are the 95% confidence
597 intervals of the fitted line. Note that the points are not weighted evenly when estimating the
598 loess, hence the line is not identical to the mean of the points.

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Dipturus spp

Amblyraja radiata

Molva molva

Anarhichas lupus

Scyliorhinus canicula

Brosme brosme

Index relative to mean of 2009-2018

Year

Index relative to mean of 2009-2018

Year

Supporting Information

Rindorf et al.: Are fish sensitive to trawling recovering in the Northeast Atlantic?

Table S1. Species groups used for calculating exploitation pattern. From Walker et al. (2017).

Species group	Group description
1	Predominately buried in sediment
2	On or near the seabed – eel-like
3	Predominantly on the seabed – flat
4	Predominantly close to the seabed, but not on it
5	Midwater species with some seabed association
6	Pelagic
7	Predominantly on seabed – lumpiform

Table S2. Life history parameters, type of exploitation pattern, species group and fishing mortality factor, $F_{25\%SSB}$, necessary to reduce the spawning stock biomass, SSB , to 25% of its unfished level. For species with clear sexual dimorphism in L_{max} , L_{∞} or K (e.g. *Callionymus lyra*), the parameters for females were used, if available.

Species	L_{max}	L_{∞}	K	L_{mat}	L_{min}	Exploitation pattern	Reproduction	Taxonomy	$F_{25\%SSB}$	IUCN
<i>Rostroraja alba</i>		200	0.04	129.4		3	Oviparous	Elasmobranchii	0.05	CR
<i>Dipturus batis-complex</i>		254	0.057	130	31	3	Oviparous	Elasmobranchii	0.08	CR
<i>Somniosus microcephalus</i>		546		400	40	7	Viviparous	Elasmobranchii	0.09	NT
<i>Conger conger</i>		265	0.07		12.5	2	Oviparous	Actinopterygia	0.10	LC
<i>Dipturus nidarosiensis</i>	200			135		3	Oviparous	Elasmobranchii	0.11	NT
<i>Dipturus oxyrinchus</i>		256	0.04	83	17	4	Oviparous	Elasmobranchii	0.13	NT
<i>Hexanchus griseus</i>	458			420	70	4	Viviparous	Elasmobranchii	0.13	LC
<i>Hippoglossus hippoglossus</i>		204	0.1	112	2	3	Oviparous	Actinopterygia	0.13	VU
<i>Dasyatis pastinaca</i>		120	0.086	63	20	3	Viviparous	Elasmobranchii	0.14	VU
<i>Raja clavata</i>		140	0.093	72	12	3	Oviparous	Elasmobranchii	0.15	NT
<i>Rajella lintea</i>	114			97		3	Oviparous	Elasmobranchii	0.16	LC
<i>Lophius piscatorius</i>		167	0.077	86	2	7	Oviparous	Actinopterygia	0.16	LC
<i>Molva molva</i>		183	0.118	95	2	2	Oviparous	Actinopterygia	0.18	LC
<i>Raja brachyura</i>		155	0.129	84	15	3	Oviparous	Elasmobranchii	0.19	NT
<i>Raja microocellata</i>	91			78	13	3	Oviparous	Elasmobranchii	0.20	NT
<i>Leucoraja circularis</i>	117					3	Oviparous	Elasmobranchii	0.20	EN
<i>Leucoraja fullonica</i>	120					3	Oviparous	Elasmobranchii	0.20	VU
<i>Molva dypterygia</i>		155	0.126	88	2	2	Oviparous	Actinopterygia	0.20	VU
<i>Raja undulata</i>		113	0.149	86	14	3	Oviparous	Elasmobranchii	0.20	NT
<i>Amblyraja hyperborea</i>	112				17	3	Oviparous	Elasmobranchii	0.22	LC
<i>Lophius budegassa</i>		94	0.10	54	2	7	Oviparous	Actinopterygia	0.22	LC
<i>Scyliorhinus stellaris</i>	162				16	7	Oviparous	Elasmobranchii	0.22	NT
<i>Deania calcea</i>		119	0.08	105	32	5	Viviparous	Elasmobranchii	0.25	EN
<i>Brosme brosme</i>		84	0.109	48	2	7	Oviparous	Actinopterygia	0.26	LC
<i>Coryphaenoides rupestris</i>		76	0.1	47	2	4	Oviparous	Actinopterygia	0.26	EN

<i>Mora moro</i>		74	0.05		2	5	Oviparous	Actinopterygia	0.26	LC
<i>Rajella bathyphila</i>	90					3	Oviparous	Elasmobranchii	0.26	LC
<i>Anarhichas minor</i>		107	0.158	83	2	7	Oviparous	Actinopterygia	0.27	NT
<i>Raja montagui</i>		73	0.18	60	12	3	Oviparous	Elasmobranchii	0.27	LC
<i>Chimaera monstrosa</i>		64	0.10	46	10	4	Oviparous	Holocephali	0.28	NT
<i>Macrourus berglax</i>		62	0.04	28.5	2	5	Oviparous	Actinopterygia	0.28	LC
<i>Phycis blennoides</i>		113	0.0886	33	2	7	Oviparous	Actinopterygia	0.28	DD
<i>Brama brama</i>		71	0.08		2	4	Oviparous	Actinopterygia	0.29	LC
<i>Dicentrarchus punctatus</i>		103	0.07		2	5	Oviparous	Actinopterygia	0.29	LC
<i>Dasyatis tortonesei</i>	250			60	20	4	Viviparous	Elasmobranchii	0.30	NA
<i>Etmopterus princeps</i>	75			61	18	4	Viviparous	Elasmobranchii	0.32	LC
<i>Polyprion americanus</i>		152	0.07	77.9	2	5	Oviparous	Actinopterygia	0.31	NT
<i>Scyliorhinus canicula</i>		75	0.15	57	9	7	Oviparous	Elasmobranchii	0.31	LC
<i>Squalus acanthias</i>		121	0.07	63	27.5	5	Viviparous	Elasmobranchii	0.31	EN
<i>Leucoraja naevus</i>		84	0.197	56	11.9	3	Oviparous	Elasmobranchii	0.32	LC
<i>Molva macrophthalma</i>	108				2	4	Oviparous	Actinopterygia	0.34	LC
<i>Scophthalmus rhombus</i>		85	0.15	37	2	3	Oviparous	Actinopterygia	0.32	LC
<i>Dalatias licha</i>		165	0.15	138	42	4	Viviparous	Elasmobranchii	0.33	EN
<i>Epigonus telescopus</i>	75			56	2	4	Oviparous	Actinopterygia	0.33	DD
<i>Galeorhinus galeus</i>		163	0.075			5	Viviparous	Elasmobranchii	0.33	VU
<i>Mustelus mustelus/asterias</i>		124	0.146	85	30	4	Viviparous	Elasmobranchii	0.33	VU
<i>Scorpaena scrofa</i>		62	0.081	29	2	7	Oviparous	Actinopterygia	0.33	LC
<i>Synaphobranchus kaupi</i>	100				2	4	Oviparous	Actinopterygia	0.35	LC
<i>Torpedo marmorata</i>		57	0.187	44	12	3	Viviparous	Elasmobranchii	0.34	LC
<i>Lepidorhombus whiffiagonis</i>		61	0.142	31	2	3	Oviparous	Actinopterygia	0.35	LC
<i>Lamna nasus</i>		333	0.061	245	79	6	Viviparous	Elasmobranchii	0.39	CR
<i>Rajella fyllae</i>	60				8	3	Oviparous	Elasmobranchii	0.40	LC
<i>Amblyraja radiata</i>		66	0.23	46	10	3	Oviparous	Elasmobranchii	0.40	LC
<i>Argyrosomus regius</i>		172	0.15	90	2	4	Oviparous	Actinopterygia	0.40	LC

