**Supplementary materials 1**

**Updating the West coast of Scotland model (Harvey, 2018)**

The West Coast of Scotland (WCS) model covers the area within the International Council for the Exploration of the Sea (ICES) Division VIa above the 200m contour of the continental shelf, as defined by Alexander et al., (2015). This area covers around 110,000km2 of sea (Figure 2A). The Ecosim model simulations span 1985-2013, as in the most recent WCS model (Serpetti et al., 2017). In Harvey (2018) the ‘cetacean’ functional group was split in ‘Harbour porpoises’, ‘Dolphins’ and ‘Minke whales’, with the distinction based on the ecology and hearing sensitivity ranges of high-, mid- and low-frequency noise for each cetacean group (National Marine Fisheries Service, 2018).

Additional biomass inputs and time-series (1985 -2013) for the new cetacean groups as well as for the seabirds functional group were estimated from outputs from species distribution models (SDM) outputs (Waggitt et al., 2020) and extracted within the Ecopath with Ecosim model domain (WCS). As the existing SDM only produced estimates for a typical calendar month between 1980 and 2018 within the North East Atlantic, modifications were needed to provide estimates for a specific calendar month. To provide these estimates, 5yr moving averages of the North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO) index were added to the existing suite of environmental conditions in the SDM. Both NAO and AMO are known to influence cetacean and seabird populations in the North Sea (Evans and Waggitt, 2020; Mitchell et al., 2020). Because relationships with climate indices could differ amongst regions, NAO and AMO were modelled as 2-way interactions with either depth (m), average temperature (oC) or temperature variance (oC). Both climate indices were added in the final stage of model selection, and only one was retained in the final model. These environmental conditions were added to the presence-absence component for cetaceans, and the count component for seabirds (see Waggitt et al. (2020) for further details). These differences between taxa were because seabird movement is constrained by their need to return to terrestrial colonies for large parts of the year. Therefore, impacts of AMO/NAO on seabirds most likely lower reproductive rates and survival, causing declines in numbers of animals (Mitchell et al. 2020). By contrast, cetacean movement is not constrained. As a consequence, impacts of AMO/NAO are likely distribution shifts, causing changes in encounter rates (Evans & Waggitt 2020).

**New functional groups inputs (pre-balancing)**

Harbour porpoise

Biomass of harbour porpoise was estimated at 0.01117 t.km-2 in 1985, with a lower confidence limit of 0.00988 t.km-2 and an upper confidence limit of 0.01231 t.km-2 (calculated from uncertainties of model predictions (Waggitt et al., 2020). A Q/B value of 16.69 was estimated based on an average body mass of 50kg (Waggitt et al., 2020) and mean daily ration (Trites et al., 1999). Diet data were taken from a study of stomach contents of stranded harbour porpoises in Scottish waters from 1992-2003 (Santos et al., 2004). Whiting (*Merlangius merlangus*) made up just over half of the prey by weight, while sandeels (Ammodytidae spp.) accounted for around 25%. Small proportions of other gadoids were also consumed: cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and saithe (Pollachius virens), in addition to Clupeids (herring, *Clupea harengus*; and sprat, *Sprattus sprattus*), other fish and cephalopods.

Dolphins

Eight species are grouped in the ‘dolphins’ functional group, in the Delphinidae family: bottlenose dolphins, short-beaked common dolphins, striped dolphins, Risso’s dolphins, white-beaked dolphins, Atlantic white-sided dolphins, pilot whales and killer whales. Biomass values within the WCS ecosystem, upper and lower confidence intervals were estimated from Waggitt et al. (2020) (Table S1), and summed for an overall dolphin biomass of 0.0761 t.km-2 . Adult body mass (kg) of dolphin species was taken from the same model and used to estimated Q/B values (Trites et al., 1999) (Table S1).

Scottish stranding and stomach content data exist for bottlenose dolphins from 1990-99 (Santos et al., 2001), striped dolphins from 1992-2003 (Santos et al., 2008), Risso’s dolphins Biomass (t.km-2 ) between 1992-2004 (MacLeod et al., 2014), and white-beaked dolphins from 1992-2003 (Canning et al., 2008). Common and white-sided dolphin diets are from more limited datasets from stranded individuals in Scotland in 1994 and 1995 (Santos et al., 1994, 1995). Most dolphins predominantly feed on gadoids (mainly whiting, in addition to cod, haddock, and saithe). Clupeids, *Trisopterus* species, other small fish and cephalopods make up the rest of the diet. Risso’s dolphins have different feeding habits with a diet consisting of >98% cephalopods, principally the octopus *Eledone cirrhosa* (MacLeod et al., 2014), while pilot whale diet (less well-defined and from stomach content analysis on English Channel cetaceans) showed they also prey mainly on cephalopods (around 75%) (De Pierrepont et al., 2005). Killer whale diet in the northeast Atlantic is not as well-defined, and two ecotypes exist in the west coast of Scotland. Type 1 killer whales have been shown to eat mainly herring or mackerel, but also feed sometimes at higher trophic levels (Foote et al., 2009) and have been observed preying on grey and harbour seals in Shetland (Deecke et al., 2011). These killer whales are wide-ranging and have been observed from Iceland, to Shetland, the west coast of Scotland and Ireland (Foote et al., 2009; Samarra and Foote, 2015). Since diet proportions were unknown, they were originally assigned 25% for grey seals, harbour seals, mackerel and herring before model balancing. The other killer whale ecotype (Type 2) in the west coast of Scotland is a resident, isolated population now numbering only 8 individuals (Foote et al., 2009; HWDT). They have a narrower diet niche and specialise on eating other cetaceans, mainly minke whales and dolphins as well as harbour porpoises (Foote et al., 2009, 2011). The diet ratios in the unbalanced model were set at 20% harbour porpoises, and 40% each for dolphins and minke whales. The overall killer whale diet was weighted to take account of the ~670 individuals on the west coast annually (Waggitt et al., 2020) out of which 10 were assumed to be the west coast community, since only 10 individuals were identified in photographic data from 1992-2008 (Foote et al., 2010). Minke whales Biomass of minke whales was estimated at 0.09947 t.km-2 with a lower confidence interval of 0.07956 t.km-2 and a higher confidence interval of 0.12152 t.km-2 in 1985. A Q/B value was estimated as 6.58 based on body mass of 5,251kg (Trites et al., 1999). Diet composition of minke whales is from stranded animals in Scotland from 1992-2002 (Pierce et al., 2004). They eat mainly sandeels (~60% of diet by weight) followed by Clupeids, herring and sprat, and other types of small fish.

|  |  |  |  |
| --- | --- | --- | --- |
| Table S1. Biomass in t.km-2 (5% and 95% confidence intervals in brackets), weight in kg and Q/B ratios for the eight species within the dolphins functional group. | | | |
|  | Biomass (t.km-2) | Weight (kg) | Q/B |
| Bottlenose dolphins | 0.00146 (0.00225 - 0.00093) | 350 | 11.31 |
| Common dolphins | 0.00625 (0.00519 - 0.00757) | 130 | 13.79 |
| Striped dolphins | 0.000003 (0.000001 - 0.000007) | 130 | 13.79 |
| Risso’s dolphins | 0.00193 (0.00138 - 0.00268) | 350 | 11.31 |
| White-beaked dolphins | 0.02509 (0.02022 - 0.03085) | 330 | 11.44 |
| White-sided dolphins | 0.00930 (0.01448 - 0.00588) | 200 | 12.65 |
| Pilot whales | 0.02282 (0.01644 - 0.03205) | 1400 | 8.57 |
| Killer whales | 0.01383 (0.02172 - 0.00922) | 3000 | 7.36 |

