A1a.4 Fish and Shellfish

A1a.4.1 UK context

This section describes the distribution and ecology of fish and commercially important shellfish species in UK waters, with reference, where information is available, to spawning and nursery grounds. The section draws on previous fishery studies commissioned for the SEA programme and a range of other technical reports and scientific publications. Information on the seasonal distribution of commercially important fish and shellfish is available from several sources, with the most reliable being the routine research vessel surveys undertaken by European research laboratories, co-ordinated by the International Council for the Exploration of the Sea (ICES). These annual surveys target major commercial species but they also record information on the distribution and abundance of the non-target components of the catch. The Fish Atlas of the Celtic Sea, North Sea and Baltic Sea (Heessen *et al.* 2015) synthesises results from these international research surveys, incorporating data from over 70,000 hauls carried out between 1977-2013.

Over 330 species of fish have been recorded on the UK continental shelf and the deep water regions which lie to the north and west of Scotland are home to many more. The following sections give a brief overview of a selection of abundant and widespread species in UK waters, grouped into pelagic (open water), demersal (bottom dwelling), elasmobranch (sharks and rays), diadromous (migrate between the sea and freshwater to spawn) and shellfish species.

A1a.4.1.1 Pelagic species

Mackerel (*Scomber scombrus*) are widely distributed around the north-east Atlantic where they tend to shoal in large schools in waters down to 1,000m deep. They usually grow to between 35 and 45cm long although they can reach 60cm. They feed on pelagic crustaceans and other zooplankton and small fish. Mackerel are fast growing and are sexually mature by three years of age (Gordon 2006). They are long-lived; individuals may live for 20-22 years (Navarro *et al.* 2012). Spawning is pelagic and the spawning season prolonged. Eggs are shed in large batches (a 200g female may produce 211,000 eggs per batch (van Damme & Thorsen 2014)) and studies of spawning patterns reveal there to be two main mackerel stocks in UK waters: a western stock and a North Sea stock (Coull *et al.* 1998). Mixing between the two stocks has increased since the 1980s, through migration of western fish into the southern and northern North Sea (Jansen & Gialson 2013).

Atlantic herring (*Clupea harengus*) are widespread throughout the north-east Atlantic, although they reach the southern limit of their range just south of the UK (Dickey-Collas *et al.* 2015). A number of different spawning grounds exist around the UK, with spawning occurring at different times (although the majority takes place in late summer). Spawning usually takes place at depths of between 15-40m, when herring deposit their sticky eggs on coarse sand and gravel. Spawning may take place in coastal waters or open sea, as long as waters are well-mixed, and temperature and salinity tolerance are wide (Pörtner & Peck 2010). The dependency of herring on these specific substrates makes the species potentially susceptible to disturbance at these sites and largely limits herring distribution to the shelf region. Shoals congregate and spawn simultaneously at traditional spawning grounds, resulting in the formation of an, “egg carpet,” which may extend over an area of one hectare (Blaxter & Hunter 1982). Each female produces a single batch of eggs every year from the age of about 3 years, although the number, size and weight of eggs will vary between spawning populations. Eggs hatch after 1-3 weeks, depending on the water temperature, and pelagic larvae will drift towards important nursery grounds (Dickey-Collas *et al.* 2015). As the length of the larval development is dependent on food availability, herring spawned later in the year when food availability has declined may not undergo metamorphosis until the following spring. These larvae are likely to drift long distances in this time (Fässler *et al.* 2011). Young herring occur in dense shoals in inshore waters, and are often found in mixed shoals with varying proportions of sprats (*Sprattus sprattus*) (Dickey-Collas *et al.* 2015).

Sprats are widespread along Atlantic coasts and are usually found in shallow water close to shore, where they can tolerate low salinities. They tend to range in length from 8-12cm and are a short-lived species, the abundance of which is heavily dependent on the strength of the recruiting year class (Gordon 2006). They feed on a range of planktonic crustaceans. Spawning mainly occurs in the summer months, near the coast or up to 100km out to sea, at depths of 10-20m (Gordon 2006). During spawning, 6,000-14,000 pelagic eggs can be produced and this fecundity, along with the rapid life-cycle, means sprat have a very short population doubling time of less than 15 months. Juvenile sprat are generally found in dense schools in shallow, coastal waters (Dickey-Collas *et al.* 2015).

Horse mackerel (*Trachurus trachurus*) is a schooling fish, particularly abundant to the south and west of the UK. Horse mackerel around the UK are split into two stocks; a western stock and a North Sea stock. The North Sea stock spends most of the year in the central North Sea, Skagerrak and Kattegat, but migrates to the southern North Sea in the summer to spawn (FishBase website[1]). Strong influxes of Atlantic water leads to periods of increased abundance in the northern North Sea (Iversen *et al.* 2002). Adults form large shoals in coastal areas with sandy sediments, where they feed on fish, cephalopods and crustaceans. Horse mackerel is notable for an irregular pattern of recruitment, with extremely strong year classes being produced at lengthy intervals. The most recent strong year classes were 1982 and 2001, with the 1982 class (three times larger than the 2001 class) strong enough to dominate the stock for years (Ellis 2015a).

Argentines are deep water salmoniformes found over muddy sediment at depths of between 55-550m, although most commonly at depths greater than 200m (Wheeler 1978, Heessen 2015a). Two species of argentine, the greater (*Argentina silus*) and lesser (*Argentina sphyraena*) are present in the north-east Atlantic. The greater argentine is larger and tends to be found in deeper water, closer to the edge of the continental shelf than the lesser argentine. They feed on bottom living worms and molluscs and also predate on pelagic fish, crustaceans and squid at night. They spawn between March and September, producing pelagic eggs and larvae.

Blue whiting (*Micromesistius poutassou*) is a meso-pelagic species, usually found in shoals 30-400m from the surface in water between 150-3,000m deep. Shoals move towards the surface at night. They are widely distributed around the north-east Atlantic, typically reach lengths of 25-30cm and live for 5-7 years (Gordon 2006). They feed primarily on small crustaceans such as euphausiids.

A1a.4.1.2 Demersal species

Gadoids

Gadoids are important components of the fish community of the north-east Atlantic, with 12 (of 31 known) species found in the region (Nelson 2006). The Atlantic cod (*Gadus morhua*) can be found from the shoreline down to depths of 600m and is widely distributed around European coasts. It can reach lengths of 190cm, but more commonly of between 50-80cm and, although

[1] http://www.fishbase.org/summary/1365

heavily exploited, has the potential to live to 15 years or older (Hislop *al.* 2015). Cod are omnivores, feeding on a variety of invertebrates and fish. Sexual maturity is reached between 4-5 years and spawning occurs over the continental shelf between January and April. Cod show a preference to spawn in waters with temperatures between 5-7ºC and high salinities, over coarse sand with a low tidal flow (González-Irusta & Wright 2016). Larval abundance peaks at fronts and juveniles remain pelagic until they reach a length of 5-7cm. Adult cod aggregate in loose shoals and generally remain within the continental shelf area (Hislop *et al.* 2015).

The haddock (*Melanogrammus aeglefinus*) is found around north-east Atlantic coasts, over rock, sand or gravel bottoms at 10-450m depth, usually between 80-200m (Albert 1994). It can reach 50-75cm long and feeds on small benthic invertebrates and fish. It is known to reach ages of up to 20 years. There is some evidence of a winter migration of adult haddock from the North Sea to north-western Scotland (Hislop *et al.* 2015). Haddock is a batch spawner, with the season typically extending from February to May, with the north-east coast of Scotland, the seas around Shetland, the north-west coast of Scotland, the Minch and the north-west Irish Sea and Celtic Sea usual spawning areas. Eggs are pelagic, and modelling suggests that a significant number of the eggs spawned off the west coast are transported into the North Sea (Heath & Gallego 1997).

Whiting (*Merlangius merlangus*) are widespread around European coasts at depths of 10-200m over sandy or muddy ground. They typically grow to 30-40cm in length and may reach 20 years of age, although 7 or 8 is more common (Gordon 2006). Their diet comprises mainly crustaceans and fish, with a greater proportion of fish as they get older. Spawning can take place as early as January in the southernmost areas of its distribution and as late as July in more northerly areas. Whiting spend their first 2-3 months near the surface, often associating with *Cyanea* jellyfish blooms (Hay *et al.* 1990), after which they adopt a demersal way of life.

Saithe (*Pollachius virens*) are most abundant at depths of between 125-200m around north-east Atlantic coastlines, usually entering coastal waters in spring and migrating back to deeper sea in winter (Hislop *et al.* 2015). They grow to 60-90cm and have a diet of fish and small crustaceans. Saithe reach maturity between 4-6 years and individuals aged 25 years have been reported (Gordon 2006). They spawn in winter and spring, later in the year for populations further north. Pollack (*Pollachius pollachius*) live inshore over rocky ground at depths of up to 200m, around north-east Atlantic coasts. They can grow to between 60 and 80cm, although individuals of up to 130cm have been found. The pollack feeds primarily on fish, with cephalopods and crustaceans also forming part of its diet. Juvenile shoals are common inshore but the adults shoal only during the spawning period, which takes place in winter and spring at about 100m depth (Whitehead *et al.* 1986).

A number of smaller gadoid species such as poor cod (*Trisopterus minutus*), Norway pout (*Trisopterus esmarkii*) and bib (*Trisopterus luscus*) can be very abundant in places and may be ecologically important as prey for other species.

Flatfish

Plaice (*Pleuronectes platessa*) live to depths of 200m, mainly on soft sediments. Spawning occurs in water temperatures of approximately 6°C to produce pelagic eggs. Larvae move to coasts, and sandy beaches and estuarine regions act as nursery grounds, before older individuals venture out to deeper waters (Gordon 2006). Plaice live on mixed substrates at depths up to 200m (although generally in much shallower waters), with older individuals generally found in deeper water (Whitehead *et al.* 1986). Plaice have a complicated life cycle, with each life stage having a specific set of habitat requirements. Larvae and juveniles rely on transport by currents to move them from spawning grounds to nursery areas, a habit that adults retain by making use of tidal transport during seasonal migrations between spawning and feeding grounds (Goldsmith *et al.* 2015).

Dab (*Limanda limanda*) and long rough dab (*Hippoglossoides platessoides*) are spring and summer spawners which mature at 2-3 years to produce pelagic eggs and larvae. Dab larvae were the most abundant to be found in the North Sea and Irish Sea during ichthyoplankton surveys. Dab are typically found in shallower water, where they feed on small benthic invertebrates (Amara *et al.* 1998). The long rough dab tends to be found in deeper waters, up to 500m, over muddy substrates. Other important flatfish include the lemon sole (*Microstomus kitt*), mainly on coarser sediments to 200m, and the sole (*Solea solea*), especially on finer sandy and muddy seabeds to around 120m, including estuarine areas. Both are widespread in British waters, but sole is much more abundant in the southern half of the British Isles than in the north as it is generally confined to warmer waters (Rijnsdorp *et al.* 2015).