<i>Anarhichas lupus</i>		91	0.23	73	2	7	Oviparous	Actinopterygia	0.41	DD
<i>Ephippion guttifer</i>	80				2	4	Oviparous	Actinopterygia	0.42	DD
<i>Galeus melastomus</i>	67			45		7	Oviparous	Elasmobranchii	0.44	LC
<i>Torpedo nobiliana</i>	180				23	5	Viviparous	Elasmobranchii	0.44	LC
<i>Pollachius virens</i>		107	0.19	71	2	4	Oviparous	Actinopterygia	0.43	LC
<i>Sparus aurata</i>		85	0.13	36.5	2	4	Oviparous	Actinopterygia	0.43	LC
<i>Myliobatis aquila</i>	183					5	Viviparous	Elasmobranchii	0.40	VU
<i>Scophthalmus maximus</i>		65	0.26	46	2	3	Oviparous	Actinopterygia	0.46	VU
<i>Solea senegalensis</i>		55	0.18		2	3	Oviparous	Actinopterygia	0.46	DD
<i>Cetorhinus maximus</i>		1000	0.062	500	175	6	Viviparous	Elasmobranchii	0.47	EN
<i>Dicentrarchus labrax</i>		85	0.097	43	2	5	Oviparous	Actinopterygia	0.49	LC
<i>Merluccius merluccius</i>		130	0.16	50	2	4	Oviparous	Actinopterygia	0.49	LC
<i>Pollachius pollachius</i>		86	0.186	47	2	4	Oviparous	Actinopterygia	0.49	LC
<i>Nettastoma melanurum</i>	80			53.5	2	1	Oviparous	Actinopterygia	0.50	LC
<i>Dentex gibbosus</i>		98	0.15	34.7	2	4	Oviparous	Actinopterygia	0.51	LC
<i>Paralichthys dentatus</i>		82	0.24	37	2	3	Oviparous	Actinopterygia	0.52	LC
<i>Lepidorhombus boscii</i>		46	0.15		2	3	Oviparous	Actinopterygia	0.53	LC
<i>Trachipterus arcticus</i>		303			2	6	Oviparous	Actinopterygia	0.54	LC
<i>Scymnodon ringens</i>	110					5	Viviparous	Elasmobranchii	0.57	LC
<i>Myoxocephalus quadricornis</i>		62	0.16		2	7	Oviparous	Actinopterygia	0.58	LC
<i>Etmopterus pusillus</i>		51	0.13	44.58		4	Viviparous	Elasmobranchii	0.60	DD
<i>Pagellus bogaraveo</i>		51	0.14	40	2	4	Oviparous	Actinopterygia	0.71	NT
<i>Gadus morhua</i>		119	0.27	59	2	4	Oviparous	Actinopterygia	0.73	LC
<i>Helicolenus dactylopterus</i>		31	0.09	23	2	7	Oviparous	Actinopterygia	0.74	LC
<i>Alopias vulpinus</i>		484	0.11	303	92	6	Viviparous	Elasmobranchii	0.75	EN
<i>Glyptocephalus cynoglossus</i>		44	0.2		2	3	Oviparous	Actinopterygia	0.76	LC
<i>Chelon labrosus</i>		61	0.12		2	5	Oviparous	Actinopterygia	0.77	LC
<i>Deania profundorum</i>	79					5	Viviparous	Elasmobranchii	0.79	LC
<i>Gnathophis mystax</i>	60				2	1	Oviparous	Actinopterygia	0.80	LC

<i>Malacocephalus laevis</i>	60			2	2	Oviparous	Actinopterygia	0.80	LC	
<i>Merlangius merlangus</i>		74	0.16	28	2	4	Oviparous	Actinopterygia	0.78	LC
<i>Myxine glutinosa</i>	80			25	2	1	Oviparous	Agnatha	0.80	LC
<i>Diplodus cervinus</i>		58	0.15	28.4	2	1	Oviparous	Actinopterygia	0.80	LC
<i>Dentex canariensis</i>		85	0.15	20	2	4	Oviparous	Actinopterygia	0.83	LC
<i>Eutrigla gurnardus</i>		46	0.16	25	2	7	Oviparous	Actinopterygia	0.83	LC
<i>Etmopterus spinax</i>		56	0.12	31	11	4	Viviparous	Elasmobranchii	0.83	NT
<i>Thunnus thynnus</i>		319	0.093	104	2	6	Oviparous	Actinopterygia	0.83	NT
<i>Callanthias ruber</i>	60				2	4	Oviparous	Actinopterygia	0.84	LC
<i>Prionace glauca</i>		371	0.13	221	40	6	Viviparous	Elasmobranchii	0.85	NT
<i>Xiphias gladius</i>		264	0.12	145	2	6	Oviparous	Actinopterygia	0.85	LC
<i>Chelon aurata</i>		69	0.14	34	2	5	Oviparous	Actinopterygia	0.86	LC
<i>Pleuronectes platessa</i>		48	0.23	23	2	3	Oviparous	Actinopterygia	0.87	LC
<i>Cyclopterus lumpus</i>		53	0.26	35	2	7	Oviparous	Actinopterygia	0.92	NT
<i>Neoraja iberica</i>	33			28		3	Oviparous	Elasmobranchii	0.97	LC
<i>Beryx decadactylus</i>		68	0.11	21.8	2	5	Oviparous	Actinopterygia	0.95	LC
<i>Lepidopus caudatus</i>		195	0.23		2	5	Oviparous	Actinopterygia	1.00	LC
<i>Trachinus draco</i>		38	0.15		2	1	Oviparous	Actinopterygia	1.07	LC
<i>Mola mola</i>		318	0.15		2	6	Oviparous	Actinopterygia	1.08	DD
<i>Lycodes vahlii</i>	52				2	2	Oviparous	Actinopterygia	1.16	NA
<i>Pagellus erythrinus</i>		47	0.084	17	2	5	Oviparous	Actinopterygia	1.14	LC
<i>Beryx splendens</i>		50	0.17	33	2	5	Oviparous	Actinopterygia	1.16	LC
<i>Halargyreus johnsonii</i>	56				2	5	Oviparous	Actinopterygia	1.24	LC
<i>Pegusa lascaris</i>		39	0.251	22	2	3	Oviparous	Actinopterygia	1.22	LC
<i>Macroparalepis affinis</i>	55				2	5	Oviparous	Actinopterygia	1.28	NA
<i>Lepidion eques</i>		42	0.15	29.5	2	5	Oviparous	Actinopterygia	1.28	LC
<i>Chaunax pictus</i>	40				2	7	Oviparous	Actinopterygia	1.29	LC
<i>Solea solea</i>		39	0.32	24	2	3	Oviparous	Actinopterygia	1.38	DD
<i>Trigla lyra</i>		52	0.21		2	2	Oviparous	Actinopterygia	1.38	DD