**Ecopath model diagnostics and balancing**

Before balancing the Ecopath model, the new groups (harbour porpoises, dolphins and minke whales) were evaluated against a set of pre-balance (PREBAL) diagnostics (Link, 2010) to check general ecological rules were met. These include a general decline in biomass with increasing trophic level on a log scale; similar declines in vital rates such as production/biomass (P/B) and consumption/biomass (Q/B) ratios (Link, 2010); and production/consumption (P/Q) ratios between 0.1-0.3 (Darwall et al., 2010). Ecotrophic efficiency (EE) should be <1 as a group cannot pass on more production to the next trophic level than it produced in the first place. Apex predators such as cetaceans should have EE values near zero since they are not exploited or significantly predated on (Darwall et al., 2010; Link, 2010). To achieve model balancing and ensure all EE values <1, biomass inputs were changed within the prediction uncertainty intervals (Waggitt et al., 2020). Decrease killer whale biomass. Killer whales caused the imbalance in the marine mammal groups as in previous models they had no predators. To reduce their impact on their prey groups, their biomass was changed to the lower confidence interval estimate, from 0.01383 to 0.00922 t.km-2, thereby reducing the overall dolphin biomass from 0.08068 to 0.07607 t.km-2 . Increase harbour porpoise biomass. To decrease the impact of killer whale predation on porpoises, porpoise biomass was increased to the upper confidence limit from 0.01117 to 0.01231 t.km-2 . Alter killer whale diet. As grey seal, harbour seal and harbour porpoise were still unbalanced, diets of Type 1 killer whales (those visiting the west coast) were adjusted to reduce the proportion of grey and harbour seals (and therefore increase the proportions of herring and mackerel). Type 2 killer whale diets were modified by decreasing the proportion of harbour porpoise, and therefore increasing the proportions of dolphins and minke whales in the diet (see Table A2 for final diet proportions). Increase immature whiting total mortality. This was increased slightly from 1.710 to 1.760 to reduce the EE to below zero. For PREBAL model diagnostic refer to Figure S1.

**Table S2**. Diet matrix showing the proportions of prey in the diet for each functional group.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Predator  Prey | Grey seals | Harbour seals | Harbour porpoises | Dolphins | Baleen whales | Seabirds | Cod mature | Cod immature | Haddock mature | Haddock immature |
| 1 | Grey seals |  |  |  | 0.0008 |  |  |  |  |  |  |
| 2 | Harbour seals |  |  |  | 0.0003 |  |  |  |  |  |  |
| 3 | Harbour porpoises |  |  |  | 0.00006 |  |  |  |  |  |  |
| 4 | Dolphins |  |  |  | 0.0006 |  |  |  |  |  |  |
| 5 | Baleen whales |  |  |  | 0.0006 |  |  |  |  |  |  |
| 6 | Seabirds |  |  |  | 0 |  |  |  |  |  |  |
| 7 | Cod mature | 0.0553 | 0.0381 |  | 0.0272 |  |  | 0.0100 |  |  |  |
| 8 | Cod immature | 0.0452 |  | 0.0144 | 0 |  | 0.0272 | 0.0771 | 0.0090 |  |  |
| 9 | Haddock mature | 0.0298 | 0.1147 |  | 0.062 |  |  | 0.0208 |  |  |  |
| 10 | Haddock immature |  |  | 0.0571 | 0 |  | 0.0059 | 0.0150 | 0.0240 | 0.0002 | 0.0043 |
| 11 | Whiting mature | 0.0271 | 0.2293 | 0.0263 | 0.0977 |  |  | 0.0450 |  |  |  |
| 12 | Whiting immature |  |  | 0.4995 | 0 |  | 0.0030 | 0.0470 | 0.0230 |  |  |
| 13 | Saithe | 0.0595 |  | 0.0349 | 0.0243 |  | 0.0067 |  |  |  |  |
| 14 | Gurnards |  |  |  | 0 |  |  | 0.0017 |  | 0.0032 |  |
| 15 | Monkfish |  |  |  | 0 |  |  | 0.0010 |  |  |  |
| 16 | Flatfish | 0.0961 | 0.0053 |  | 0.0155 |  |  | 0.0389 |  |  |  |
| 17 | Rays |  |  |  | 0 |  |  | 0.0010 |  |  |  |
| 18 | Sharks |  |  |  | 0 |  |  |  |  |  |  |
| 19 | Large demersals | 0.1180 | 0.0965 | 0.0085 | 0.0099 |  |  |  |  |  |  |
| 20 | Benthopelgic\_fish | 0.0097 |  | 0.0005 | 0.0019 |  | 0.0304 | 0.0004 |  | 0.0389 |  |
| 21 | Mackerel |  | 0.0178 | 0.0150 | 0.0438 | 0.0583 | 0.0304 | 0.0060 |  |  |  |
| 22 | Horse mackerel |  | 0.3459 | 0.0001 | 0.0388 |  | 0.0135 |  |  |  |  |
| 23 | Blue whiting | 0.0097 |  | 0.0022 | 0 |  | 0.0323 | 0.0190 |  |  |  |
| 24 | Other pelagics |  |  |  | 0 |  | 0.1254 | 0.1073 |  | 0.0185 |  |
| 25 | Herring | 0.0540 | 0.0771 | 0.0164 | 0.0406 | 0.1134 | 0.3558 | 0.0921 |  | 0.0006 |  |
| 26 | Norway pout | 0.0381 | 0.0543 | 0.0185 | 0.0471 | 0.0005 | 0.0202 | 0.0148 |  | 0.0093 |  |
| 27 | Poor cod | 0.0097 |  | 0.0185 | 0.0471 | 0.0005 | 0.0010 | 0.0001 |  | 0.0010 |  |
| 28 | Sandeel | 0.4383 | 0.0116 | 0.2479 | 0.0239 | 0.6171 | 0.0861 | 0.0435 | 0.0400 | 0.0300 |  |
| 29 | Sprat | 0.0097 |  | 0.0057 | 0.0004 | 0.2102 | 0.1355 | 0.0010 |  | 0.0800 |  |
| 30 | Nephrops |  |  |  | 0 |  |  | 0.0140 |  |  |  |
| 31 | Lobster |  |  |  | 0 |  |  | 0.0007 |  |  |  |
| 32 | Edible crab |  |  |  | 0 |  |  | 0.0061 |  |  |  |
| 33 | Velvet crab |  |  |  | 0 |  |  | 0.0010 |  |  |  |
| 34 | Crustaceans |  |  |  | 0 |  | 0.0354 | 0.2761 | 0.0501 | 0.3700 | 0.0503 |
| 35 | Cephalopod |  | 0.0095 | 0.0345 | 0.5175 |  |  | 0.0182 |  |  |  |
| 36 | Large zooplankton |  |  |  | 0 |  | 0.0202 |  | 0.3534 |  | 0.5029 |
| 37 | Small zooplankton |  |  |  | 0 |  |  |  | 0.2503 |  | 0.1509 |
| 38 | Infauna |  |  |  | 0.0001 |  |  | 0.0744 | 0.1502 | 0.1162 | 0.0503 |
| 39 | Scallops |  |  |  | 0 |  |  | 0.0010 |  | 0.0010 |  |
| 40 | Epifauna |  |  |  | 0 |  | 0.0709 | 0.0664 | 0.0501 | 0.3310 | 0.0402 |
| 41 | Algae |  |  |  |  |  |  |  |  |  |  |
| 42 | Phytoplankton |  |  |  |  |  |  |  | 0.0501 |  | 0.2011 |
| 43 | Detritus |  |  |  |  |  |  |  |  |  |  |