Other species

Two similar species of monkfish, white-bellied (*Lophius piscatorius*) and black-bellied (*L. budegassa*) are typically found in northern UK waters ranging from shallow, inshore waters down to depths of up to 1,100m. Spawning is thought to take place in deep water, with each female thought to produce just one batch of eggs (in a large, buoyant and gelatinous ribbon) in winter and spring (Laurenson *et al.* 2008). Juvenile monkfish descend to the seabed after 3-4 months spent in the water column and are generally found in shallower water than adults. Female monkfish do not mature until they are at least seven years old and so the species is particularly vulnerable to overfishing. Monkfish are ambush predators, enticing prey (typically fish, cephalopods and crustaceans) towards their mouths with a lure that extends from the top of their head (Fariña *et al.* 2008). Monkfish are generally viewed as typical demersal fish; however, large females, perhaps undertaking spawning migrations, are regularly caught in pelagic trawls in deep water between the UK and Norway (Hislop *et al.* 2001).

Several species of gurnard are abundant in UK waters. The grey gurnard (*Eutrigla gurnardus*) is very abundant in shallow, sandy areas and migrates inshore during summer (Wheeler 1978). Spawning takes place between January and June, with juveniles moving into deeper water as they mature. Red gurnards (*Aspitrigla cuculus*) tend to be found in shallow water and spawn over the summer months. Gurnards are predators, feeding on a range of fish, crustaceans and benthic invertebrates. The rays of their pectoral fins are modified into sensory organs with which they detect prey (Wheeler 1978).

The scorpionfish include bullrout (*Myoxocephalus scorpius*), sea scorpions (*Taurulus bubalis*) and pogge (*Agonus cataphractus*). These species tend to favour coarse sediments in shallow waters and may enter estuaries and river mouths (Power & Attrill 2002). They feed on crustaceans and small fish and pogge have sensory barbels to detect prey (Wheeler 1978). Most scorpionfish will spawn between October and April, with exact periods dependent on the species. They produce benthic eggs which they deposit on a secure holdfast (Ellis 2015b).

Dragonets are typically found inshore on sand and gravel sediments. Of the three main species found in UK waters, the common dragonet (*Callionymus lyra*) is the most abundant (Russell 1976). This species spawns in depths of less than 50m from early spring to August, producing pelagic eggs and larvae (Russell 1976). The other species found in UK waters are the spotted (*Callionymus maculatus*) and reticulated (*Callionymus reticulatus*) dragonets. Dragonets feed primarily on polychaetes, crustaceans and molluscs (King *et al.* 1994). Male dragonets are colourful fish with complex courtship behaviours. *C. lyra* develop iridescent stripes and an elongated snout, which is useless for feeding. Spawning occurs in pairs, with matched males and females ascending together through the water column and, if courtship has proved satisfactory, releasing eggs and milt in synchrony on the descent. The starved male is likely to die following the spawning season (Daan 2015a).

Sandeels (Ammodytidae, principally *Ammodytes* spp. and *Hyperoplus* spp.) are shoaling species which lie buried in the sand at night and feed in mid-water during daylight (Winslade 1974). Spawning usually takes place between November and February, on sandy sediments. The eggs (up to 15,000 from a large fish (Gauld & Hutcheon 1990)) are demersal and are laid in sticky clumps on sandy substrates. Larvae remain pelagic for between 2-5 months after which they are thought to over-winter buried in the sand (Sparholt 2015). Boulcott & Wright (2011) discovered evidence of regional variation in fecundity of the lesser sandeel, *Ammodytes marinus*, with fecundity of individuals in areas of the central North Sea being greater than that of individuals of the north-east coast of the UK. There is little movement between spawning and feeding grounds, and so fishing activity may have a direct effect on spawning (Sparholt 2015). As well as being a major component of the industrial fishery, sandeels are an important food item for predatory fish and seabirds. There are five species of sandeels in the North Sea, of which *A. marinus* is the most abundant and comprise 90% of commercial landings (Marine Scotland website[2]).

There are 19 species of goby found in UK waters (Ellis & Rogers 2015). They are found in inshore waters and estuaries where they feed on a wide range of food from planktonic organisms to crustaceans. Gobies spawn on the seabed in summer, with males guarding eggs that have been left under rocks or in shells.

Bass (*Dicentrarchus labrax*) are attracted to warm water discharges and so are common inshore, close to the mouths of rivers, particularly around the southern coasts of the UK (Jennings & Ellis 2015). Bass move inshore to spawn from March to June and form large shoals during this migration, making them a target for fisheries.

The pipefish family includes the pipefish and seahorses. There are six species of pipefish and two seahorses found in north-western European waters. The short-snouted (*Hippocampus hippocampus*) and long-snouted (*Hippocampus guttulatus*) seahorses may be found around UK coasts, although are most common along the south coast of England. They are cryptic species and inhabit seagrass meadows in which they are well camouflaged. Seahorses are notable as the only animals that exhibit a genuine male pregnancy, with the female depositing fertilised eggs into the male brood-pouch, where they become embedded into the tissue. Fry are released after a gestation period of 3-5 weeks, during which they will obtain their nutritional requirements through a placenta-like structure. Breeding takes place over the summer months in UK waters (Wheeler 1978). Juveniles are pelagic, where predation levels are high, but those that survive youth will settle at an appropriate demersal habitat. Pipefish are found around the UK coast and can survive in a wide range of habitats from coastal seagrass meadows to oceanic waters. The snake pipefish (*Entelurus aequoreus*) underwent a remarkable increase in abundance in the early 2000s in UK waters, although since 2008, the abundance has declined just as sharply (Daan 2015b).

A1a.4.1.3 Elasmobranchs

The most abundant sharks found in UK waters are the lesser and greater spotted dogfish (*Scyliorhinus canicula* and *Scyliorhinus stellaris*), the spurdog (*Squalus acanthias*) and the tope (*Galeorhinus galeus*). Dogfish show a wide but patchy distribution in the North Sea.

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[2] https://www2.gov.scot/Topics/marine/marine-environment/species/fish/sandeels

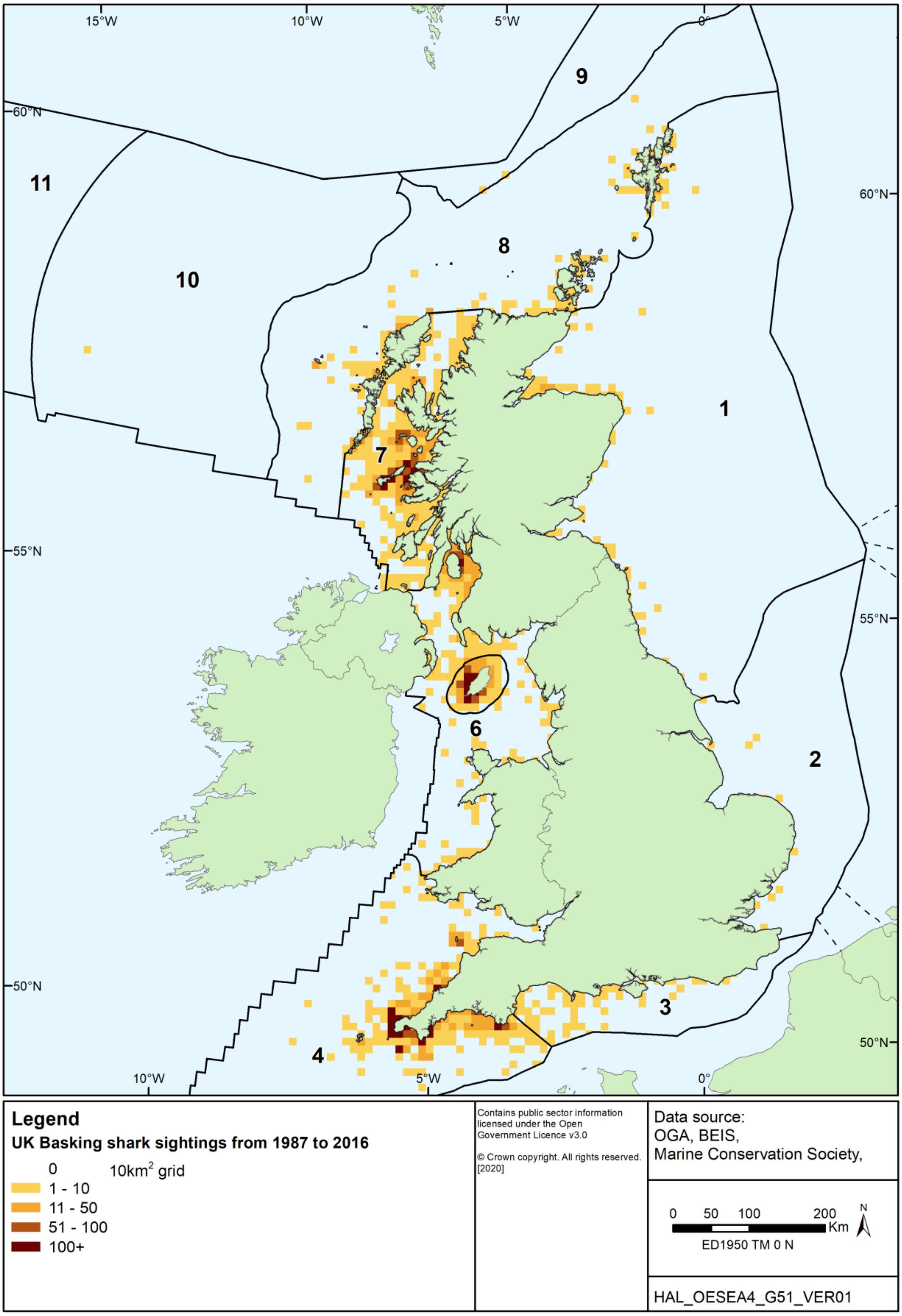
They feed on crustaceans, cephalopods and fish (Ellis *et al.* 1996) and are egg layers, with the peak of breeding in June and July. Tope are also widespread and juveniles are often found in large bays and estuaries. They are long-lived, reaching an age of at least 36 years (Peres & Vooren 1991). They are viviparous and young are generally born during the summer, after a year-long gestation period. Large open water species such as the porbeagle (*Lamna nasus*) may occasionally occur around the coast of the UK. Waters to the west of Scotland, beyond the continental shelf, are home to a large number of deep-water shark species. Many of these species remain mysterious, with little known about their biology and behaviour.