<i>Benthodesmus elongatus</i>	100			2	6	Oviparous	Actinopterygia	1.43	NA	
<i>Chelon ramada</i>		47	0.15	25	2	5	Oviparous	Actinopterygia	1.43	LC
<i>Galeus atlanticus</i>	46			36.9		4	Oviparous	Elasmobranchii	1.45	NT
<i>Gaidropsarus vulgaris</i>		46		27	2	2	Oviparous	Actinopterygia	1.50	LC
<i>Sarpa salpa</i>		50	0.20	29.4	2	5	Oviparous	Actinopterygia	1.57	LC
<i>Trachyrincus murrayi</i>	45				2	2	Oviparous	Actinopterygia	1.64	LC
<i>Platichthys flesus</i>		39	0.25	18	2	3	Oviparous	Actinopterygia	1.66	LC
<i>Umbrina canariensis</i>		57	0.26		2	4	Oviparous	Actinopterygia	1.72	LC
<i>Enchelyopus cimbrius</i>	41			25	2	2	Oviparous	Actinopterygia	1.85	LC
<i>Pagrus pagrus</i>		60	0.17	22.6	2	4	Oviparous	Actinopterygia	1.86	LC
<i>Microchirus azevia</i>		34	0.35	23	2	3	Oviparous	Actinopterygia	1.89	LC
<i>Chelidonichthys obscurus</i>	51				2	4	Oviparous	Actinopterygia	1.92	LC
<i>Microstomus kitt</i>		35	0.1955	16	2	3	Oviparous	Actinopterygia	2.00	LC
<i>Chelidonichthys lucerna</i>		52	0.25	28	2	5	Oviparous	Actinopterygia	2.03	LC
<i>Gaidropsarus mediterraneus</i>	50				2	4	Oviparous	Actinopterygia	2.04	LC
<i>Mugil cephalus</i>		49	0.302	33	2	5	Oviparous	Actinopterygia	2.08	LC
<i>Lumpenus lampretaeformis</i>		48	0.205	20	2	2	Oviparous	Actinopterygia	2.13	LC
<i>Cepola macrophthalma</i>		61	0.23	23.8	2	4	Oviparous	Actinopterygia	2.17	LC
<i>Chelidonichthys cuculus</i>		41	0.24	28	2	5	Oviparous	Actinopterygia	2.19	LC
<i>Hoplostethus mediterraneus</i>		30	0.11	16.5	2	5	Oviparous	Actinopterygia	2.20	LC
<i>Citharus linguatula</i>		30	0.19		2	3	Oviparous	Actinopterygia	2.23	LC
<i>Chauliodus sloani</i>	40				2	5	Oviparous	Actinopterygia	2.51	LC
<i>Limanda limanda</i>		33	0.19	14	2	3	Oviparous	Actinopterygia	2.53	LC
<i>Zeus faber</i>		51	0.47	36	2	4	Oviparous	Actinopterygia	3.01	DD
<i>Myoxocephalus scorpioides</i>	30				2	7	Oviparous	Actinopterygia	3.11	NA
<i>Raniceps raninus</i>	30				2	7	Oviparous	Actinopterygia	3.11	LC
<i>Lampanyctus crocodilus</i>	36				2	5	Oviparous	Actinopterygia	3.16	LC
<i>Labrus bergylta</i>		44	0.103		2	4	Oviparous	Actinopterygia	3.16	LC
<i>Diplodus sargus</i>		50	0.13	21.6	2	4	Oviparous	Actinopterygia	3.21	LC

<i>Trachyrincus scabrus</i>		49	0.22		2	4	Oviparous	Actinopterygia	3.24	LC
<i>Scorpaena porcus</i>		29	0.16	13.8	2	7	Oviparous	Actinopterygia	3.31	LC
<i>Micromesistius poutassou</i>		33	0.24	21	2	5	Oviparous	Actinopterygia	3.45	LC
<i>Zeugopterus punctatus</i>	28				2	3	Oviparous	Actinopterygia	3.49	LC
<i>Nezumia sclerorhynchus</i>		26	0.16	15	2	5	Oviparous	Actinopterygia	3.62	LC
<i>Argentina silus</i>		43	0.19	29	2	4	Oviparous	Actinopterygia	4.05	NA
<i>Zoarces viviparus</i>		35	0.37	17	5	7	Viviparous	Actinopterygia	4.19	LC
<i>Cyttopsis rosea</i>	31				2	5	Oviparous	Actinopterygia	4.21	DD
<i>Echiodon drummondii</i>	30				2	2	Oviparous	Actinopterygia	4.23	LC
<i>Arnoglossus imperialis</i>	25				2	3	Oviparous	Actinopterygia	5.78	LC
<i>Polymetme corythaeola</i>	26				2	5	Oviparous	Actinopterygia	5.92	LC
<i>Acantholabrus palloni</i>	25				2	5	Oviparous	Actinopterygia	6.33	LC
<i>Sarda sarda</i>		81	0.35	37	2	6	Oviparous	Actinopterygia	6.84	LC
<i>Entelurus aequoreus</i>	60				2	6	Oviparous	Actinopterygia	7.11	LC
<i>Trigloporus lastoviza</i>		28	0.409	16	2	7	Oviparous	Actinopterygia	7.24	DD
<i>Mullus surmuletus</i>		51	0.19	17	2	4	Oviparous	Actinopterygia	7.63	DD
<i>Hippoglossoides platessoides</i>		25	0.34	15	2	3	Oviparous	Actinopterygia	7.65	LC
<i>Chlorophthalmus agassizi</i>		19	0.24		2	5	Oviparous	Actinopterygia	7.86	LC
<i>Caranx rhonchus</i>		45	0.30		2	4	Oviparous	Actinopterygia	7.92	DD
<i>Polymetme thaeocoryla</i>	22				2	5	Oviparous	Actinopterygia	7.97	LC
<i>Notoscopelus kröyeri</i>		15	0.20		2	5	Oviparous	Actinopterygia	8.04	NA
<i>Balistes capriscus</i>		46	0.33		2	4	Oviparous	Actinopterygia	8.10	DD
<i>Dicologlossa cuneata</i>		27	0.42	15	2	3	Oviparous	Actinopterygia	8.14	LC
<i>Spondyliosoma cantharus</i>		41	0.11	20	2	4	Oviparous	Actinopterygia	8.48	LC
<i>Lestidiops jayakari</i>	20				2	5	Oviparous	Actinopterygia	8.97	LC
<i>Melanogrammus aeglefinus</i>		50	0.30	20	2	4	Oviparous	Actinopterygia	8.87	LC
<i>Chirolophis ascanii</i>	18				2	5	Oviparous	Actinopterygia	10.41	LC
<i>Nezumia aequalis</i>		16	0.18	4.5	2	5	Oviparous	Actinopterygia	10.53	LC
<i>Gaidropsarus biscayensis</i>	40				2	4	Oviparous	Actinopterygia	10.55	LC