**Table S2**. Diet composition matrix (cont.)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Predator  Prey | Whiting mature | Whiting immature | Saithe | Gurnards | Monkfish | Flatfish | Rays | Sharks | Large demersals | Benthopelgic\_fish |
| 1 | Grey seals |  |  |  |  |  |  |  |  |  |  |
| 2 | Harbour seals |  |  |  |  |  |  |  |  |  |  |
| 3 | Harbour porpoises |  |  |  |  |  |  |  |  |  |  |
| 4 | Dolphins |  |  |  |  |  |  |  |  |  |  |
| 5 | Baleen whales |  |  |  |  |  |  |  |  |  |  |
| 6 | Seabirds |  |  |  |  |  |  |  |  |  |  |
| 7 | Cod mature |  |  |  |  | 0.0090 |  |  |  |  |  |
| 8 | Cod immature | 0.0083 | 0.0045 | 0.0520 | 0.0117 | 0.1564 | 0.0018 |  | 0.0215 |  |  |
| 9 | Haddock mature |  |  | 0.0020 |  | 0.0590 |  |  | 0.0060 |  |  |
| 10 | Haddock immature | 0.0060 | 0.0022 | 0.0370 | 0.0015 | 0.0590 | 0.0009 | 0.0090 | 0.0010 | 0.0006 |  |
| 11 | Whiting mature | 0.0020 |  | 0.0060 |  | 0.0517 |  |  | 0.0100 |  |  |
| 12 | Whiting immature | 0.0335 | 0.0070 | 0.0300 | 0.0020 | 0.0517 | 0.0014 | 0.0330 | 0.0204 | 0.0300 |  |
| 13 | Saithe | 0.0068 |  |  |  | 0.0326 | 0.0010 |  | 0.0005 | 0.0013 |  |
| 14 | Gurnards |  |  |  |  | 0.0024 | 0.0040 | 0.0050 | 0.0200 |  |  |
| 15 | Monkfish |  |  |  |  | 0.0104 |  | 0.0010 | 0.0010 |  |  |
| 16 | Flatfish | 0.0010 |  | 0.0291 | 0.0010 | 0.0635 | 0.0040 | 0.0410 | 0.0100 | 0.0371 |  |
| 17 | Rays |  |  |  |  | 0.0007 |  | 0.0010 | 0.0100 |  |  |
| 18 | Sharks |  |  |  |  |  |  |  | 0.0417 |  |  |
| 19 | Large demersals |  |  |  |  |  |  |  |  | 0.0560 |  |
| 20 | Benthopelgic\_fish |  |  |  | 0.0302 | 0.0982 | 0.0100 |  | 0.0241 | 0.0700 | 0.0500 |
| 21 | Mackerel | 0.1260 |  |  |  | 0.0104 | 0.0050 |  | 0.0169 | 0.1640 |  |
| 22 | Horse mackerel | 0.0136 |  | 0.0262 |  |  |  |  | 0.0102 | 0.1000 |  |
| 23 | Blue whiting |  |  | 0.0340 |  |  |  |  |  | 0.1714 |  |
| 24 | Other pelagics | 0.1229 |  | 0.0120 | 0.0152 | 0.0229 | 0.0381 | 0.0100 |  | 0.0814 |  |
| 25 | Herring | 0.3462 |  | 0.1473 | 0.0312 | 0.1082 |  | 0.1300 | 0.3013 | 0.0801 |  |
| 26 | Norway pout | 0.0205 |  | 0.2007 | 0.0041 | 0.1128 | 0.0150 | 0.0100 | 0.0023 | 0.0100 |  |
| 27 | Poor cod | 0.0010 |  |  | 0.0010 | 0.0010 |  |  | 0.0010 | 0.0010 |  |
| 28 | Sandeel | 0.0512 | 0.0201 | 0.0301 | 0.0843 | 0.1044 | 0.0200 | 0.0500 | 0.0208 | 0.0010 |  |
| 29 | Sprat | 0.1331 |  | 0.0903 | 0.0059 |  |  | 0.0400 | 0.0981 | 0.0100 |  |
| 30 | Nephrops |  |  |  |  |  | 0.0209 | 0.1300 |  |  |  |
| 31 | Lobster | 0.0010 |  |  |  |  |  | 0.0010 |  |  |  |
| 32 | Edible crab | 0.0010 |  |  | 0.0010 |  | 0.0010 | 0.0050 | 0.0010 |  |  |
| 33 | Velvet crab | 0.0010 |  |  |  |  |  | 0.0010 | 0.0010 |  |  |
| 34 | Crustaceans | 0.0031 | 0.0502 | 0.1154 | 0.4312 | 0.0010 | 0.1060 | 0.2490 | 0.1100 | 0.0380 | 0.0039 |
| 35 | Cephalopod | 0.0295 |  | 0.0050 |  | 0.0447 | 0.0070 |  | 0.1200 | 0.0326 |  |
| 36 | Large zooplankton | 0.0205 | 0.4445 | 0.1828 | 0.2230 |  | 0.1002 |  | 0.0407 | 0.0036 | 0.6479 |
| 37 | Small zooplankton |  | 0.2007 |  |  |  | 0.1022 |  |  |  | 0.0003 |
| 38 | Infauna |  | 0.1003 |  | 0.0557 |  | 0.2144 | 0.0400 | 0.0001 | 0.0002 | 0.1099 |
| 39 | Scallops | 0.0010 |  |  | 0.0020 |  | 0.0010 | 0.0010 |  |  |  |
| 40 | Epifauna | 0.0707 | 0.0452 |  | 0.0990 |  | 0.3460 | 0.2430 | 0.1105 | 0.1116 | 0.1879 |
| 41 | Algae |  |  |  |  |  |  |  |  |  |  |
| 42 | Phytoplankton |  | 0.1254 |  |  |  |  |  |  |  |  |
| 43 | Detritus |  |  |  |  |  |  |  |  |  |  |