There are thought to be 27 species of skate within the north-east Atlantic (Ellis *et al.* 2015), of which many are present in UK waters. Among the most widespread are the thornback ray (*Raja clavata*) and the cuckoo ray (*Raja naevus*). The starry ray (*Amblyraja radiata*), the blonde ray (*Raja brachyuran*), the small-eyed ray (*Raja microocellata*), the undulate ray (*Raja undulata*) and the spotted ray (*Raja montagui*) are regionally abundant. The common skate (*Leucoraja batis*), listed as "critically endangered" on the IUCN Red List, is also present, but rare.

Basking shark

The basking shark (*Cetorhinus maximus*) is the largest fish in the North Atlantic and the second largest in the world. It is widespread and feeds by filtering plankton from the water with its gill rakers. The shark is commonly seen at the surface in the summer months, particularly around the western coasts of the UK, but it is less clear where they spend the winter. Research (Sims *et al.* 2003) suggests that they make extensive migrations both vertically and horizontally to locate high concentrations of plankton that will often be associated with fronts, and that they principally migrate north to south during the winter months along the continental shelf of Europe (Sims *et al.* 2005a, b). Further detail was provided by the summer deployment of seventy satellite tags on basking sharks over four years (2012–2015) off the west coast of Scotland and the Isle of Man (Doherty *et al.* 2017a). Basking sharks exhibited wide-ranging post-summer movements, stretching from 33° to 61°N latitude (*ca*. 3,100 km range) within a longitudinal range (2° to 20°W); along the eastern fringe of the North Atlantic Ocean. The general pattern of movement followed a transition to more southerly latitudes from October onwards in each year although movements varied in distance and duration. Tagged individuals exhibited one of three migration behaviours: remaining in waters of UK, Ireland and the Faroe Islands; migrating south to the Bay of Biscay or moving further south to waters off the Iberian Peninsula, and North Africa. Sharks used both continental shelf areas and oceanic habitats, primarily in the upper 50–200 m of the water column. Doherty *et al.* (2017) indicate that it is not yet known whether adopted migration strategy by individuals is annually consistent or changes with body condition, reproductive status, resource availability or other factors. In the summer of 2007 one of two sharks tagged in the Irish Sea was found to migrate more than 9,500km over a period of *ca*. 2.5 months to a point off Newfoundland, Canada, reaching depths of over 1,200m on the way (Gore *et al.* 2008). Basking shark sightings in UK waters are typically centred on three main areas: the Minch, the Isle of Man and Cornwall (Solandt & Chassin 2014, Witt *et al.* 2012, Dolton *et al.* 2020, Figure A1a.5.1).

Figure A1a.5.1: UK basking shark sightings between 1987-2016



Predictive habitat modelling, informed by regional scale surveys off Cornwall and to the west of Scotland, highlighted several regions of high relative habitat suitability for basking sharks in summer months in UK waters. The model incorporated known hotspots but also identified other areas to the west of Scotland, north east coast of Scotland as well as parts of the southern North Sea (Austin *et al.* 2019). Interestingly, Hayes *et al.* (2018) reported breaching behaviour of a number of basking sharks observed during an offshore geophysical survey conducted in July and August 2013, west of Shetland. The occurrence and distribution of basking sharks in this region remains poorly understood with only few sightings documented in this region over the past 20 years (Witt *et al.* 2012). Breaching has been proposed as a male-male competitive behaviour during courtship displays and female basking sharks may breach to signal their readiness for mating. Hayes *et al.* (2018) suggest that the high number of sightings of sharks recorded during a relatively short time frame in addition to breaching behaviour and presence of young individuals, may indicate that the area west of Shetland may be an important habitat for the basking shark. The authors noted that although startle responses to acoustic sources have been recorded in some elasmobranch species, research in the behaviour of basking sharks and other elasmobranch species to seismic sources is poorly understood and yet to be investigated. The limited dataset did not allow them to draw any conclusions on the potential issue.

A1a.4.1.4 Diadromous species

Diadromous species are those which migrate between marine and freshwater as part of their lifecycle.

Lampreys are eel-like, jawless fish. Both the river lamprey (*Lampetra fluviatilis*) and the sea lamprey (*Petromyzon marinus*) migrate up rivers to spawn (anadromy) and spend the larval stage buried in muddy substrates in freshwater. Both species need clean gravel for spawning, and silt or sand for the burrowing juveniles (JNCC website[3]). Once metamorphosis takes place, the adults migrate to the sea where they live as a parasite on various species of fish (Kloppmann 2015a). Sea lampreys are thought to venture further out to sea and spawn in lower reaches of the rivers than the river lampreys (Kloppmann 2015a). The sea lamprey is uncommon in the UK, while the river lamprey or lampern is widespread with substantial populations in some rivers and streams. The main populations of both species are found in the Bristol Channel and adjacent offshore waters.

The allis and twaite shads (*Alosa alosa* and *A. fallax*) and the Atlantic salmon (*Salmo salar*) also display an anadromous lifecycle. The shads are clupeids, or herring-like fish. They are rare but are most abundant around the west coast and the southern North Sea, where they feed in estuaries before moving upstream to spawn between April and July. A water temperature of 12-20ºC is thought to trigger this upstream migration (Dickey-Collas *et al.* 2015). Significant spawning populations of the twaite shad are still found in the UK, while the allis shad, displays little spawning activity in the UK. Juveniles are thought to remain in freshwater for up to two years, before returning to the sea (Maitland & Hatton-Ellis 2003).

Salmonids, including Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*) undertake extensive migrations out to sea to feed, before returning to “home” rivers to spawn, which takes place in the late autumn to winter in UK rivers. Spawning takes place in shallow excavations (redds), in shallow gravelly areas in clean rivers and streams. After a period of 1-6 years the young salmon migrate downstream to the sea as smolts. Salmon have a homing instinct and spawn in the river of their birth after 1-4 years at sea (Heessen & Daan 2015).

Extensive research on the freshwater phase of the salmon life cycle has revealed much about the factors affecting juvenile production, but much less is known about the salmon’s life at sea.

[3] https://sac.jncc.gov.uk/species/S1095/

Low return rates of salmon in recent years suggest that their abundance is strongly influenced by factors in the marine environment (ICES 2020a), although initial results of the Moray Firth tracking project suggest higher than expected losses of migrating smolts before they reach the marine environment[4].

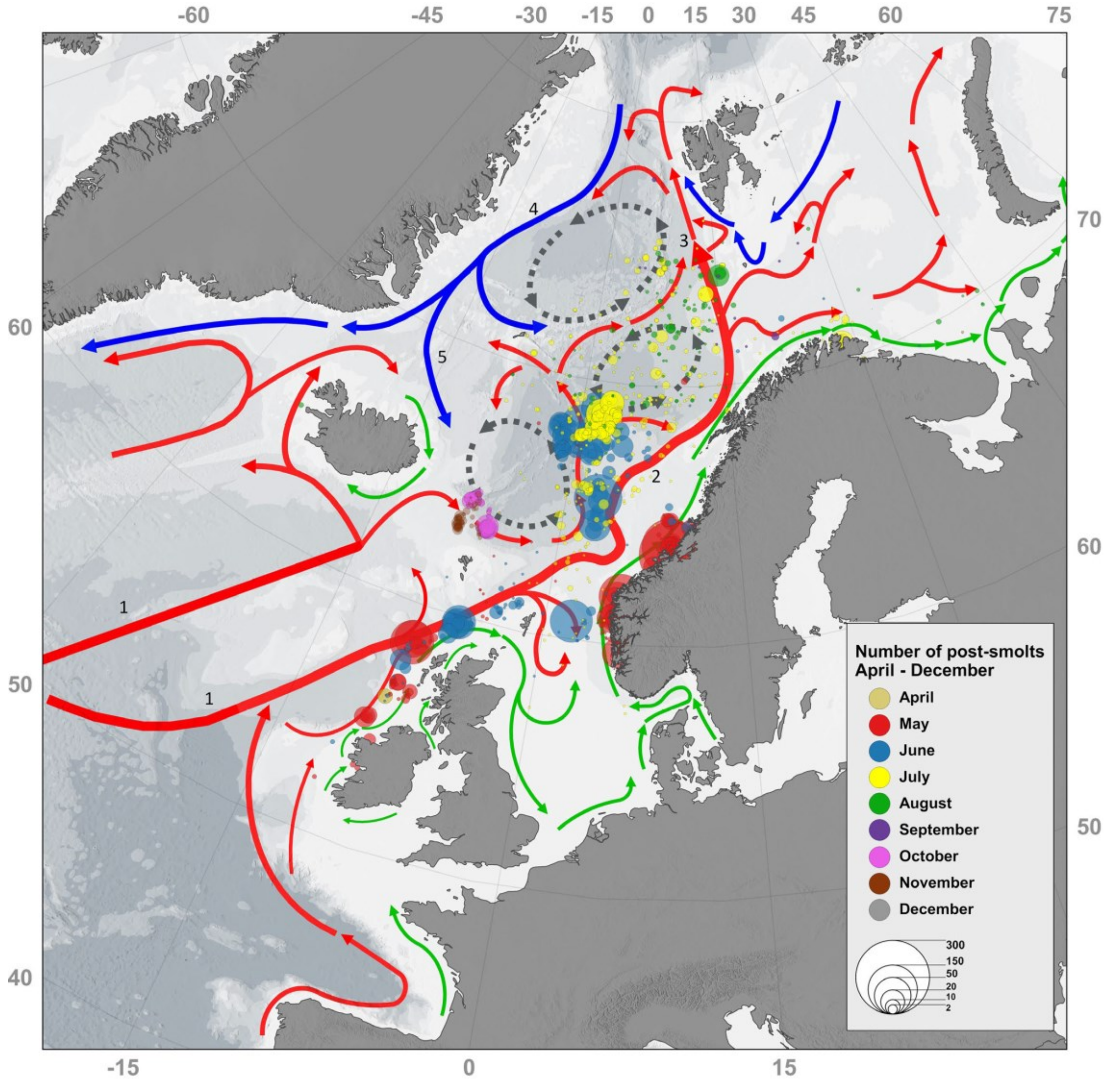
Atlantic salmon leave their home rivers in spring and early summer as smolts and migrate towards feeding areas in the Nordic Seas and West Greenland (Guerin *et al.* 2014, Malcolm *et al.* 2010, 2015). Juvenile fish, including herring, sandeel and blue whiting form an important part of the diet of smolts during oceanic feeding (Haugland *et al.* 2006). Over the past 10–15 years, a number of post-smolts have been caught in oceanic areas of the north east Atlantic during pelagic trawl surveys in the Norwegian Sea in July and August (Holm *et al.* 2000) and north of Scotland in May and June (Holm *et al.* 1998, Holst *et al.* 1996, Shelton *et al.* 1997). Based on the distribution of catches north of Scotland, the fish appeared to move northwards with the shelf edge current (Shelton *et al.* 1997). Farther north in the Norwegian Sea, post-smolts were caught beyond 70°N in July. Analysis of growth and smolt age distribution strongly suggested that most of the post-smolts originated from rivers in southern Europe (Holst *et al.* 1996). This was supported by the recapture of salmon that had been tagged in April 1995 in western Ireland and southern UK (England and Wales) and recovered up to 2,000km farther north three months later, demonstrating post-smolts capacity for rapid travel (Ó Maoiléidigh *et al.* 2018). Marine Scotland has developed a model of post-smolt migration from Scottish shores to these northern feeding grounds (Ounsley *et al.* 2020). The model simulated various different notional swimming behavioural scenarios, including current-orientated and compass-directed movement across a range of swimming speeds. Current-following behaviours did not facilitate migration towards feeding grounds in the North Atlantic. In addition, modelled trajectories resulting from directed-swimming behaviours implied that populations around Scotland need to adopt different locally adapted migratory strategies to successfully reach their feeding grounds. Currently, the west coast[5] and Moray Firth[6] tracking projects are attempting to track smolts from a number of Scottish rivers as they enter the marine environment in order to determine factors responsible for the declines in returning fish. Similarly, the COMPASS[7] and SeaMonitor[8] projects are tracking smolt migration in marine waters between Northern Ireland, the Republic of Ireland and Scotland (e.g. Barry *et al.* 2020).