<i>Pholis gunnellus</i>		22	0.1986	10	2	2	Oviparous	Actinopterygia	11.00	LC
<i>Trisopterus luscus</i>		47	0.21	18	2	4	Oviparous	Actinopterygia	11.28	LC
<i>Belone belone</i>		58	0.468	45	2	6	Oviparous	Actinopterygia	12.64	LC
<i>Coelorinchus caelorhincus</i>		39	0.15		2	4	Oviparous	Actinopterygia	12.85	DD
<i>Gadiculus argenteus</i>	15				2	5	Oviparous	Actinopterygia	12.96	LC
<i>Leptoclinus maculatus</i>	20				2	2	Oviparous	Actinopterygia	14.20	LC
<i>Echiichthys vipera</i>		15	0.33		2	1	Oviparous	Actinopterygia	15.69	LC
<i>Sebastes viviparus</i>		36	0.07	15	2	4	Viviparous	Actinopterygia	16.88	LC
<i>Serranus cabrilla</i>		39	0.10	15.4	2	4	Oviparous	Actinopterygia	16.97	LC
<i>Blennius ocellaris</i>	20				2	7	Oviparous	Actinopterygia	17.13	LC
<i>Trachurus picturatus</i>		50	0.11	27.7	2	6	Oviparous	Actinopterygia	17.59	LC
<i>Trisopterus esmarkii</i>		20	0.71	14	2	5	Oviparous	Actinopterygia	18.27	LC
<i>Microchirus variegatus</i>		21	0.374	14	2	3	Oviparous	Actinopterygia	18.33	LC

<i>Agonus cataphractus</i>		15	0.475		2	7	Oviparous	Actinopterygia	20.00	LC
<i>Anthias anthias</i>	27				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Aphia minuta</i>		9	2.23	5	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Arctozenus risso</i>	30				2	6	Oviparous	Actinopterygia	20.00	LC
<i>Argentina sphyraena</i>		22	0.28		2	4	Oviparous	Actinopterygia	20.00	LC
<i>Argyropelecus olfersii</i>	9				2	5	Oviparous	Actinopterygia	20.00	LC
<i>Arnoglossus laterna</i>		16	0.84	11	2	3	Oviparous	Actinopterygia	20.00	LC
<i>Arnoglossus rueppelii</i>	15				2	3	Oviparous	Actinopterygia	20.00	DD
<i>Arnoglossus thori</i>		18	0.51	12	2	3	Oviparous	Actinopterygia	20.00	DD
<i>Atherina presbyter</i>		16	0.138	7	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Auxis rochei rochei</i>		46	0.70		2	6	Oviparous	Actinopterygia	20.00	LC
<i>Bathysolea profundicola</i>		15	0.58		2	3	Oviparous	Actinopterygia	20.00	LC
<i>Benthosema glaciale</i>		7	0.36		2	6	Oviparous	Actinopterygia	20.00	LC
<i>Boops boops</i>		36	0.17	14.3	2	4	Oviparous	Actinopterygia	20.00	LC

<i>Buenia jeffreysii</i>	6			2	4	Oviparous	Actinopterygia	20.00	LC	
<i>Buglossidium luteum</i>		12	0.54	8	2	1	Oviparous	Actinopterygia	20.00	LC
<i>Callionymus lyra</i>		18	0.55		2	7	Oviparous	Actinopterygia	20.00	LC
<i>Capros aper</i>		17	0.145	10	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Centrolabrus exoletus</i>		13	0.69	11	2	5	Oviparous	Actinopterygia	20.00	LC
<i>Ceratoscopelus maderensis</i>	8				2	5	Oviparous	Actinopterygia	20.00	LC
<i>Clupea harengus</i>		30	0.33	26	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Cottunculus microps</i>	30				2	4	Oviparous	Actinopterygia	20.00	DD
<i>Crystallogobius linearis</i>		5			2	6	Oviparous	Actinopterygia	20.00	LC
<i>Ctenolabrus rupestris</i>		15	0.297		2	4	Oviparous	Actinopterygia	20.00	LC
<i>Dentex maroccanus</i>		32	0.18	16	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Diplecogaster bimaculata</i>	6				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Diplodus annularis</i>		25	0.24	13	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Diplodus bellottii</i>		26	0.27		2	4	Oviparous	Actinopterygia	20.00	LC
<i>Diplodus vulgaris</i>		28	0.39	17.65	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Engraulis encrasicolus</i>		23	0.44	12	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Epigonus denticulatus</i>	20				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Gadella maraldi</i>	30				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Gaidropsarus argentatus</i>	35				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Gaidropsarus macrophthalmus</i>	25				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Gasterosteus aculeatus</i>		8	0.67		2	6	Oviparous	Actinopterygia	20.00	LC
<i>Gobius gasteveni</i>	12				2	2	Oviparous	Actinopterygia	20.00	LC
<i>Gobius paganellus</i>		14	0.73		2	2	Oviparous	Actinopterygia	20.00	LC
<i>Hygophum benoiti</i>	6				2	6	Oviparous	Actinopterygia	20.00	LC
<i>Hymenocephalus italicus</i>		6	0.18	2.7	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Icelus bicornis</i>	19				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Labrus mixtus</i>		35		18	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Lepidotrigla cavillone</i>		17	0.56	9.3	2	2	Oviparous	Actinopterygia	20.00	LC
<i>Lepidotrigla dieuzeidei</i>	20				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Leptagonus decagonus</i>	21				2	4	Oviparous	Actinopterygia	20.00	LC