**Table S2**. Diet composition matrix (cont.)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Predator  Prey | | Mackerel | | Horse mackerel | | Blue whiting | | Other pelagics | | Herring | | Norway pout | | Poor cod | | Sandeel | | Sprat | | Nephrops | |
| 1 | | Grey seals | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 2 | | Harbour seals | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 3 | | Harbour porpoises | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 4 | | Dolphins | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 5 | | Baleen whales | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 6 | | Seabirds | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 7 | | Cod mature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 8 | | Cod immature | | 0.0048 | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 9 | | Haddock mature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 10 | | Haddock immature | | 0.0070 | | 0.0140 | |  | | 0.0025 | |  | |  | |  | |  | |  | |  | |
| 11 | | Whiting mature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 12 | | Whiting immature | | 0.0069 | | 0.0070 | |  | |  | |  | |  | |  | |  | |  | |  | |
| 13 | | Saithe | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 14 | | Gurnards | |  | |  | |  | | 0.0020 | |  | |  | |  | |  | |  | |  | |
| 15 | | Monkfish | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 16 | | Flatfish | |  | |  | |  | | 0.0020 | |  | |  | | 0.0005 | |  | |  | |  | |
| 17 | | Rays | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 18 | | Sharks | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 19 | | Large demersals | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 20 | | Benthopelgic\_fish | | 0.0056 | |  | |  | |  | |  | | 0.0018 | | 0.1107 | |  | |  | |  | |
| 21 | | Mackerel | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 22 | | Horse mackerel | | 0.0201 | |  | |  | | 0.0300 | |  | |  | |  | |  | |  | |  | |
| 23 | | Blue whiting | |  | |  | | 0.0200 | |  | |  | |  | |  | |  | |  | |  | |
| 24 | | Other pelagics | | 0.0100 | |  | | 0.1500 | | 0.0341 | |  | |  | |  | |  | |  | |  | |
| 25 | | Herring | | 0.1004 | | 0.0165 | | 0.0500 | | 0.0299 | |  | |  | |  | |  | |  | |  | |
| 26 | | Norway pout | | 0.0100 | | 0.0165 | | 0.0700 | | 0.0050 | |  | |  | |  | |  | |  | |  | |
| 27 | | Poor cod | | 0.0010 | |  | |  | |  | |  | | 0.0010 | | 0.0010 | |  | |  | |  | |
| 28 | | Sandeel | | 0.0100 | |  | | 0.0100 | | 0.0273 | | 0.0005 | |  | | 0.0018 | |  | |  | |  | |
| 29 | | Sprat | | 0.0101 | |  | | 0.1000 | | 0.0065 | | 0.0003 | |  | | 0.0014 | |  | |  | |  | |
| 30 | | Nephrops | |  | |  | |  | | 0.0010 | |  | |  | | 0.0308 | |  | |  | |  | |
| 31 | | Lobster | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 32 | | Edible crab | |  | |  | |  | |  | |  | |  | |  | |  | |  | | 0.1000 | |
| 33 | | Velvet crab | |  | |  | |  | |  | |  | |  | |  | |  | |  | | 0.1000 | |
| 34 | | Crustaceans | | 0.0100 | | 0.0100 | | 0.0100 | | 0.0100 | | 0.0100 | | 0.1932 | | 0.3001 | | 0.0500 | | 0.0500 | | 0.1000 | |
| 35 | | Cephalopod | |  | |  | |  | | 0.1220 | |  | |  | | 0.0006 | |  | |  | |  | |
| 36 | | Large zooplankton | | 0.6984 | | 0.7115 | | 0.5900 | | 0.1892 | | 0.9827 | | 0.7520 | | 0.0969 | | 0.9480 | | 0.7500 | | 0.1991 | |
| 37 | | Small zooplankton | | 0.1004 | | 0.2151 | |  | | 0.0341 | |  | |  | | 0.0036 | | 0.0010 | | 0.2000 | | 0.1614 | |
| 38 | | Infauna | | 0.0050 | | 0.0094 | |  | | 0.1363 | |  | |  | | 0.1615 | | 0.0010 | |  | | 0.0508 | |
| 39 | | Scallops | |  | |  | |  | |  | |  | |  | | 0.0010 | |  | |  | |  | |
| 40 | | Epifauna | |  | |  | |  | | 0.3682 | |  | | 0.0520 | | 0.2900 | |  | |  | | 0.2887 | |
| 41 | | Algae | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 42 | | Phytoplankton | |  | |  | |  | |  | | 0.0065 | |  | |  | |  | |  | |  | |
| 43 | | Detritus | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |

**Table S2**. Diet composition matrix (cont.)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | Predator  Prey | | Lobster | | Edible crab | | Velvet crab | | Crustaceans | | Cephalo-pods | | Large zooplankton | | Small zooplankton | | Infauna | | Scallops | | Epifauna | |
| 1 | Grey seals | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 2 | Harbour seals | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 3 | Harbour porpoises | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 4 | Dolphins | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 5 | Baleen whales | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 6 | Seabirds | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 7 | Cod mature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 8 | Cod immature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 9 | Haddock mature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 10 | Haddock immature | |  | |  | |  | |  | | 0.0040 | |  | |  | |  | |  | |  | |
| 11 | Whiting mature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 12 | Whiting immature | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 13 | Saithe | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 14 | Gurnards | |  | |  | |  | |  | | 0.0019 | |  | |  | |  | |  | |  | |
| 15 | Monkfish | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 16 | Flatfish | |  | | 0.0309 | |  | |  | | 0.0153 | |  | |  | |  | |  | |  | |
| 17 | Rays | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 18 | Sharks | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 19 | Large demersals | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 20 | Benthopelgic\_fish | |  | |  | |  | | 0.0010 | | 0.0050 | |  | |  | |  | |  | |  | |
| 21 | Mackerel | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 22 | Horse mackerel | |  | |  | |  | |  | | 0.0191 | |  | |  | |  | |  | |  | |
| 23 | Blue whiting | |  | |  | |  | |  | | 0.0050 | |  | |  | |  | |  | |  | |
| 24 | Other pelagics | |  | |  | |  | |  | | 0.0019 | |  | |  | |  | |  | |  | |
| 25 | Herring | |  | |  | |  | |  | | 0.0272 | |  | |  | |  | |  | |  | |
| 26 | Norway pout | |  | |  | |  | |  | | 0.0038 | |  | |  | |  | |  | |  | |
| 27 | Poor cod | |  | |  | |  | | 0.0001 | | 0.0010 | |  | |  | |  | |  | |  | |
| 28 | Sandeel | |  | |  | |  | |  | | 0.0191 | |  | |  | |  | |  | |  | |
| 29 | Sprat | |  | |  | |  | |  | | 0.0038 | |  | |  | |  | |  | |  | |
| 30 | Nephrops | |  | |  | |  | | 0.0010 | | 0.0019 | |  | |  | |  | |  | |  | |
| 31 | Lobster | | 0.0076 | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 32 | Edible crab | | 0.0010 | | 0.0500 | |  | |  | |  | |  | |  | |  | |  | |  | |
| 33 | Velvet crab | | 0.0050 | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 34 | Crustaceans | | 0.3199 | | 0.1958 | | 0.2530 | | 0.0100 | | 0.0019 | |  | |  | |  | |  | |  | |
| 35 | Cephalopod | |  | |  | |  | |  | |  | |  | |  | |  | |  | |  | |
| 36 | Large zooplankton | |  | |  | |  | | 0.0840 | | 0.5922 | | 0.0119 | |  | |  | |  | |  | |
| 37 | Small zooplankton | | 0.0031 | |  | |  | | 0.1050 | | 0.2732 | | 0.1398 | | 0.0300 | |  | |  | | 0.0981 | |
| 38 | Infauna | | 0.0590 | |  | |  | | 0.1330 | | 0.0198 | |  | |  | | 0.0356 | |  | | 0.1490 | |
| 39 | Scallops | |  | | 0.0010 | | 0.0010 | | 0.0200 | |  | |  | |  | |  | |  | | 0.0100 | |
| 40 | Epifauna | | 0.5472 | | 0.5760 | | 0.1390 | | 0.2200 | | 0.0038 | |  | |  | |  | |  | | 0.0900 | |
| 41 | Algae | |  | |  | |  | |  | |  | |  | |  | |  | |  | | 0.1000 | |
| 42 | Phytoplankton | |  | |  | |  | | 0.1000 | |  | | 0.7103 | | 0.8000 | | 0.4995 | | 0.5000 | | 0.3780 | |
| 43 | Detritus | | 0.0572 | | 0.1463 | | 0.6070 | | 0.3260 | |  | | 0.1381 | | 0.1700 | | 0.4649 | | 0.5000 | | 0.1750 | |

**Table S3**. Basic estimates in final Ecopath model with parameters estimated by the model in bold, including trophic level, biomass, total mortality per year, production/biomass ratio (P/B), consumption/biomass (Q/B), ecotrophic efficiency (EE), and production/consumption (P/Q).