To advance understanding of post-smolt distributional ecology in the North-east Atlantic, Gilbey *et al*. (2021) analysed data from 385 marine cruises, 10,202 individual trawls, and 9,269 captured post-smolts, spanning three decades and ~4.75 million km^2 of ocean, with 3,423 individuals genetically assigned to regional phylogeographic origin. The findings confirmed major migrational post-smolt aggregations on the continental shelf-edge off Ireland, Scotland and Norway, and an important marine foraging area in the Norwegian Sea (Figure A1a.5.2). Movement of this migrational aggregation associated strongly with the warm northward flowing regional current that facilitates movement to the more northerly foraging areas. Genetic analysis showed that aggregational stock composition did not simply reflect distance to natal rivers, with northern phylogeographic stock groups significantly under-represented in sampled high-seas aggregations (potentially migrating further north). It identified a key foraging habitat for primarily southern European post-smolts (includes those from UK and Ireland) located in international waters immediately west of the Vøring Plateau escarpment, potentially exposing them to a high by-catch mortality from extra-territorial pelagic fisheries. The differential distribution of regional stocks points to fundamental differences in their migration behaviours

4 https://youtu.be/V_MiK1JtFzQ
5 https://atlanticsalmontrust.org/the-west-coast-tracking-project/
6 https://atlanticsalmontrust.org/morayfirthtrackingproject/
7 https://compass-oceanscience.eu/
8 https://www.loughs-agency.org/managing-our-loughs/funded-programmes/current-programmes/sea-monitor/

and may lead to inter-stock variation in responses to environmental change and marine survival (Gilbey *et al.* 2021). The authors also noted a major offshore migrational aggregation likely to have been missed by the analysis was in the northern North Sea, through which a large proportion of British post-smolts, from east coast rivers, have to migrate to reach their more northerly feeding areas, an area poorly sampled during the May to June period following smolt runs from North Sea rivers. Interestingly, post-smolts from the chalk streams in southern England, which could migrate north through North Sea, may migrate westwards and join the shelf-edge aggregation, suggesting a migration divide associated with the now submerged Norfolk-Zeeland ridge and previously terrestrial divide (Cauwelier *et al*. 2018).

Figure A1a.5.2: Post-smolt distribution, bathymetry, ocean currents and oceanic gyres in the NE Atlantic



Notes: Red, green and blue arrows represent Atlantic, coastal, and Arctic currents, respectively. Oceanic gyres indicated by grey dashed arrows. Arrow sizes are proportional to current strengths. Major currents denoted by numbers: 1 - North Atlantic Current; 2 - Norwegian Atlantic Current; 3 – West Spitsbergen Current; 4 – East Greenland Current; 5 – East Icelandic Current. Source: Gilbey *et al.* (2021).

Recapture data from tagged adult salmon strongly suggest that the oceanic homing migration, the opposite of the smolt migration, is independent of currents with homing fish often moving along the shortest distance from tagging site to the coast (Hansen *et al.* 1993). Returns of salmon to western rivers are confined largely to the summer months. In contrast, sea trout appear to remain within nearshore waters rather than undergoing extensive migrations leading to concerns about their greater risk of exposure to sea lice infections from salmon farms in these areas (Gillibrand *et al.* 2005).

Salmonids play a critical role in the life cycle of the freshwater pearl mussel *Margaritifera margaritifera*. The freshwater pearl mussel is long lived with records of individuals over 100 years old (Bauer 1992). The larval stage (or glochidia) of the mussel is inhaled by juvenile Atlantic salmon and brown or sea trout where it attaches to the gills and encysts. Encysted larvae live and grow in the hyper-oxygenated environment on the gills before dropping off in the following spring, an infection apparently without a negative influence either on the lifecycle or the health of the fish (Makhrov & Bolotov 2011).

The European eel (*Anguilla anguilla*) spends most of its life in freshwater or inshore coastal waters, before migrating across the Atlantic to the Sargasso Sea to spawn in late summer (McCleave & Arnold 1999). The larvae drift north-east with the Gulf Stream and return to European coastal waters during the spring where they transform into transparent elvers (glass eels). Glass eels gather in river estuaries and wait for the river water to reach 10-12°C, before swimming upstream and migrating into inland waters. Peak migration takes place on the increasing tides in April and May, with predators such as porbeagle shark taking advantage (Béguer-Pon *et al.* 2012). Eels which successfully reach fresh water acquire green and brown pigments and become yellow eels. Yellow eels spend between 2 and 20 years in rivers and other inland waters although there are records of longer lived animals. Mature fish migrate seawards as silver eels and are thought to migrate westwards at depth to the Sargasso Sea, where they spawn and die. Experimental studies suggest eels are able to use innate magnetic compass orientation to orient themselves relative to magnetic North and, in conjunction with sea temperatures, navigate the long distances required to undertake these migrations (Durif *et al.* 2013). A tagging study followed over eighty eels released from four regions in Europe between August and December as they migrated from western mainland Europe to the Azores region, more than 5,000km toward the Sargasso Sea (Righton *et al.* 2016). All eels exhibited diel vertical migrations, moving from deeper water during the day into shallower water at night, at a range of migration speeds (3 to 47 km/day). With spawning in the Sargasso Sea thought to begin in December and peaking in February, the authors postulated that the timing of autumn escapement and the rate of migration of the tagged eels are inconsistent with the long held assumption that eels spawn as a single reproductive cohort in the spring following their escapement. Instead, they suggest that European eels adopt a mixed migratory strategy, with some individuals able to achieve a rapid migration, whereas others arrive only in time for the following spawning season (Righton *et al.* 2016).

Very large declines in eel populations since the 1970's have been reported throughout Europe. Recent estimates of glass eel recruitment for an area including the UK, Ireland, France, Spain, Portugal and Italy, were 6.2% (2019), 7.1% (2020) and 5.4% (provisional 2021 figure) of the 1960-1979 recruitment level. The UK profile for glass eel catches reflects the ICES data (ICES 2021). Greater declines were estimated for the "North Sea" area (which includes Norway, Sweden, Germany, Denmark, the Netherlands and Belgium), with glass eel recruitment estimated at 1.4% (2019), 0.9% (2020) and 0.6% (2021 provisional figure) of the 1960-1979 level. Since 2011, there has been a very slight increase in recruitment (ICES 2021), but the European eel is listed as critically endangered. Many reasons have been proposed for this decline: habitat loss, pollution, parasitism, increased migration barriers, changes in oceanographic conditions, reduction of available prey in freshwater habitats, exotic fish invasions, and overexploitation of fisheries (Castonguay *et al.* 1994, Jacoby *et al.* 2015, Miller *et al.* 2016, Bornarel *et al.* 2018). Little is known about the characteristics of eels inhabiting UK coastal and estuarine waters, and even less of their potential or actual production (ICES 2009), primarily due to the difficulties in catching and representatively sampling eels in these environments (see Walmsley *et al.* 2018). Stock indicator estimates and commercial catch returns provided to ICES for each of the UK's Eel Management Units (EMU, generally the same area as the WFD River Basin Districts) provide useful data (ICES 2019).

A1a.4.1.5 Shellfish

The benthic fauna of the UK waters is rich and diverse. An important component of this benthic fauna is a collection of molluscs and crustaceans loosely referred to as shellfish. This section considers shellfish of commercial importance, with other species considered in detail in the Benthos section (Section A1a.3). Detail on the fisheries for these species may be found in Section A1h.16.

Crustaceans

The Norway lobster (*Nephrops norvegicus*), commonly known as *Nephrops*, lives in burrows dug into muddy and sandy sediments, at depths between 20-800m. They range in body length from 8-24cm. *Nephrops* feed mainly on detritus, small crustaceans and worms and are most active at night (Marine Scotland website[9]). Eggs hatch in spring or summer after being carried by females for 9 months. The relative inactivity of females during this period, when they remain hidden in burrows, means that males are more heavily exploited in the fishery through most of the year. There is considerable variation in the life-histories of *Nephrops* at different locations. In part, this is linked to sediment type, with higher population densities found at sandier sites, resulting in a reduction in the rate of growth and maximum size. *Nephrops* is more abundant in northern UK waters, although significant populations exist in the Irish and Celtic Seas and on the Fladen Ground.

The brown (or edible) crab (*Cancer pagurus*) is most abundant on rocky grounds, where it hides in holes and crevices. The crab is generally found in shallow water close to shorelines, particularly along the east coast and the south-west of England, although it can be found in water as deep as 100m (FAO website[10]). It is both an active predator and a scavenger. The species spawns between November and February, during which time the females remain in deeper waters offshore (Edwards 1979). Other crabs that are abundant around UK coasts include the green crab (*Carcinus maenas*) and velvet crab (*Necora puber*). The European lobster (*Homarus gammarus*) is found from the shoreline to depths of 150m, usually on a hard substrate such as rock or hard mud, growing to lengths of 60cm. Lobsters are most active at night, remaining in crevices during the day. Females lay eggs in July and carry them for 10 or 11 months (FAO website). The related crawfish *Palinurus elephas* is another valuable crustacean but catches are much reduced since the 1970s. It is most abundant on hard bottoms off the extreme south-west of England and Wales and the west of Scotland. Crawfish feed on a variety of benthic organisms but are thought to have a preference for echinoderms such as urchins. Long distance migrations are a feature of many crabs and lobsters, the edible crab, European lobster, crawfish and spider crab (*Maja squinado = brachydactyla*) (Edwards 1979).