<i>Lesueurigobius friesii</i>	13			2	2	Oviparous	Actinopterygia	20.00	LC	
<i>Lesueurigobius sanzi</i>	11			2	2	Oviparous	Actinopterygia	20.00	LC	
<i>Lithognathus mormyrus</i>		35	0.26	16	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Lycenchelys sarsi</i>	20			11	2	7	Oviparous	Actinopterygia	20.00	LC
<i>Lycodes gracilis</i>		15	0.39		2	4	Oviparous	Actinopterygia	20.00	LC
<i>Macroramphosus scolopax</i>		15.7	0.654		2	5	Oviparous	Actinopterygia	20.00	LC
<i>Maurolicus muelleri</i>		6	0.88		2	6	Oviparous	Actinopterygia	20.00	LC
<i>Micrenophrys lilljeborgii</i>		7			2	4	Oviparous	Actinopterygia	20.00	LC
<i>Microchirus boscanion</i>	20				2	3	Oviparous	Actinopterygia	20.00	LC
<i>Monochirus hispidus</i>		17	0.24	9	2	3	Oviparous	Actinopterygia	20.00	LC
<i>Myctophum punctatum</i>		9	0.32	5	2	5	Oviparous	Actinopterygia	20.00	LC
<i>Myoxocephalus scorpius</i>		27	0.83	12	2	7	Oviparous	Actinopterygia	20.00	LC
<i>Naucrates ductor</i>		44	2.15		2	5	Oviparous	Actinopterygia	20.00	LC
<i>Nerophis lumbriciformis</i>	15				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Ophidion barbatum</i>	25				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Pagellus acarne</i>		34	0.21	16	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Parablennius gattorugine</i>	30				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Phrynorhombus norvegicus</i>		12			2	3	Oviparous	Actinopterygia	20.00	LC
<i>Pomatoschistus lozanoi</i>	8				2	2	Oviparous	Actinopterygia	20.00	LC
<i>Pomatoschistus norvegicus</i>	8				2	2	Oviparous	Actinopterygia	20.00	LC
<i>Pterycombus brama</i>	46				2	6	Oviparous	Actinopterygia	20.00	LC
<i>Pungitius pungitius</i>		5.7	0.13		2	5	Oviparous	Actinopterygia	20.00	LC
<i>Sardina pilchardus</i>		19	0.4	15	2	6	Oviparous	Actinopterygia	20.00	NT
<i>Scomber colias</i>		56	0.19	21.6	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Scomber scombrus</i>		43	0.26		2	6	Oviparous	Actinopterygia	20.00	LC
<i>Scomberesox saurus</i>		35	0.71		2	6	Oviparous	Actinopterygia	20.00	LC
<i>Scorpaena loppei</i>		11	0.53		2	7	Oviparous	Actinopterygia	20.00	LC
<i>Scorpaena notata</i>		18	0.43		2	7	Oviparous	Actinopterygia	20.00	LC
<i>Serranus hepatus</i>		15	0.36	7.8	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Serranus scriba</i>		28	0.16	17.3	2	4	Oviparous	Actinopterygia	20.00	LC

<i>Sprattus sprattus</i>		14	0.63		2	6	Oviparous	Actinopterygia	20.00	LC
<i>Stomias boa</i>	32				2	6	Oviparous	Actinopterygia	20.00	LC
<i>Symphodus bailloni</i>	20				2	4	Oviparous	Actinopterygia	20.00	LC
<i>Symphodus melops</i>		21	0.31	16	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Symphodus roissali</i>		13	0.59	5	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Taurulus bubalis</i>		19	0.251		2	7	Oviparous	Actinopterygia	20.00	LC
<i>Taurulus lilljeborgi</i>	7				2	7	Oviparous	Actinopterygia	20.00	NA
<i>Trachurus mediterraneus</i>		43	0.21	20	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Trachurus trachurus</i>		40	0.21	22	2	6	Oviparous	Actinopterygia	20.00	LC
<i>Triglops murrayi</i>		18	0.22		2	7	Oviparous	Actinopterygia	20.00	LC
<i>Trisopterus minutus</i>		24	0.40	13	2	4	Oviparous	Actinopterygia	20.00	LC
<i>Xenodermichthys copei</i>	31				2	6	Oviparous	Actinopterygia	20.00	LC
<i>Zeugopterus regius</i>	20				2	3	Oviparous	Actinopterygia	20.00	LC

Table S3. References for life history parameters used.

Species	Source of L_{max} or L_{∞} & K	Source of L_{mat}	Source of L_{min}
<i>Acantholabrus palloni</i>	Gomon, M.F. and P. Forsyth, 1990. Labridae. p. 868-882. In J.C. Quéro, J.C. Hureau, C. Karrer, A. Post and L. Saldanha (eds.) Check-list of the fishes of the eastern tropical Atlantic (CLOFETA). JNICT, Lisbon, SEI, Paris; and UNESCO, Paris. Vol. 2.		
<i>Agonus cataphractus</i>	Pauly, D., 1978. A preliminary compilation of fish length growth parameters. Ber. Inst. Meereskd. Christian-Albrechts-Univ. Kiel (55):1-200.		
<i>Alopias vulpinus</i>	Natanson, L.J., Hamady, L.L. and Gervelis, B.J., 2016. Analysis of bomb radiocarbon data for common thresher sharks, <i>Alopias vulpinus</i> , in the northwestern Atlantic Ocean with revised growth curves. Environmental biology of fishes, 99(1), pp.39-47.	Smith, S.E., R.C. Rasmussen, D.A. Ramon and G.M. Cailliet, 2008. The biology and ecology of thresher sharks (Alopiidae). p. 60-68. In M.D. Camhi, E.K. Pikitch and E.A. Babcock (eds) Sharks of the open ocean. Blackwell Publishing, Oxford, UK, 502 p.	Moreno, J.A., Parajúa, J.I. and Morón, J. 1989. Biología reproductiva y fenología de <i>Alopias vulpinus</i> (Bonnaterre, 1788) (Squaliformes: Alopiidae) en el Atlántico nororiental y Mediterráneo occidental. Scientia Marina 53(1): 37-46.
<i>Amblyraja hyperborea</i>	Last, P.R., W.T. White, M.R. de Carvalho, B. Séret, M.F.W. Stehmann and G.J.P. Naylor, 2016. Rays of the world. CSIRO Publishing, Comstock Publishing Associates. i-ix + 1-790.		Last, P.R., W.T. White, M.R. de Carvalho, B. Séret, M.F.W. Stehmann and G.J.P. Naylor, 2016. Rays of the world. CSIRO Publishing, Comstock Publishing Associates. i-ix + 1-790.
<i>Amblyraja radiata</i>	Jennings, S., S.P.R. Greenstreet and J.D. Reynolds, 1999. Structural change in an exploited fish community: a consequence of differential fishing effects on species with	Jennings, S., S.P.R. Greenstreet and J.D. Reynolds, 1999. Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. J. Animal Ecol. 68:617-627.	Last, P.R., W.T. White, M.R. de Carvalho, B. Séret, M.F.W. Stehmann and G.J.P. Naylor, 2016. Rays of the world. CSIRO Publishing, Comstock Publishing Associates. i-ix + 1-790.