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | | Trophic level | Biomass (t/km-²) | Total mortality (/year) | P/B (/year) | Q/B (/year) | EE | P/Q (/year) |
| 1 | | Grey seals | 4.4768 | 0.0362 |  | **0.1139** | 11.3875 | **0.1472** | 0.0100 |
| 2 | | Harbour seals | 4.6018 | 0.0112 |  | **0.1012** | 10.1241 | **0.2013** | 0.0100 |
| 3 | | Harbour porpoises | 4.1760 | 0.0123 |  | 0.0200 | 16.6916 | **0.1794** | **0.0012** |
| 4 | | Dolphins | 4.4210 | 0.0761 |  | 0.0200 | 9.9767 | **0.2993** | **0.0020** |
| 5 | | Baleen whales | 4.1851 | 0.0995 |  | 0.0200 | 6.5803 | **0.2289** | **0.0030** |
| 6 | | Seabirds | 4.1447 | 0.0064 |  | 0.4000 | 83.0508 | **0.0000** | **0.0048** |
| 7 | | Cod mature | 4.0193 | 0.2966 | 1.1427 |  | 3.5000 | **0.6531** | **0.3265** |
| 8 | | Cod immature | 3.1778 | 0.2638 | 2.2069 |  | 9.0481 | **0.7825** | **0.2439** |
| 9 | | Haddock mature | 3.6136 | 0.5630 | 1.0964 |  | 4.9600 | **0.4777** | **0.2211** |
| 10 | | Haddock immature | 2.9393 | 0.4160 | 1.7433 |  | 11.0371 | **0.8978** | **0.1579** |
| 11 | | Whiting mature | 4.1570 | 0.3896 | 1.1312 |  | 4.5000 | **0.7611** | **0.2514** |
| 12 | | Whiting immature | 3.0454 | 0.4111 | 1.7600 |  | 9.0892 | **0.9951** | **0.1936** |
| 13 | | Saithe | 3.9713 | 0.5054 |  | **0.9372** | 4.6862 | **0.6446** | 0.2000 |
| 14 | | Gurnards | 3.6042 | **0.1238** |  | **0.8244** | 4.1220 | 0.9500 | 0.2000 |
| 15 | | Monkfish | 4.3232 | **0.0939** |  | **0.4799** | 1.7140 | 0.9500 | 0.2800 |
| 16 | | Flatfish | 3.4133 | **0.7734** |  | **1.1303** | 3.7678 | 0.9500 | 0.3000 |
| 17 | | Rays | 3.8580 | **0.1186** |  | **0.4486** | 2.2430 | 0.9500 | 0.2000 |
| 18 | | Sharks | 4.0656 | **0.2416** |  | **0.6819** | 3.4096 | 0.9500 | 0.2000 |
| 19 | | Large demersals | 4.2743 | **1.0416** |  | **0.4884** | 2.4420 | 0.9500 | 0.2000 |
| 20 | | Benthopelgic\_fish | 3.2447 | **0.5813** |  | **1.5810** | 5.2700 | 0.9500 | 0.3000 |
| 21 | | Mackerel | 3.3401 | 4.3191 |  | 0.6260 | 4.4000 | **0.6607** | **0.1423** |
| 22 | | Horse mackerel | 3.1868 | 3.3105 |  | **0.7400** | 3.7000 | **0.7177** | 0.2000 |
| 23 | | Blue whiting | 3.6351 | 1.9784 |  | 1.5000 | **6.0000** | **0.5914** | 0.2500 |
| 24 | | Other pelagics | 3.5160 | **1.8706** |  | **1.8000** | 6.0000 | 0.9500 | 0.3000 |
| 25 | | Herring | 3.1564 | 5.9434 |  | 1.5000 | 10.1000 | **0.6470** | **0.1485** |
| 26 | | Norway pout | 3.2763 | **1.2989** |  | **1.6800** | **5.6000** | 0.9500 | 0.3000 |
| 27 | | Poor cod | 3.5303 | **0.0941** |  | **1.1700** | 3.9000 | 0.9500 | 0.3000 |
| 28 | | Sandeel | 3.1843 | **1.4112** |  | **1.8255** | 6.0850 | 0.9500 | 0.3000 |
| 29 | | Sprat | 3.1591 | **1.7137** |  | **1.5840** | 5.2800 | 0.9500 | 0.3000 |
| 30 | | Nephrops | 3.4149 | 1.0000 |  | 0.7300 | 4.8760 | **0.4922** | **0.1497** |
| 31 | | Lobster | 3.3951 | **0.0346** |  | 0.3380 | 3.6500 | 0.8000 | **0.0926** |
| 32 | | Edible crab | 3.3240 | **2.4979** |  | 0.3540 | **2.3600** | 0.9500 | 0.1500 |
| 33 | | Velvet crab | 2.6222 | **0.8085** |  | 0.6460 | 12.7750 | 0.9500 | **0.0506** |
| 34 | | Crustaceans | 2.6912 | **14.0688** |  | 0.8710 | 5.8065 | 0.9500 | **0.1500** |
| 35 | | Cephalopod | 3.2415 | **1.0959** |  | 1.9810 | 15.0000 | 0.9500 | **0.1321** |
| 36 | | Large zooplankton | 2.1579 | **14.9539** |  | 10.0000 | 35.0000 | 0.9500 | **0.2857** |
| 37 | | Small zooplankton | 2.0309 | **7.8857** |  | 18.0000 | 72.0000 | 0.9500 | **0.2500** |
| 38 | | Infauna | 2.0369 | **3.0109** |  | 20.0000 | 80.0000 | 0.9500 | **0.2500** |
| 39 | | Scallops | 2.0000 | **9.3097** |  | 0.4450 | 14.3335 | 0.9500 | **0.0310** |
| 40 | | Epifauna | 2.3908 | **2.7697** |  | 20.0000 | 80.0000 | 0.9500 | **0.2500** |
| 41 | | Algae | 1.0000 | **12.6609** |  | 5.0000 |  | 0.3500 |  |
| 42 | | Phytoplankton | 1.0000 | **31.6235** |  | 70.0000 |  | 0.5000 |  |
| 43 | | Detritus | 1.0000 | 100.0000 |  |  |  | **0.2670** |  |

Model diagnostics PREBAL

|  |
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|  |
| Figure S1. PREBAL diagnostics of the updated WCS model plotting a) biomass estimates (t.km-2); b) annual production/biomass (P/B) ratio; and c) annual consumption/biomass (Q/B) ratio on a log scale, against model functional groups from lowest to highest trophic level. Solid grey bars indicate values entered in model input while white bars are parameters estimated by the model. New functional groups (harbour porpoise, dolphins and minke whales) are highlighted in red. |

**Ecosim input parameters and fitting the model to time-series**The Ecosim model simulations span 1985-2013, as in the most recent WCS model (Serpetti et al. 2017). Biomass and catch time-series data were carried over with additional time-series of biomass data for seabirds, harbour porpoises, dolphins and minke whales, extracted for the model domain as annual averages from 1985-2013 (Waggitt et al., 2020). Fishing mortality was used as a driver in model fitting while depth-integrated temperature data 10 and relative species response functions were used as described in Serpetti et al. (2017). In Ecosim time-series of observed biomass and catch data were used by the fitting procedure to search for the best input parameters such as vulnerability values controlling predator-prey interactions and the number of spline points in a primary production (PP) anomaly (Scott et al. 2015) to find the best statistical fit (the lowest Aikaike’s Information Criterion (Akaike 1974)). Model fitting was performed (searching by predator/prey interactions) following the methodology described by Scott et al. (2015) and Serpetti et al. (2017) to fit the vulnerabilities parameters (Table S4).

**Table S4**. Fitted vulnerability matrix of the updated WCS model showing the 42 most sensitive top-down (>2) and bottom-up (<2) controls in predator-prey relationships (estimated value for large zooplankton/horse mackerel was removed as it was close to 2, the default value).