A number of valuable shrimp species are found around the UK. The three most important are the brown shrimp (*Crangon crangon*), the pink shrimp (*Pandalus montagui*) and the deep-water shrimp (*Pandalus borealis*). The brown and pink shrimps are typically found in shallow waters, in bays and estuaries along the east coast of England. The brown shrimp generally favours areas with soft, sandy sediments, in which it can burrow, while the pink shrimp is more common over hard substrates. Eggs are carried by females over the winter months, before hatching in spring (Lee & Ramster 1981). The deep-water shrimp is larger and longer lived

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9 https://www2.gov.scot/Topics/marine/marine-environment/species/fish/shellfish/nephrops
10 http://www.fao.org/fishery/species/2627/en

than the other species. It has a more northerly distribution in UK waters and the North Sea represents the southern edge of its range. It is a detritivore, found as deep as 900m, typically over muddy sediments and in areas of slow moving water where detritus accumulates (Lee & Ramster 1981).

Molluscs

The most commercially valuable molluscs are scallops (*Pecten maximus*). Scallops are found predominantly to the south and west of the UK on sandy, muddy, shell and gravel substrates, down to depths of over 100m. They occupy depressions in the sediment and are able to escape danger by swimming using jet propulsion (Chapman 2004). Their shells are lined with eyes and sensory tentacles, allowing them to detect light levels and even to form rudimentary images (Marine Scotland website[11]). Scallops are filter feeders, sieving the water for phytoplankton and suspended detritus. They first spawn in autumn, at two years old. Older scallops also spawn in spring (Mason 1983). Queen scallops (*Aequipecten opercularis*) are a much smaller shellfish, without the upward facing flat valve characteristic of *P. maximus*. Habitats and distributions of the two species are similar, but queen scallops are able to live on harder gravel and shell substrates (Chapman 2004) and have a much greater ability to swim.

Cockles (*Cerastoderma edule*) live on inter-tidal beaches of sand, muddy sand and fine gravel, where they burrow into the sediment. They use a siphon tube to feed on material suspended in the water column and can be found in very high densities (several 100/m^2) (Chapman 2004). Cockles mature after 2 years and spawn in spring, with each female producing up to a million eggs. The eggs spend about a month in the water column, meaning that settlement of spats and subsequent recruitment can be highly variable (Chapman 2004).

Mussels (*Mytilus edulis*) are suspension feeders generally found attached to hard substrates within the inter-tidal zone, although they also attach to reefs and man-made structures in shallow waters (Chapman 2004). Mussels reach maturity after one year and each female can release over 5 million larvae (Bannister 1998, cited by Chapman 2004), with spawning taking place in late spring. The settlement of spat is influenced by a range of factors, including tidal currents, water temperature and predation and so can be variable (Bannister 1998, cited by Chapman 2004). Other bivalve molluscs common in UK waters include the horse mussel (*Modiolus modiolus*) (although these are little exploited) and razor clams (*Ensis arcuatus* and *Ensis siliqua*).

The most harvested gastropod molluscs in UK waters are whelks (*Buccinum undatum*) and periwinkles (*Littorina littorea*). Whelks are carnivorous, mobile species found close to the coast along rocky shores and on soft sediments. They spawn in November, with eggs attaching to the seabed (Chapman 2004). Winkles are herbivorous, typically found attached to rocks in the inter-tidal zone. They spawn between January and July, releasing planktonic egg capsules (Chapman 2004).

A1a.4.1.6 Spawning and nursery grounds

Most fish display external fertilisation and therefore need to aggregate in large groups to coordinate spawning. Figures A1a.5.3 – A1a.5.6 show the spawning sites of 22 selected fish species and *Nephrops* around the UK coast. These maps are based on a wide-ranging study by Coull *et al.* (1998), which was added to by a larger survey of spawning and nursery sites conducted by Ellis *et al.* (2010, 2012). This survey covered more fish species and has been used as a reference source for this section. In some instances (particularly herring, in which

[11] https://www2.gov.scot/Topics/marine/marine-environment/species/fish/shellfish/scallop

spawning is very site specific) they may be broad in their overview and areas indicated should be regarded as areas in which spawning may occur, rather than well-defined zones. A recent ORJIP study (Boyle & New 2018), developed a methodology using data from ICES international herring and bottom trawl surveys and predicted seabed habitat types, to refine where herring spawning activity may be focused within the more general areas defined by Coull *et al.* (1998), to inform OWF piling mitigation. Table A1a.5.1 indicates the main spawning periods of selected fish species around the UK. These periods are estimates, based mainly on plankton trawls and spawning periods are likely to vary with location.

Table A1a.5.1: Spawning periods of selected species and groups

Group	J	F	M	A	M	J	J	A	S	O	N	D
Dab, long rough dab & solenette		■	■	■	■	■	■	■				
Plaice	■	■	■									■
Sole			■	■	■							
Lemon sole				■	■	■	■	■	■			
Turbot & megrim				■	■	■	■	■				
Gurnards	■	■	■	■	■	■	■	■				
Scorpionfish	■	■	■	■						■	■	■
Dragonets				■	■	■	■	■				
Bass			■	■	■	■						
Haddock		■	■	■	■							
Whiting		■	■	■	■	■						
Cod & saithe	■	■	■	■								
Norway pout & poor cod	■	■	■	■							■	■
Dogfish & tope						■	■					
Monkfish	■	■	■	■	■	■						
Sandeels	■	■									■	■
Argentines		■	■	■	■	■	■	■	■			
Blue whiting				■	■	■						
Herring												
- Buchan/Shetland								■	■			
- Banks/Dogger								■	■	■		
- SE England	■										■	■
- NW Scotland			■	■				■	■			
- Clyde			■	■								
- Mourne									■	■		
Sprat					■	■	■	■				
North Sea mackerel					■	■	■	■				

Group	J	F	M	A	M	J	J	A	S	O	N	D
Western stock mackerel												

Source: Information taken from Coull *et al.* (1998), Cefas (2007) and Ellis *et al.* (2012).

Juvenile fish are vulnerable to predators and harsh conditions in the open water. Therefore it is typical for juvenile fish to stay in sheltered nursery grounds which provide an abundance of food. Selected nursery grounds are shown in Figures A1a.5.7 – A1a.5.9, with the information taken from Coull *et al.* (1998) and Ellis *et al.* (2010). These figures should be referred to where nursery sites are mentioned in this baseline. At nursery and spawning grounds, fish aggregate in large numbers and so are particularly vulnerable to disturbance.