	contrasting life histories. J. Animal Ecol. 68:617-627.	
<i>Anarhichas lupus</i>	Liao, Y.-Y. and M.C. Lucas, 2000. Growth, diet and metabolism of common wolf-fish in the North Sea, a fast-growing population. J. Fish Biol. 56(4):810-825.	Gunnarsson, A., Hjörleifsson, E., Thórarinnsson, K. and Marteinsdóttir, G., 2006. Growth, maturity and fecundity of wolffish <i>Anarhichas lupus</i> L. in Icelandic waters. Journal of fish biology, 68(4), pp.1158-1176.
<i>Anarhichas minor</i>	Gunnarsson, A., Hjörleifsson, E., Thórarinnsson, K. and Marteinsdóttir, G., 2008. Growth, maturity and fecundity of female spotted wolffish <i>Anarhichas minor</i> in Icelandic waters. Journal of Fish Biology, 73(6), pp.1393-1406.	Gunnarsson, A., Hjörleifsson, E., Thórarinnsson, K. and Marteinsdóttir, G., 2008. Growth, maturity and fecundity of female spotted wolffish <i>Anarhichas minor</i> in Icelandic waters. Journal of Fish Biology, 73(6), pp.1393-1406.
<i>Anthias anthias</i>	Bauchot, M.-L., 1987. Poissons osseux. p. 891-1421. In W. Fischer, M.L. Bauchot and M. Schneider (eds.) Fiches FAO d'identification pour les besoins de la pêche. (rev. 1). Méditerranée et mer Noire. Zone de pêche 37. Vol. II. Commission des Communautés Européennes and FAO, Rome.	
<i>Aphia minuta</i>	Iglesias, M., E.B. Brothers and B. Morales-Nin, 1997. Validation of daily increment deposition in otoliths. Age and growth determination of <i>Aphia minuta</i> (Pisces: Gobiidae) from the northwest Mediterranean. Mar. Biol. 129(2):279-287.	Iglesias, M. and B. Morales-Nin, 2001. Life cycle of the pelagic goby <i>Aphia minuta</i> (Pisces: Gobiidae). Sci. Mar. 65(3):183-192.
<i>Arctozenus risso</i>	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.	
<i>Argentina silus</i>	Bergstad, O.A., 1993. Distribution, population structure, growth, and reproduction of the	Johannesen, A. & Monstad, T., 2003. Distribution, growth and exploitation

	greater silver smelt, <i>Argentina silus</i> (Pisces, Argentinidae), of the Skagerrak and the north-eastern North Sea. ICES J. mar. Sci. 50:129-143.	of greater silver smelt (<i>Argentina silus</i> (Ascanius, 1775)) in Norwegian waters 1980-83. Journal of Northwest Atlantic Fishery Science 31:319-332
<i>Argentina sphyraena</i>	Lee, J.Y., 1963. Les Argentines du Golfe du Lion, <i>Argentina sphyraena</i> L., <i>Argentina leioglossa</i> Val. Rev. Trav. Inst. Pêches Marit. 27(1-4):189-202.	
<i>Argyropelecus olfersii</i>	Reiner, F., 1996. Catálogo dos peixes do arquipélago de Cabo Verde. Publ. Avuls. Inst. Port. Invest. Mar. 2:339 p.	
<i>Argyrosomus regius</i>	González-Quirós, R., J. del Árbol, M.M. García-Pacheco, A.J. Silva-García, J.M. Naranjo and B. Morales-Nin, 2011. Life-history of the meagre <i>Argyrosomus regius</i> in the Gulf of Cádiz (SW Iberian Peninsula). Fish. Res. 109(1):140-149.	González-Quirós, R., J. del Árbol, M.M. García-Pacheco, A.J. Silva-García, J.M. Naranjo and B. Morales-Nin, 2011. Life-history of the meagre <i>Argyrosomus regius</i> in the Gulf of Cádiz (SW Iberian Peninsula). Fish. Res. 109(1):140-149.
<i>Arnoglossus imperialis</i>	Schneider, W., 1990. FAO species identification sheets for fishery purposes. Field guide to the commercial marine resources of the Gulf of Guinea. Prepared and published with the support of the FAO Regional Office for Africa. Rome: FAO. 268 p.	
<i>Arnoglossus laterna</i>	Deniel, C., 1990. Comparative study of growth of flatfishes on the west coast of Brittany. <i>Journal of Fish Biology</i> , 37(1), pp.149-166.	Deniel, C., 1990. Comparative study of growth of flatfishes on the west coast of Brittany. <i>Journal of Fish Biology</i> , 37(1), pp.149-166.
<i>Arnoglossus rueppelii</i>	Nielsen, J.G., 1986. Bothidae. p. 1294-1298. In P.J.P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen and E. Tortonese (eds.) Fishes of the North-eastern Atlantic and the Mediterranean. UNESCO, Paris. Vol. 3.	

<i>Arnoglossus thori</i>	Deniel, C., 1990. Comparative study of growth of flatfishes on the west coast of Brittany. J. Fish Biol. 37(1):149-166	Félix, P.M., Vinagre, C. and Cabral, H.N., 2011. Life-history traits of flatfish in the Northeast Atlantic and Mediterranean Sea. Journal of Applied Ichthyology, 27(1), pp.100-111.
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<i>Auxis rochei rochei</i>	Valeiras, X., D. Macias, M.J. Gomez, L. Lema, S. Garcia-Barcelona, J.M. De Urbinqa Ortiz and J.M. de la Serna, 2008. Age and growth of bullet tuna (<i>Auxis rochei</i>) in the western Mediterranean Sea. Collect. Vol. Sci. Pap. ICCAT 62(5):1629-1637	
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<i>Bathysolea profundicola</i>	Cau, A. and A. Deiana, 1983. Reproduction et accroissement dans quelques Soleidae de la Mediterranee du centre occidental. Rapp. Comm. int. Mer Médit. 28(5):61-62.	
<i>Belone belone</i>	Potoschi, A., A. Cefali and G. Cavallaro, 1983. Notes on the biology of <i>Belone belone gracilis</i> Lowe 1839, captured in the area of the strait of Messina. Mem. Biol. Mar. Ocean. 13:19-36.	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedeusene, Denmark. 340 p.
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<i>Benthoosema glaciale</i>	Gjøsaeter, J., 1973. Age, growth and mortality of the myctophid fish <i>Benthoosema glaciale</i> (Reinhardt) from western Norway. Sarsia 52:1-14.	
<i>Beryx decadactylus</i>	Krug, H., D. Carvalho & J.A. González 2010. Age and growth of the alfoncino <i>Beryx decadactylus</i> (Cuvier, 1829) from the Azores, Madeira and Canary Islands, based on historical data. Arquipelago. Life and Marine Sciences 28:25-31	Estácio, S. and Krug, H., 2001. Aspects of the reproduction of six exploited demersal fish species in the Azores Archipelago. Fauna and Flora of the Atlantic Islands. Arquipelago, Life and Marine Sciences, suppl 2(Part B), p.83.
<i>Beryx splendens</i>	Rico, V., J.M. Lorenzo, J.A. González, H.M. Krug, A. Mendonça, E. Gouveia and M.A. Dias, 2001. Age and growth of the alfoncino <i>Beryx splendens</i> Lowe, 1834 from the Macronesian archipelagos. Fish. Res. 49(3):233-240.	Lehodey, P. and R. Grandperrin, 1996. Age and growth of the alfoncino <i>Beryx splendens</i> over the seamounts off New Caledonia. Mar. Biol. 125:249-258.
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<i>Boops boops</i>	Zuniga, L.R., 1967. Estudio del crecimiento de <i>Boops boops</i> (L.) del Levante Español. Inv. Pesq. 31(3):383-418	Layachi, M., M.H. Idrissi, M. Ramdani, F. Sahnouni and R. Flower, 2015. Growth and reproduction of the Bogue <i>Boops boops</i> L. 1758 in the editerranean coastal area