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Prey \ predator | Cod mature | Cod immature | Haddock immature | Whiting mature | Whiting immature | Saithe | Monkfish | Rays | Large demersals | Other small fish | Horse mackerel |
| Cod immature |  |  |  |  |  | >1000 |  |  |  |  |  |
| Haddock immature |  |  |  |  |  | >1000 |  |  |  |  | 1 |
| Whiting immature |  |  |  | 1 |  | >1000 |  |  |  |  |  |
| Mackerel |  |  |  | 3.73 |  |  |  |  | 1.65 |  |  |
| Blue whiting |  |  |  |  |  |  |  |  | 1 |  |  |
| Other pelagics | 1.15 |  |  |  |  |  |  |  |  |  |  |
| Sandeel | >1000 |  |  |  |  |  | 1 |  |  |  |  |
| Sprat |  |  |  |  |  | >1000 |  |  |  |  |  |
| Crustaceans | 1.01 |  |  |  |  |  |  | 1 |  |  |  |
| Large zooplankton |  | 1.68 | 1 |  | >1000 |  |  |  |  | >1000 |  |
| Small zooplankton |  |  |  |  |  |  |  |  |  |  | 1 |
| Infauna | 1.14 |  |  |  |  |  |  |  |  | 138.34 |  |
| Epifauna |  |  |  |  |  |  |  | 1 |  | 1 |  |
| Prey \ predator | **Blue** **whiting** | **Other pelagics** | **Herring** | **Norway pout** | **Poor cod** | **Sandeels** | **Sprat** | **Nephrops** | **Cephalopod** | **Large zooplankton** | **Small zooplankton** |
| Gurnards |  |  |  |  |  |  |  |  | 1 |  |  |
| Other small fish |  |  |  |  | 1 |  |  |  |  |  |  |
| Horse mackerel |  | 1 |  |  |  |  |  |  | >1000 |  |  |
| Sprat | 1 |  |  |  |  |  |  |  |  |  |  |
| Crustaceans |  |  |  |  | 1.72 |  |  |  |  |  |  |
| Large zooplankton |  |  | 1.75 | >1000 | 1.04 | 1 | 0.06 | 1.14 | 1.01 |  |  |
| Small zooplankton |  |  |  |  |  |  |  |  |  | >1000 |  |
| Infauna |  |  |  |  | >1000 |  |  |  |  |  |  |
| Epifauna |  |  |  |  | 3.69 |  |  | 1.20 |  |  |  |
| Phytoplankton |  |  |  |  |  |  |  |  |  | 1 | >1000 |

**Ecospace inputs**

The Ecospace habitat map was created in QGIS (version 3.10.10) by combining extracted georeferenced sediment substrates (from the Mapping European Seabed Habitats project, <http://www.searchmesh.net/>) and depth (fromSeazone/Edina, <http://edina.ac.uk/>) properties at each grid node (Figure 2 and Figure S2), following the habitat categories (Figure S2) adjusted from Alexander et al. (2016). The fish farm was added in 2011 as a new habitat using the temporal-spatial framework plug-in (Steenbeek et al., 2016) to simulate the presence of the fish farm from 2011. The fish farm habitat size extended from 3 grid cell (300m, approximatively the dimension covered by 2x3 salmon cages), the habitat farms was then smoothed in order to extend habitat proportion to the souring grid cells to allowed a better performances of Ecospace. Species attraction to the farm was simulated by changing the relative habitat foraging usage for selected species (saithe, Atlantic cod, whiting, haddock, seabirds and harbour seals) with the highest proportion of preferences at the ‘farm’ habitat (table S5). Functional groups habitat foraging usage preferences were assigned to habitats based on a combination of data from the Marine Life Information Network (MARLIN) and Fishbase website (<http://www.fishbase.org/>).

|  |  |
| --- | --- |
|  | **Figure S2.** Habitat categories of the model domain around isle of Muck with the grid illustrating the region within which the model results were extracted in order to assess biomass changes driven by the MPP pressures. |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table S5**. Relative habitat foraging usage and basic dispersal rate | | | | | | | | | | |
|  | Habitat/dispersal rate | Sand  0-50 m | Sand  50-200 m | Mix sediments  0-50 m | Mix sediments 50-200 m | Mud  0-50 m | Mud  50-200 m | Farm | | Dispersal rate (km/year) |
|  | Group |  |  |  |  |  |  |  |  | |
| 1 | Grey seals | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 275 | |
| 2 | Harbour seals | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 275 | |
| 3 | Harbour porpoises | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 975 | |
| 4 | Dolphins | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 975 | |
| 5 | Minke whales | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 652 | |
| 6 | Seabirds | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 275 | |
| 7 | Cod mature | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 1 | 197 | |
| 8 | Cod immature | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 1 | 110 | |
| 9 | Haddock mature | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 1 | 197 | |
| 10 | Haddock immature | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 1 | 110 | |
| 11 | Whiting mature | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 1 | 197 | |
| 12 | Whiting immature | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 1 | 110 | |
| 13 | Saithe | 0.1 | 0.37 | 0.1 | 0.7 | 0.1 | 0.37 | 1 | 197 | |
| 14 | Gurnards | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 157 | |
| 15 | Monkfish | 0.7 | 1 | 0.7 | 1 | 0.7 | 1 | 0 | 157 | |
| 16 | Flatfish | 1 | 0.9 | 1 | 0.9 | 1 | 0.9 | 0 | 79 | |
| 17 | Rays | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 157 | |
| 18 | Sharks | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 79 | |
| 19 | Large demersals | 0.9 | 1 | 0.9 | 1 | 0.9 | 1 | 0 | 197 | |
| 20 | Benthopelgic\_fish | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 79 | |
| 21 | Mackerel | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 236 | |
| 22 | Horse Mackerel | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1000 | |
| 23 | Blue Whiting | 0 | 0.1 | 0 | 0.1 | 0 | 0.1 | 0 | 157 | |
| 24 | Other pelagics | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 141 | |
| 25 | Herring | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 110 | |
| 26 | Norway pout | 0.1 | 1 | 0.1 | 1 | 0.1 | 1 | 0 | 500 | |
| 27 | Poor cod | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 157 | |
| 28 | Sandeel | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 75 | |
| 29 | Sprat | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 79 | |
| 30 | Nephrops | 0 | 0 | 0.7 | 0.7 | 1 | 1 | 0 | 5 | |
| 31 | Lobster | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 20 | |
| 32 | Edible crab | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 20 | |
| 33 | Velvet crab | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 20 | |
| 34 | Crustaceans | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 30 | |
| 35 | Cephalopod | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 141 | |
| 36 | Large zooplankton | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 30 | |
| 37 | Small zooplankton | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 30 | |
| 38 | Infauna | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | |
| 39 | Scallops | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 30 | |
| 40 | Epifauna | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 30 | |
| 41 | Kelp | 1 | 0 | 0.5 | 0 | 0 | 0 | 0 | 3 | |
| 42 | Phytoplankton | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 30 | |
| 43 | Detritus | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 | |

**Ecospace outputs**



Figure S3. Species annual biomasses extracted (2011-2013) to assess the impact of MPP pressure within the region for each scenario and, biomass changes for scenarios 2-6 were visualised standardising the species biomasses by the baseline. All groups ranked by trophic level from top-predators to primary producers.