Figure A1a.5.3: UK spawning grounds

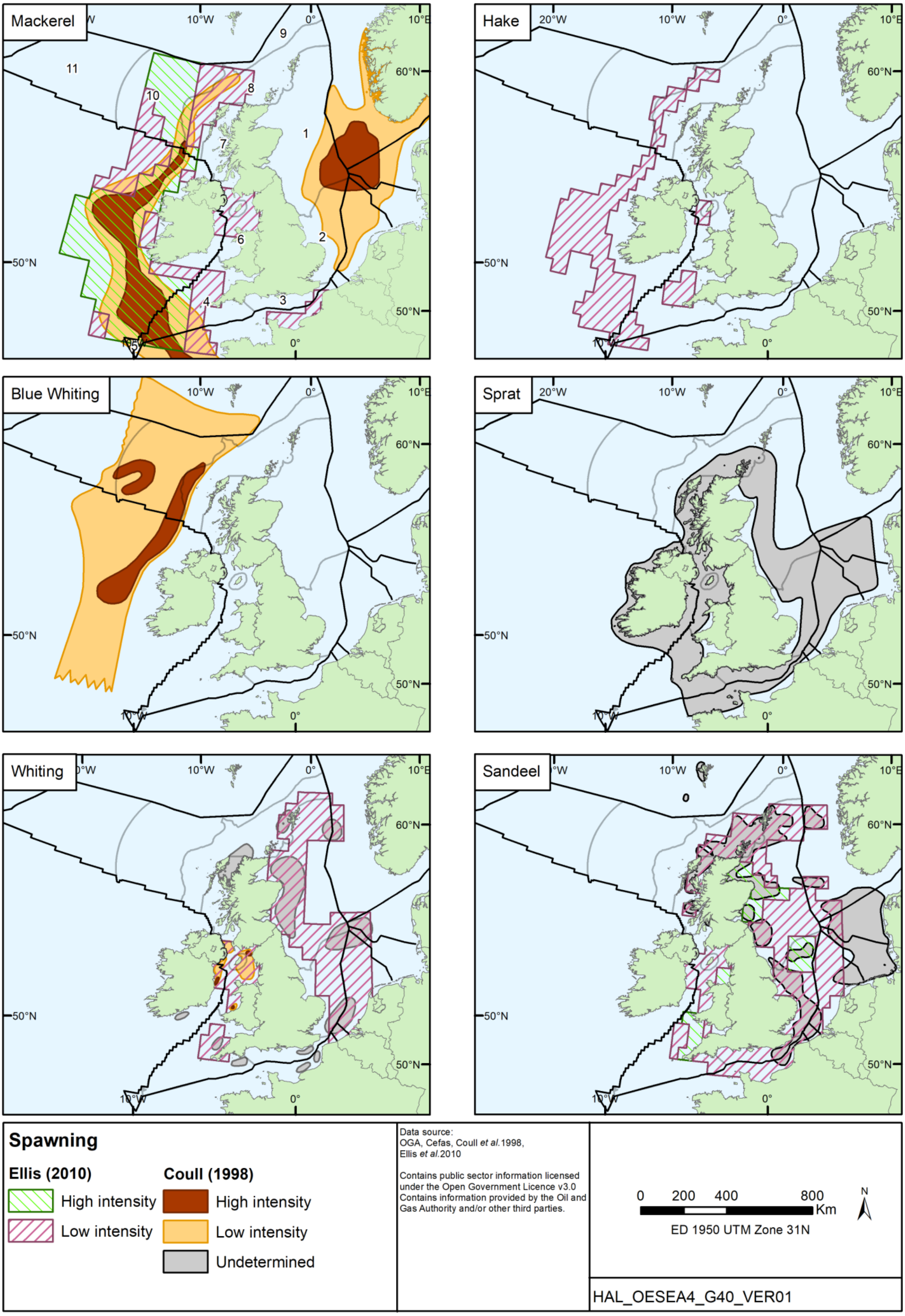


Figure A1a.5.4: UK spawning grounds

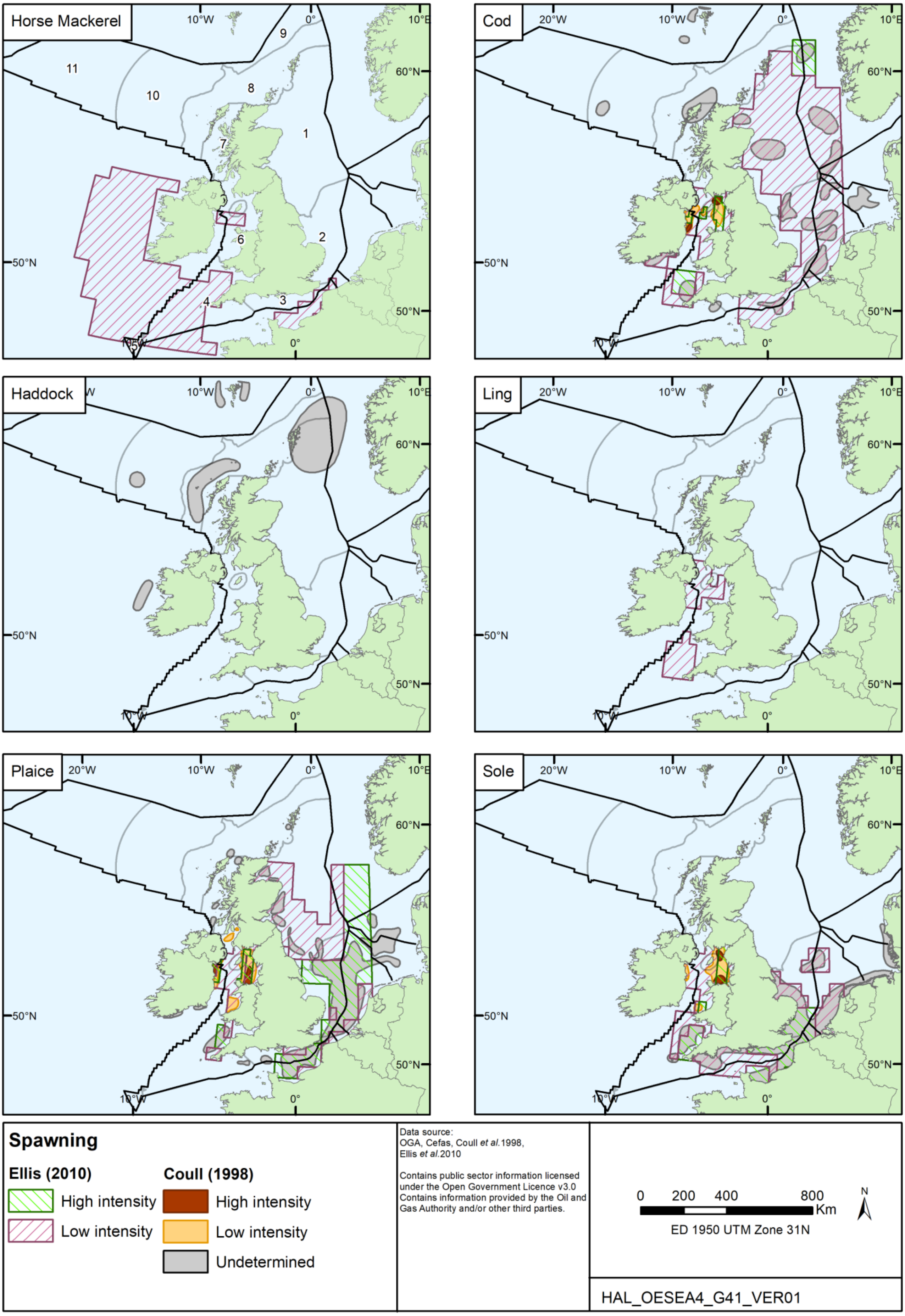


Figure A1a.5.5: UK spawning grounds

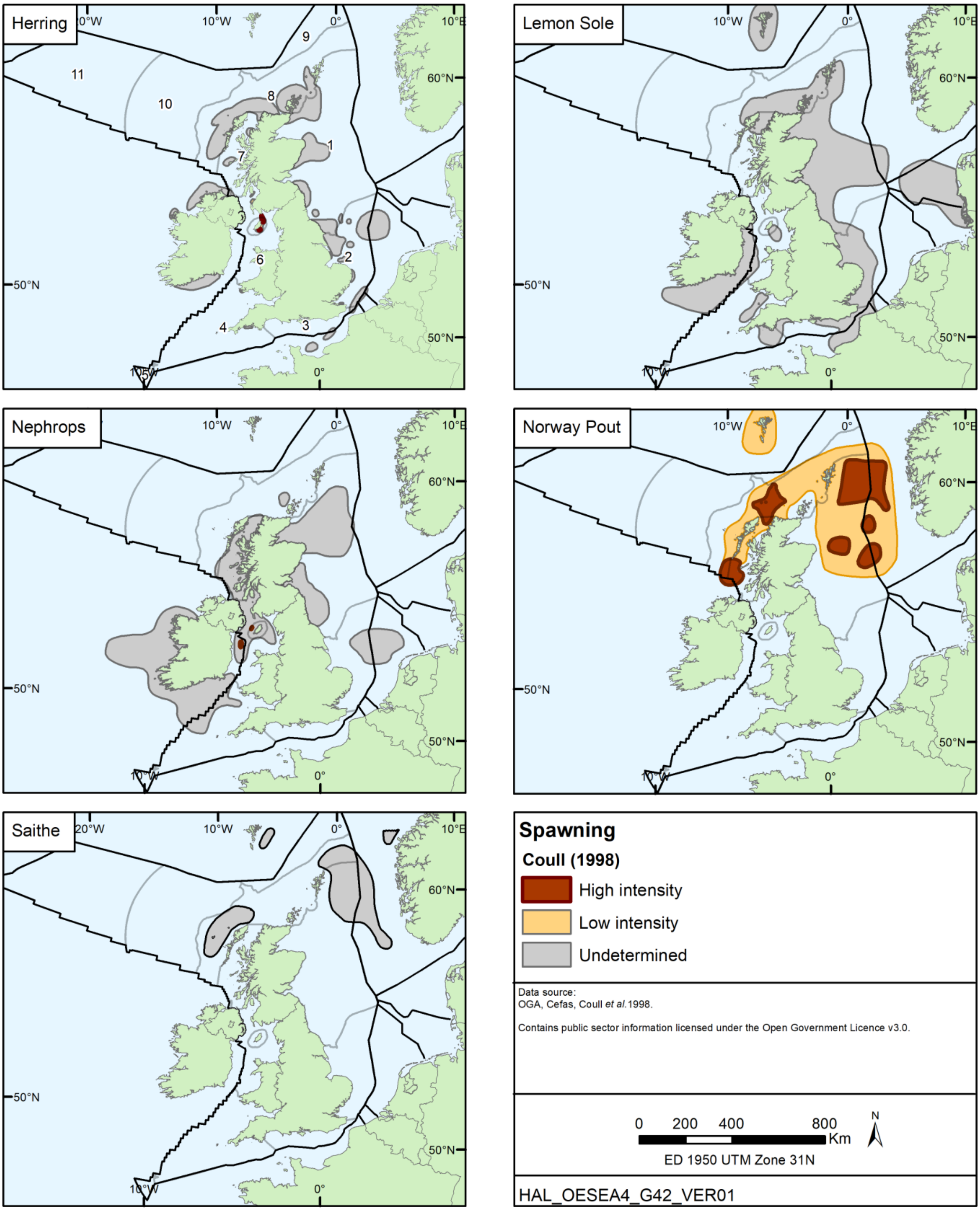


Figure A1a.5.6: UK spawning grounds