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<i>Brosme brosme</i>	ICES, 2018. Report of the Working Group on Biology and Assessment of Deep-sea Fisheries Resources. Stock annex: Tusk (<i>Brosme brosme</i>) in subareas 4 and 7–9, and in divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic)	ICES, 2018. Report of the Working Group on Deep Sea Fisheries. Stock annex: Tusk (<i>Brosme brosme</i>) in subareas 4 and 7–9, and in divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic)
<i>Buenia jeffreysii</i>	Miller, P.J., 1986. Gobiidae. p. 1019-1085. In P.J.P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen and E. Tortonese (eds.) Fishes of the North-eastern Atlantic and the Mediterranean. Volume 3. UNESCO, Paris.	
<i>Buglossidium luteum</i>	Deniel, C., 1990. Comparative study of growth of flatfishes on the west coast of Brittany. <i>Journal of Fish Biology</i> , 37(1), pp.149-166.	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.
<i>Callanthias ruber</i>	Edwards, A., 1990. Fish and fisheries of Saint Helena Island. Centre for Tropical Coastal Management Studies, University of Newcastle upon Tyne, England.	
<i>Callionymus lyra</i>	Beverton, R.J.H. and S.J. Holt, 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. p. 142-180. In G.E.W. Wolstenholme and M. O'Connor (eds.) CIBA Foundation colloquia on ageing: the lifespan of animals. volume 5. J & A Churchill Ltd, London.	

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<i>Centrolabrus exoletus</i>	Sayer, M. D. J., R. N. Gibson, and R. J. A. Atkinson. "Growth, diet and condition of corks wing wrasse and rock cook on the west coast of Scotland." <i>Journal of Fish Biology</i> 49, no. 1 (1996): 76-94.	Sayer, M. D. J., R. N. Gibson, and R. J. A. Atkinson. "Growth, diet and condition of corks wing wrasse and rock cook on the west coast of Scotland." <i>Journal of Fish Biology</i> 49, no. 1 (1996): 76-94.
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<i>Cetorhinus maximus</i>	Pauly, D., 2002. Growth and mortality of the basking shark <i>Cetorhinus maximus</i> and their implications for management of whale sharks <i>Rhincodon typus</i> . IUCN SSC SHARK SPECIALIST	Pauly, D., 2002. Growth and mortality of the basking shark <i>Cetorhinus maximus</i> and their implications for management of whale sharks <i>Rhincodon typus</i> . IUCN SSC SHARK Sund, O. 1943. Et brugdelbarsel. <i>Naturen</i> 67: 285–286.

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Rostroraja alba

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<i>Trisopterus luscus</i>	Labarta, U. and M.J. Ferreira, 1982. Age and growth of the Galician coast pouting	Labarta, U. and M.J. Ferreira, 1982. Age and growth of the Galician coast pouting

	(<i>Trisopterus luscus</i> L.). Preliminary data. ICES C.M. 1982/G:65.	(<i>Trisopterus luscus</i> L.). Preliminary data. ICES C.M. 1982/G:65.
<i>Trisopterus minutus</i>	Beverton, R.J.H. and S.J. Holt, 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. p. 142-180. In G.E.W. Wolstenholme and M. O'Connor (eds.) CIBA Foundation colloquia on ageing: the lifespan of animals. volume 5. J & A Churchill Ltd, London.	Beverton, R.J.H. and S.J. Holt, 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. p. 142-180. In G.E.W. Wolstenholme and M. O'Connor (eds.) CIBA Foundation colloquia on ageing: the lifespan of animals. volume 5. J & A Churchill Ltd, London.
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<i>Xenodermichthys copei</i>	Bernardes, R.Á., J.L. de Figueiredo, A.R. Rodrigues, L.G. Fischer, C.M. Vooren, M. Haimovici and C.L.D.B. Rossi-Wongtschowski, 2005. Peixes de zona econômica exclusiva da região sudeste-sul do Brasil: Levantamento com armadilhas, pargueiras e rede de arrasto de fundo. São Paulo: Editora da Universidade de São Paulo. 295 p.	
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<i>Zeugopterus regius</i>	Bauchot, M.-L., 1987. Poissons osseux. p. 891-1421. In W. Fischer, M.L. Bauchot and M. Schneider (eds.) Fiches FAO d'identification pour les besoins de la pêche. (rev. 1). Méditerranée et mer Noire. Zone de pêche 37. Vol. II. Commission des Communautés Européennes and FAO, Rome.		
<i>Zeus faber</i>	Dunn, M.R., 2001. The biology and exploitation of John dory, Zeus faber (Linnaeus, 1758) in the waters of England and Wales. ICES Journal of Marine Science, 58(1), pp.96-105.	Dunn, M.R., 2001. The biology and exploitation of John dory, Zeus faber (Linnaeus, 1758) in the waters of England and Wales. ICES Journal of Marine Science, 58(1), pp.96-105.	
<i>Zoarces viviparus</i>	Wiêcaszek, B., 1998. On the morphometry and growth rate in the viviparous eel-pout, Zoarces viviparus (Zoaridae) from waters of different salinity. Ital. J. Zool. 65:211-214.	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedeusene, Denmark. 340 p.	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedeusene, Denmark. 340 p.

Table S4. Years included for each survey.

Region	Survey	Years included
Baltic Sea	BITS Q1 small	1996-2018
	BITS Q4 small	1999-2018
North Sea	BTS	1987-2018
	DYFS	2002-2018
	IBTS Q1	1967-2018
	IBTS Q3	1991-2018
	SNS	2002-2018
West of UK	ROCKALL	1999, 2001-2003, 2005-2009, 2011-2018
	SWC-IBTS Q1	1985-2018
	SWC-IBTS Q4	1990-2009, 2011-2018
	IE-IGFS	2011-2018
	NIGFS	2006-2017
	SP-PORC	2001-2018
Bay of Biscay/Celtic Sea	BTSVIII	2011-2017
	EVHOE	1997-2016
	FR-CGFS	1988-2018
	SP-NORTH	1990-1992, 1994, 1997, 2001-2018
Iberian Peninsula	PT-IBTS	2002-2011, 2013-2017
	SP-ARSA	1996, 2000-2018

Table S5. $F_{25\%SSB}$ average and range for each IUCN category.

IUCN rating	Average	Minimum	Maximum	Number of species
CR	0.17	0.05	0.39	3
EN	0.37	0.20	0.75	7
VU	0.27	0.13	0.46	8
NT	1.54	0.09	20	18
LC	9.96	0.10	20	207
DD	6.17	0.28	20	19

Table S6. 2019 EU Catch and landing obligations.