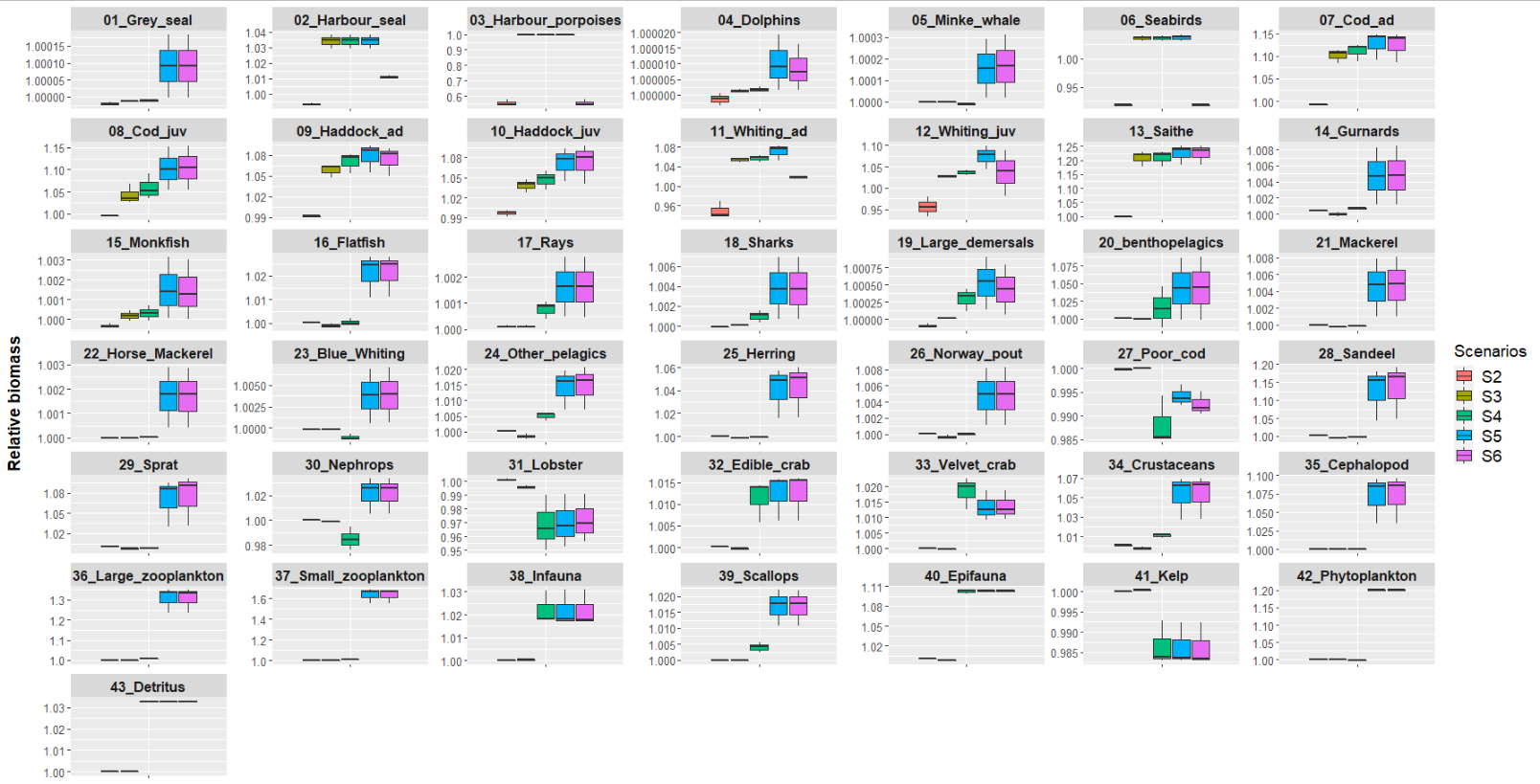


Figure S4. Species relative annual biomasses extracted (2011-2013) to assess the impact of MPP pressure within the region for each scenario and, biomass changes for scenarios 2-6 were visualised standardising the species biomasses by the baseline (all groups)

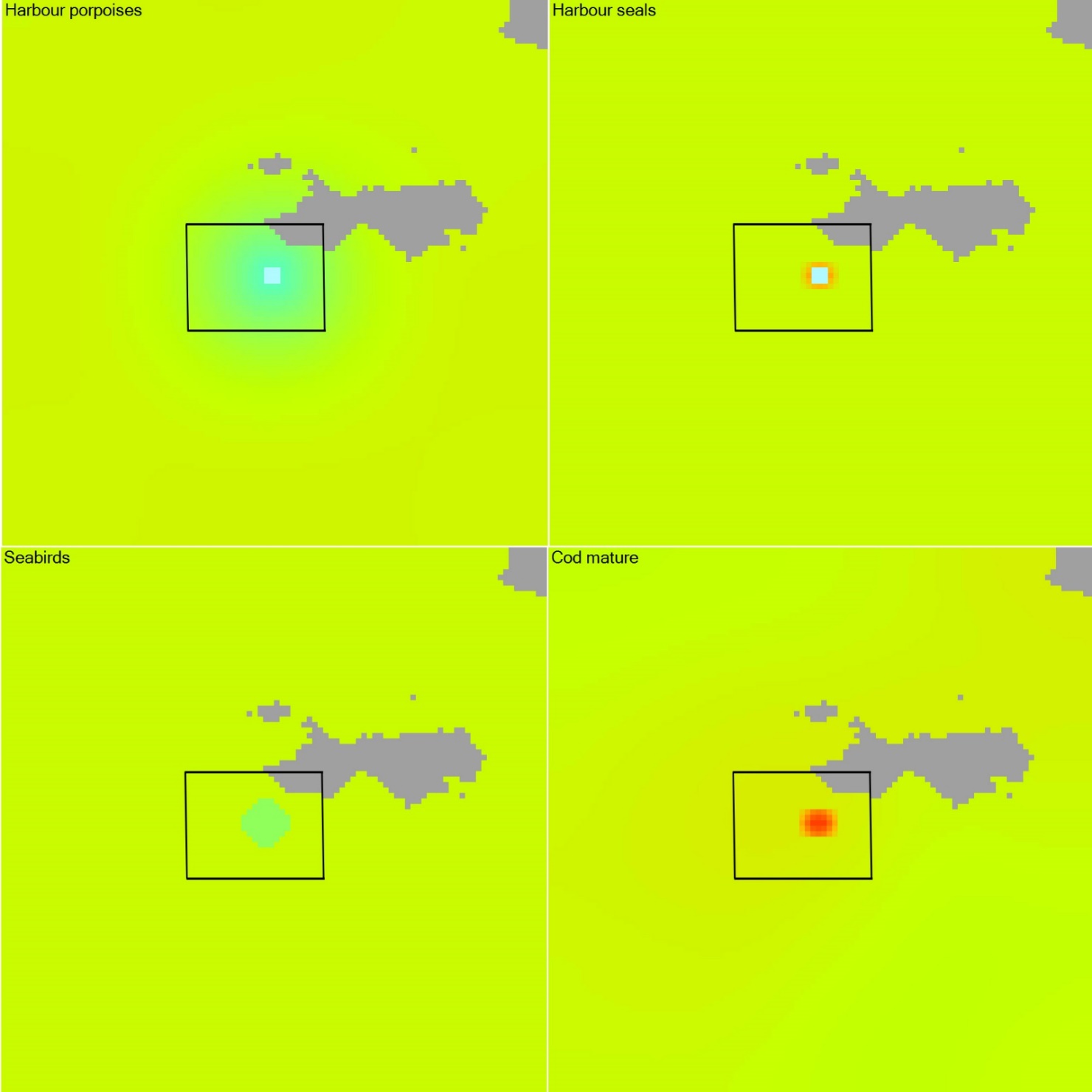


Figure S5. Spatial changes of distribution for relative biomasses extracted in 2013 (end of the simulation of cumulative scenario) of harbour porpoise (top-left) and harbour seals (top-right) caused by low frequency noise produced by offshore wind turbines), of seabirds (bottom-left) caused by displacement by offshore wind turbines and of cod (bottom-right) caused by attraction to farming site . Ecospace resolution ~100m x 100m.

|  |  |
| --- | --- |
|  | Figure S6. Ecospace temporal (monthly) simulations showed decrease of whiting biomass when testing the impact of noise (Figure 5, scenario 2). This is determined by small cumulative impacts among its predators, mainly on its juvenile stages. Temporal scenarios showed that this pressure impacted whiting trophic interactions only at the beginning of the simulation and at the steady state trends suggested higher biomasses of both whiting stages. |

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Figure S7. Ecospace temporal (monthly) simulations of all functional groups under cumulative scenario 6 from the beginning of the cumulative impacts (Jan-2011) to the end of the temporal simulations (Dec-2013).