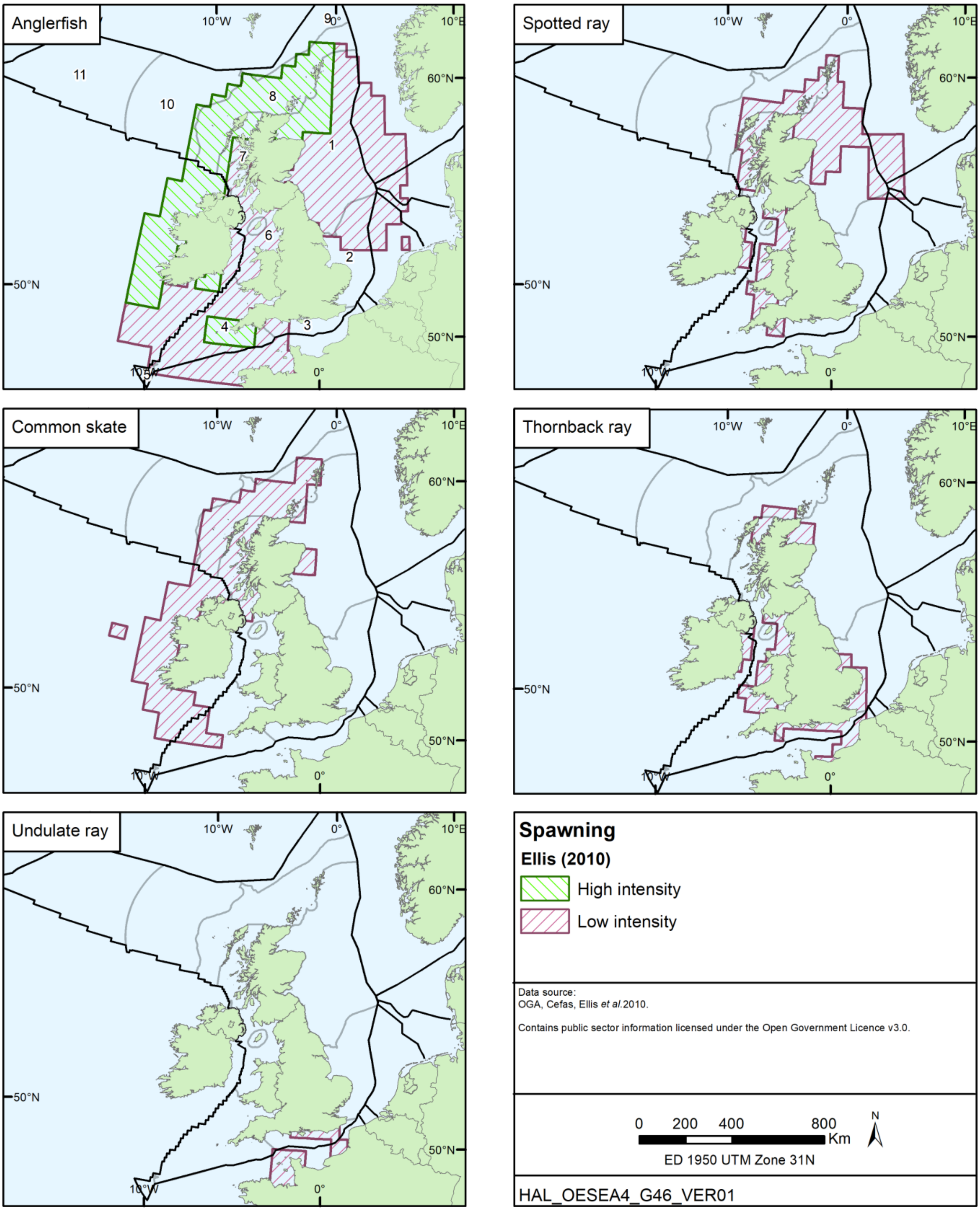


Figure A1a.5.7: UK nursery grounds

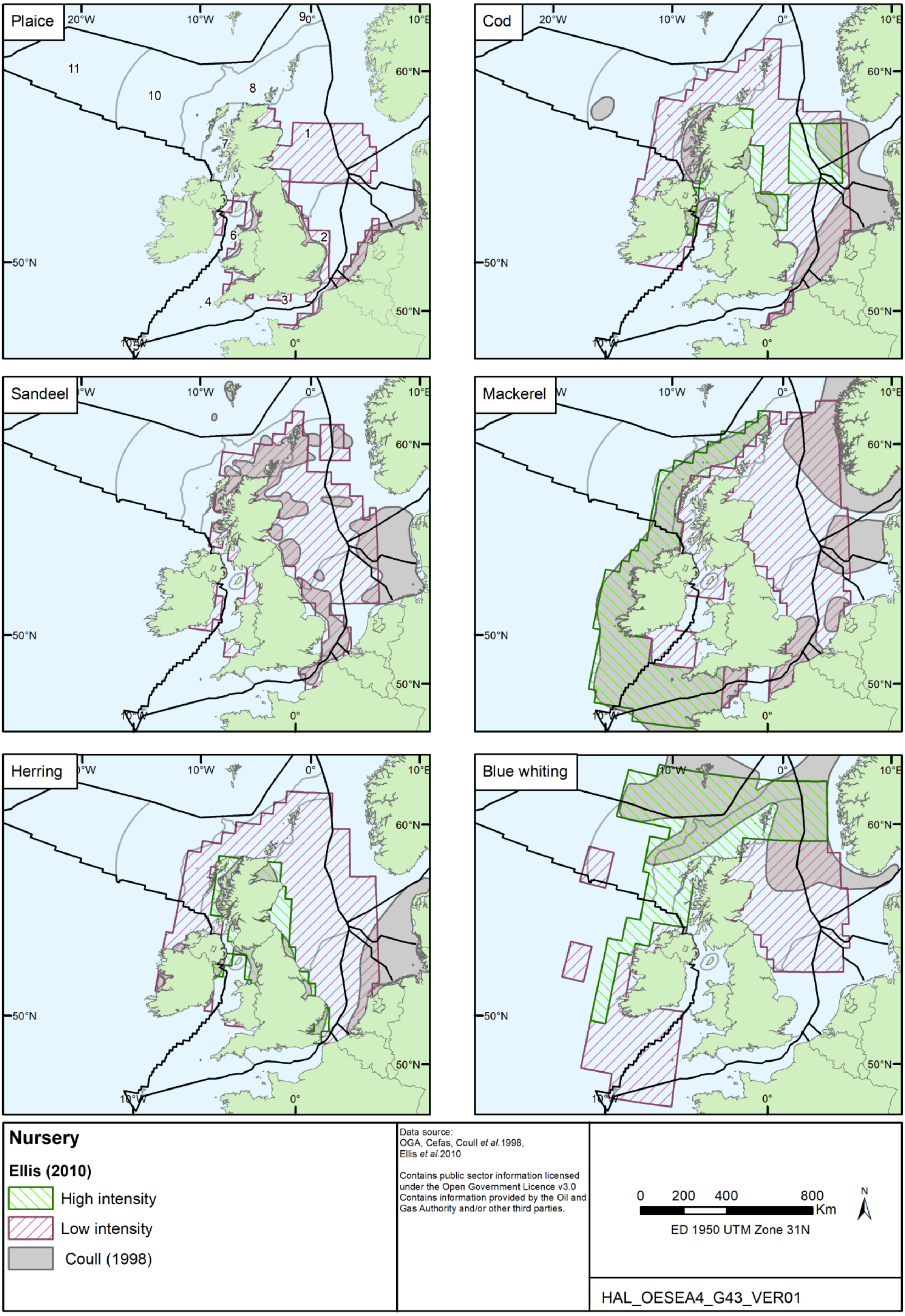


Figure A1a.5.8: UK nursery grounds

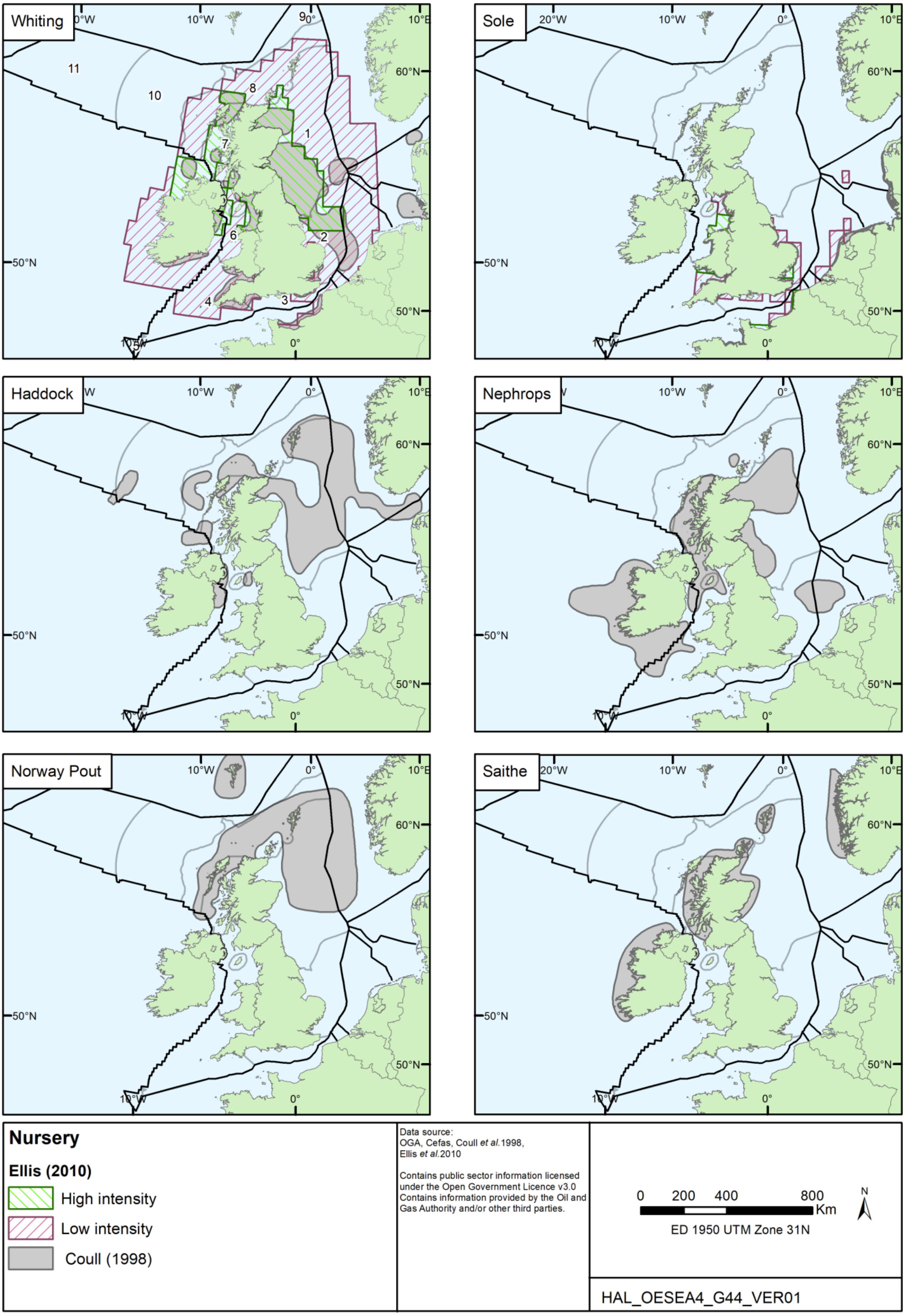
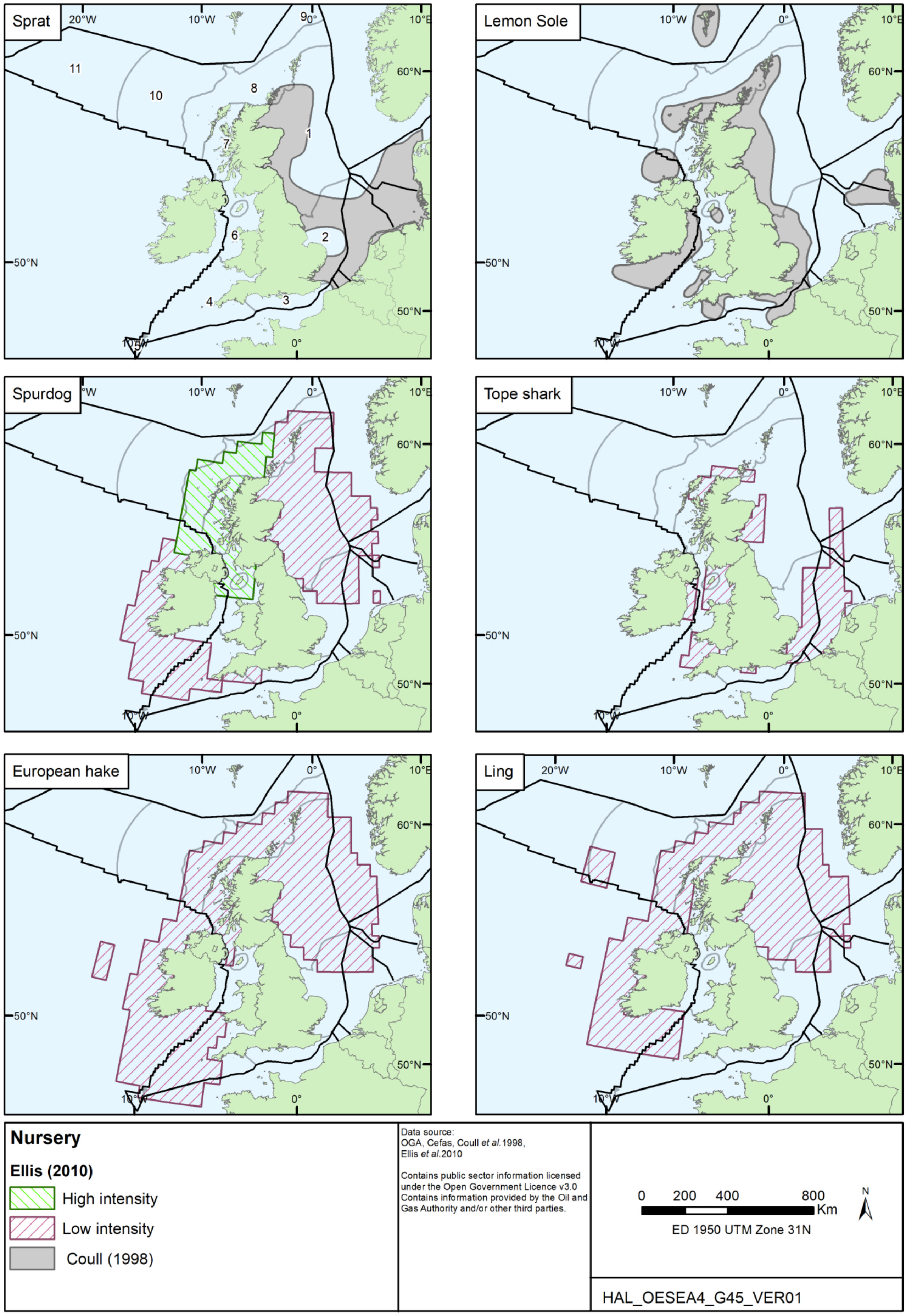