Type of management	Species	Management applicable
No TAC	<i>Anarhichas minor</i>	No TAC
	<i>Anarhichas lupus</i>	No TAC
	<i>Argyrosomus regius</i>	No TAC
	<i>Brama brama</i>	No TAC
	<i>Chimaera monstrosa</i>	No TAC
	<i>Conger conger</i>	No TAC
	<i>Dasyatis pastinaca</i>	No TAC
	<i>Dasyatis tortonesei</i>	No TAC
	<i>Dicentrarchus punctatus</i>	No TAC
	<i>Ephippion guttifer</i>	No TAC
	<i>Epigonus telescopus</i>	No TAC
	<i>Galeus melanostomus</i>	No TAC
	<i>Hippoglossus hippoglossus</i>	No TAC
	<i>Molva macrophthalma</i>	No TAC

	<i>Mora moro</i>	No TAC
	<i>Mustelus mustelus/asterias</i>	No TAC
	<i>Phycis blennoides</i> ²	TACs enforce (up to 2017-2018), removed from TAC management from 2019
	<i>Polyprion americanus</i>	No TAC
	<i>Scorpaena scrofa</i>	No TAC
	<i>Scyliorhinus canicula</i>	No TAC
	<i>Scyliorhinus stellaris</i>	No TAC
	<i>Synaphobranchus kaupi</i>	No TAC
	<i>Torpedo marmorata</i>	No TAC
	<i>Torpedo nobiliana</i>	No TAC
TAC applied at the level of Order	<i>Amblyraja hyperborea</i>	Included within the TACs for 'skates and rays'
	<i>Dipturus oxyrinchus</i>	Included within the TACs for 'skates and rays'
	<i>Leucoraja circularis</i> ¹	Included within the TACs for 'skates and rays'. Must be reported by species in Subarea 6 and Divisions 7.a-c, 7.e-k.

	<i>Leucoraja fullonica</i> ¹	Included within the TACs for 'skates and rays'. Must be reported by species in Subarea 6 and Divisions 7.a-c, 7.e-k.
	<i>Leucoraja naevus</i> ¹	Included within the TACs for 'skates and rays'. Must be reported separately.
	<i>Raja brachyura</i> ¹	Included within the TACs for 'skates and rays'. Must be reported separately. Must be promptly release unharmed in ICES Division 2a (minor part of distribution range)
	<i>Raja clavata</i> ¹	Included within the TACs for 'skates and rays'. Must be reported separately. Must be promptly release unharmed in ICES Division 3.a (minor part of distribution range).
	<i>Raja microocellata</i> ¹	Species-specific TAC within skates and rays TAC (applied to Divisions 7.f-g only). Promptly release unharmed in ICES Divisions 2.a and 4 (minor part of distribution range) and in Divisions 6.a-b, 7.a-c, h-k. Included within the TACs for 'skates and rays' in Division 7.d and in Subareas 8-9.
	<i>Raja montagui</i> ¹	Included within the TACs for 'skates and rays'. Must be reported separately in some areas.
	<i>Raja undulata</i> ¹	Species-specific TACs (within skates and rays TAC) for Divisions 7.d-e; Subarea 8 and Subarea 9). Promptly release unharmed elsewhere.
	<i>Rajella bathyphila</i>	Included within the TACs for 'skates and rays'

	<i>Rajella fyllae</i>	Included within the TACs for 'skates and rays'
	<i>Rajella lintea</i>	Included within the TACs for 'skates and rays'
TAC applied at the genus-level or family level	<i>Lepidorhombus whiffiagonis</i> ¹	TACs for <i>Lepidorhombus</i> spp.
	<i>Lophius budegassa</i> ¹	TACs for anglerfish Lophiidae
	<i>Lophius piscatorius</i> ¹	TACs for anglerfish Lophiidae
	<i>Scophthalmus rhombus</i> ¹	TAC for <i>Scophthalmus rhombus</i> and <i>S. maximus</i> (EU waters of Division 2.a and Subarea 4 only)
	<i>Sebastes</i> spp. ¹	TAC for <i>Sebastes</i> spp.
Species-TACs by management area(s)	<i>Brosme brosme</i> ¹	TACs in place
	<i>Coryphaenoides rupestris</i> ²	Precautionary TACs for 3; 5b, 6-, 7; and 8, 9, 10, 12 and 14. Combined TAC for grenadiers in Greenland and Arctic waters. No TAC in other areas.
	<i>Molva dypterygia</i> ¹	TACs in place
	<i>Molva molva</i> ¹	TACs in place
Conservative management	<i>Lamna nasus</i> ¹	Prohibited species, to be promptly released unharmed when caught (all waters)
	<i>Macrourus berglax</i> ²	No target fisheries. Landings of upto 1% of the TAC for <i>Coryphaenoides rupestris</i> .

	<i>Amblyraja radiata</i> ¹	Prohibited species, to be promptly released unharmed when caught in ICES Divisions 2.a, 3.a and 7.d, and Subarea 4 (the main part of the distribution range in EU waters)
	<i>Dipturus batis</i> ¹	Prohibited species, to be promptly released unharmed when caught in EU waters of Division 2.a and Subareas 3-4, 6-10.
	<i>Dipturus nidarosiensis</i> ¹	Prohibited species, to be promptly released unharmed when caught in EU waters of Division 6.a, 6.b, 7a-c, e-h and k.
	<i>Rostroraja alba</i> ¹	Prohibited species, to be promptly released unharmed in ICES areas 6-10 (the main part of the distribution range in EU Atlantic waters)
	<i>Galeorhinus galeus</i> ¹	Promptly release unharmed when taken with longlines in Union waters of ICES division 2a and ICES subareas 1, 4, 5, 6, 7, 8, 12 and 14. No TAC for other gears and areas (can be landed as 'others'). Regional and national laws restrict landings in some areas (e.g. UK), but no other species-specific restrictions in other areas
	<i>Squalus acanthias</i> ¹	Prohibited species, to be promptly released unharmed (unless taken by a fishery within a bycatch avoidance scheme in Subareas 1, 5, 6, 7, 8, 12 and 14)
	<i>Dalatias licha</i> ^{1,2}	Managed under the deep-water shark complex. It is prohibited for Union fishing vessels to fish for deep-sea sharks in Subareas 5–9, in Union and international

		waters of Subarea 10, in international waters of Subarea 12 and in Union waters of CECAF 34.1.1, 34.1.2 and 34.2 (although a limited TAC for deep-sea sharks allows for bycatch in longline fisheries targeting black scabbardfish, except for Subarea 12). Also to be promptly release unharmed when caught in ICES Divisions 2.a, 4 and international waters of 1 and 14.
	<i>Deania calcea</i> ^{1,2}	See <i>Dalatias licha</i>
	<i>Etmopterus princeps</i> ^{1,2}	See <i>Dalatias licha</i>
	<i>Hexanchus griseus</i> ²	Managed under the deep-water shark complex. It is prohibited for Union fishing vessels to fish for deep-sea sharks in Subareas 5–9, in Union and international waters of Subarea 10, in international waters of Subarea 12 and in Union waters of CECAF 34.1.1, 34.1.2 and 34.2 (although a limited TAC for deep-sea sharks allows for bycatch in longline fisheries targeting black scabbardfish, except for Subarea 12).
	<i>Somniosus microcephalus</i> ²	See <i>Hexanchus griseus</i>

¹EU 2018a. COUNCIL REGULATION (EU) 2019/124 of 30 January 2019 fixing for 2019 the fishing opportunities for certain fish stocks and groups of fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters.

² EU 2018b. Council Regulation (EU) 2018/2025 of 17 December 2018 fixing for 2019 and 2020 the fishing opportunities for Union fishing vessels for certain deep-sea fish stocks. Supplementary figures

Figure S1. Spatial distribution of sensitive species.

Figure S1. Spatial distribution of sensitive species continued.

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