**References**

Alexander, K. A., Heymans, J. J., Magill, S., Tomczak, M. T., Holmes, S. J., and Wilding, T. A. (2015). Investigating the recent decline in gadoid stocks in the west of Scotland shelf ecosystem using a foodweb model. *ICES J. Mar. Sci.* 72, 436–449.

Canning, S. J., Santos, M. B., Reid, R. J., Evans, P. G. H., Sabin, R. C., Bailey, N., et al. (2008). Seasonal distribution of white-beaked dolphins (Lagenorhynchus albirostris) in UK waters with new information on diet and habitat use. *J. Mar. Biol. Assoc. U. K.* 88, 1159–1166.

Darwall, W. R. T., Allison, E. H., Turner, G. F., and Irvine, K. (2010). Lake of flies, or lake of fish? A trophic model of Lake Malawi. *Ecol. Model.* 221, 713–727. doi:10.1016/j.ecolmodel.2009.11.001.

De Pierrepont, J. F., Dubois, B., Desormonts, S., Santos, A. M., and Robin, J. P. (2005). Stomach contents of English Channel cetaceans stranded on the coast of Normandy. *J. Mar. Biol. Assoc. U. K.* 85, 1539–1546.

Deecke, V. B., Nykanen, M., Foote, A. D., and Janik, V. M. (2011). Vocal behaviour and feeding ecology of killer whales Orcinus orca around Shetland, UK. *Aquat. Biol.* 13, 79-U186.

Evans, P. G. H., and Waggitt, J. J. (2020). Impacts of climate change on marine mammals, relevant to the coastal and marine environment around the UK. Marine Climate Change Impacts Partnership (MCCIP), Lowestoft, UK Available at: http://www.mccip.org.uk/media/2022/19\_marine\_mammals\_2020.pdf [Accessed May 26, 2021].

Foote, A. D., Newton, J., Piertney, S. B., Willerslev, E., and Gilbert, M. T. P. (2009). Ecological, morphological and genetic divergence of sympatric North Atlantic killer whale populations. *Mol. Ecol.* 18, 5207–5217.

Foote, A. D., Simila, T., Vikingsson, G. A., and Stevick, P. T. (2010). Movement, site fidelity and connectivity in a top marine predator, the killer whale. *Evol. Ecol.* 24, 803–814.

Foote, A. D., Vilstrup, J. T., de Stephanis, R., Verborgh, P., Nielsen, S. C. A., Deaville, R., et al. (2011). Genetic differentiation among North Atlantic killer whale populations. *Mol. Ecol.* 20, 629–641.

Harvey, B. J. (2018). Exploring impacts of noise from shipping and acoustic deterrent devices on cetaceans on the west coast of Scotland using an ecosystem modelling approach. *Ecosyst.-Based Manag. Mar. Syst.* MSc.

HWDT Killer Whale. *Hebrid. Whale Dolphin Trust*.

Link, J. S. (2010). Adding rigor to ecological network models by evaluating a set of pre-balance diagnostics: A plea for PREBAL. *Ecol. Model.* 221, 1580–1591.

MacLeod, C. D., Santos, M. B., Burns, F., Brownlow, A., and Pierce, G. J. (2014). Can habitat modelling for the octopus Eledone cirrhosa help identify key areas for Risso’s dolphin in Scottish waters? *Hydrobiologia* 725, 125–136.

Mitchell, I., Daunt, F., Frederiksen, M., and Wade, K. (2020). Impacts of climate change on seabirds, relevant to the coastal and marine environment around the UK. Marine Climate Change Impacts Partnership (MCCIP), Lowestoft, UK Available at: http://www.mccip.org.uk/impacts-report-cards/full-report-cards/2020 [Accessed May 26, 2021].

National Marine Fisheries Service (2018). 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA.

Pierce, G. J., Santos, M. B., Reid, R. J., Patterson, I. A. P., and Ross, H. M. (2004). Diet of minke whales Balaenoptera acutorostrata in Scottish (UK) waters with notes on strandings of this species in Scotland 1992-2002. *J. Mar. Biol. Assoc. U. K.* 84, 1241–1244.

Samarra, F. I. P., and Foote, A. D. (2015). Seasonal movements of killer whales between Iceland and Scotland. *Aquat. Biol.* 24, 75–79.

Santos, A. M., Pearce, J. L., Ross, H. M., Reid, R. J., and Wilson, B. (1994). Diets of small cetaceans from the Scottish coast.

Santos, A. M., Pearce, J. L., Ross, H. M., Reid, R. J., and Wilson, B. (1995). Diets of small cetaceans stranded in Scotland.

Santos, M. B., Pierce, G. J., Learmonth, J. A., Reid, R. J., Ross, H. M., Patterson, I. a. P., et al. (2004). Variability in the Diet of Harbor Porpoises (phocoena Phocoena) in Scottish Waters 1992–2003. *Mar. Mammal Sci.* 20, 1–27. doi:https://doi.org/10.1111/j.1748-7692.2004.tb01138.x.

Santos, M. B., Pierce, G. J., Learmonth, J. A., Reid, R. J., Sacau, M., Patterson, I. A. P., et al. (2008). Strandings of striped dolphin Stenella coeruleoalba in Scottish waters (1992-2003) with notes on the diet of this species. *J. Mar. Biol. Assoc. U. K.* 88, 1175–1183.

Santos, M. B., Pierce, G. J., Reid, R. J., Patterson, I. a. P., Ross, H. M., and Mente, E. (2001). Stomach contents of bottlenose dolphins (Tursiops truncatus) in Scottish waters. *J. Mar. Biol. Assoc. U. K.* 81, 873–878. doi:10.1017/S0025315401004714.

Serpetti, N., Baudron, A. R., Burrows, M. T., Payne, B. L., Helaouët, P., Fernandes, P. G., et al. (2017). Impact of ocean warming on sustainable fisheries management informs the Ecosystem Approach to Fisheries. *Sci. Rep.* 7, 13438. doi:10.1038/s41598-017-13220-7.

Steenbeek, J., Buszowski, J., Christensen, V., Akoglu, E., Aydin, K., Ellis, N., et al. (2016). Ecopath with Ecosim as a model-building toolbox: Source code capabilities, extensions, and variations. *Ecol. Model.* 319, 178–189.

Trites, A. W., Livingston, P. A., Vasconcellos, M. C., Mackinson, S., Springer, A. M., and Pauly, D. (1999). Ecosystem change and the decline of marine mammals in the Eastern Bering Sea: testing the ecosystem shift and commercial whaling hypotheses. Vancouver, Canada: Fisheries Centre, University of British Columbia.

Waggitt, J. J., Evans, P. G. H., Andrade, J., Banks, A. N., Boisseau, O., Bolton, M., et al. (2020). Quantifying seabird and cetacean distributions at annual and monthly scales in the North-East Atlantic. *J. Appl. Ecol.* 57, 253–269. doi:10.1111/1365-2664.13525.