Figure A1a.5.9: UK nursery grounds



A1a.4.2 Features of Regional Sea 1

A1a.4.2.1 Fish community

The northern North Sea is an ecosystem characterised by oceanic inflows from the Norwegian Sea and Atlantic Ocean and by seasonal stratification in the water column. Species diversity within the fish community is not as great in the central and northern North Sea as in the southern North Sea, with the exception of some areas of the Scottish coast (Callaway *et al.* 2002). The highest richness of northerly species is found in waters off the north-east of Scotland, including Orkney and Shetland (Daan 2006). Statistical analyses of North Sea fish assemblages using data collected in groundfish surveys (Callaway *et al.* 2002, Reiss *et al.* 2010) found that the 50m depth contour that separates the southern North Sea from the central and northern regions acts as a conspicuous boundary between different fish assemblages. Within the northern North Sea, a number of assemblages were identified, with divisions typically occurring at the 100m depth contour. At depths between 50-100m, the benthic community was dominated by dab and long rough dab. Of species more loosely associated with the seabed, haddock, whiting, herring and plaice were dominant. At depths of between 100-200m, the community was characterised by long rough dab, hagfish (*Myxine glutinosa*) and Norway pout. In the deepest areas of the region, below 200m, assemblages were notable for the low abundances of demersal fish and the prevalence of silvery pout (*Gadiculus argenteus*).

A1a.4.2.2 Pelagic species

In the North Sea, there are thought to be three sub-populations of herring which spawn at different times, although the complex migratory behaviour of herring makes the population structure difficult to define. These groups are mixed for the majority of the year but migrate to different spawning grounds during the breeding season (Daan *et al.* 1990), although fidelity to particular spawning sites may not be absolute (Slotte & Fiksen 2000). One of these populations is of importance in the northern North Sea - Buchan / Shetland herring, which spawns off the north-east coasts of Scotland and Shetland in August and September (Coull *et al.* 1998, Ellis *et al.* 2012). Juveniles migrate into nursery grounds in coastal areas such as the Moray Firth and the Firth of Forth. North Sea mackerel overwinter in deep water to the east and north of Shetland, before migrating south to spawn between May and August (Coull *et al.* 1998, Ellis & Heessen 2015a). Spawning may take place as far south as the Dogger Bank and following spawning, North Sea mackerel will mix with immigrant western stock mackerel in northern North Sea feeding grounds, before returning to over-wintering sites (Lockwood 1988). Juvenile fish remain in nursery areas in the shallow waters of the Southern Bight (Coull *et al.* 1998). Other pelagic species abundant in the region include sprat, which spawns over a wide area of the region within the summer months and the argentines, typically found in deeper waters.

A1a.4.2.3 Demersal species

Many of the larger, more commercially valuable gadoid species are abundant in the deeper waters of the central and northern North Sea. Whiting is one of the most numerous and widespread species. Recaptures of tagged whiting and the use of parasitic markers, show that the populations to the north and south of the Dogger Bank form separate populations (Hislop & MacKenzie 1976, Tobin *et al.* 2010). Whiting is one of the major predators of commercially important fish stocks in the North Sea (Barreto & Bailey 2015). In the region, major spawning areas are found north of the Dogger Bank and east of Scotland and the spawning season extends from February to June (Coull *et al.* 1998, Ellis *et al.* 2012). Much of the North Sea acts as a nursery ground for <1 year old whiting within the pelagic phase, particularly around the east coasts of Scotland and England (Coull *et al.* 1998, Ellis *et al.* 2012). Analysis of size-class indicate that larger whiting (>20cm length) are more abundant in waters to the east of

Shetland and Orkney than smaller fish, which tend to congregate in inshore areas such as the Moray Firth and northeast England (Hislop *et al.* 2015). Haddock is found throughout the northern North Sea, where spawning takes place during spring between Shetland and the Norwegian Deep (Coull *et al.* 1998), before adults disperse west and into the central North Sea to feed (Albert 1994). During the summer months, the density of juveniles is greatest off the north-east coast of Scotland, although once haddock have reached a size of 4-8cm, they adopt a demersal way of life and distributions of juveniles and adults overlap almost completely (Hislop *et al.* 2015).

Cod are more abundant in the northern North Sea than in the southern North Sea (a trend that has become increasingly distinct over recent decades (Hislop *et al.* 2015)) and there are a number of spawning sites in the region (Coull *et al.* 1998, Ellis *et al.* 2012), with significant larval abundance off the north coast of Scotland and in the Moray Firth (Edwards *et al.* 2011). Nursery areas are most extensive in the eastern North Sea, but the Firth of Forth and other coastal, shallow areas in the north-western North Sea act as important nurseries in the region (Coull *et al.* 1998, Gibb *et al.* 2007, Hislop *et al.* 2015). Tagging experiments have shown that there is a limited exchange of individuals between the northern North Sea and waters to the west of Scotland, although migrations are generally limited to 200 miles (Rogers & Stocks 2001). Analysis suggests that genetic differentiation of North Sea cod is greatest between those living at depths >100m and those in shallower areas (Heath *et al.* 2014). Analysis of size-class indicates that larger cod (>25cm) are abundant both along the coasts of Scotland and north-east England and in deeper, offshore waters, east of Shetland, while smaller cod are more restricted to coastal areas, both in the east and west of the North Sea (Hislop *et al.* 2015). Young saithe migrate into coastal waters of the north of Scotland, Orkney and Shetland, where they remain for 3-4 years, before recruiting to stocks in the northern North Sea (Newton 1984). Abundances are greatest in the deeper waters north of the 100m contour (Hislop *et al.* 2015). There are extensive spawning and nursery grounds for the species in the region. Other large gadoids that are abundant in the region include pollack and ling (*Molva molva*).

Small gadoid species include Norway pout and silvery pout. Norway pout is a small, commercially valuable species of particular importance to the industrial fleet. It is found throughout the central and northern North Sea, typically at depths of between 80-200m. Fish mature at 1-2 years and spawning takes place between January and April on the continental shelf and slightly later in deeper waters. No specific spawning sites have been identified and it is believed that the activity is widely dispersed. Silvery pout is a shelf edge species, commonly found at between 200-500m. They are small, short-lived, benthopelagic fish which spawn from mid-winter to spring. A number of flatfish are present in the region, including plaice (although juveniles are largely restricted to sheltered coastal waters (Goldsmith *et al.* 2015)), lemon sole, dab and witch (*Glyptocephalus cynoglossus*). Monkfish are widely distributed across the northern and central North Sea. Spawning is thought to take place in deeper waters and the presence of nursery sites in shallow waters around Shetland has been proposed (Laurenson *et al.* 2008), although juveniles are widely distributed around the North Sea (Ellis *et al.* 2012).

Hagfish are a very primitive group of fish, eel-like and lacking true jaws. They are remarkable for their ability to produce large quantities of mucus. The species is widely distributed throughout the northern North Sea usually in depths greater than 50m (and more abundant in deeper waters), where they favour muddy sediments in which they can bury themselves (Kloppmann 2015b). They are scavengers of dead and dying fish that have sunk to the seabed, but will also feed on benthic invertebrates (Shelton 1978). Very little is known about their life history, although it is thought that there may be 3 annual spawning events (Grant 2006), during which females produce a small number of large eggs.

Grey gurnards are a dominant demersal species in the North Sea, having undergone a substantial population increase in recent years (Sell & Heessen 2015). They are most abundant in the central North Sea, to the north of the Dogger Bank during winter, their distribution spreading eastwards over summer (Sell & Heessen 2015). In the North Sea, they tend to live at depths of between 70-100m although they may move in surface or pelagic waters both during spawning and at night (Sell & Heessen 2015). Predation on juvenile gadoids by large gurnards may be a contributing factor slowing the population recovery of cod and whiting in the North Sea (Floeter *et al.* 2005).

A1a.4.2.4 Elasmobranchs

The most abundant sharks found in the northern North Sea are the lesser and greater spotted dogfish, spurdog and the tope. The starry ray is the most abundant skate, mainly found in the northern and central North Sea, between 50m and 100m depth (Ellis *et al.* 2015). The cuckoo ray has an abundance hotspot off the Aberdeenshire coast (Ellis *et al.* 2015). Dogfish show a wide but patchy distribution in the North Sea. Sightings of other species, such as the common skate, basking shark and porbeagle are rare in the northern North Sea (Rogers & Stocks 2001).

A1a.4.2.5 Diadromous species

The sea lamprey and river lamprey have both been recorded in the region. Although once an important fishery, lampreys are now rarely caught in large numbers. Several rivers in the region have a high concentration of salmon. In particular, the Rivers Spey, Tweed and Dee support large salmon populations. Sea trout are also present but are more abundant on the west coast. Estimates of silver eel biomass for Scotland indicate that eel stocks appear in relatively good condition, with the estimated silver eel biomass escaping to the sea to spawn in 2018 representing 66% of baseline (1960-1979) estimates. There are no commercial eel fisheries in Scotland (ICES 2019a).

A1a.4.2.6 Shellfish

The soft, sandy sediments of the Fladen Ground provide an important habitat for *Nephrops* and *P. borealis*. These species are also found over soft sediments around the Farne Deeps, while important populations of *Nephrops* also exist in the Firth of Forth and the Moray Firth (Lee & Ramster 1981). Scallop grounds may be found along the northern coast of the Moray Firth (Mason 1983). Cockles are particularly abundant in the Firth of Forth and at Findhorn Bay and the Culbin Bars in the Moray Firth (Chapman 2004), while mussels are harvested from the Dornoch Firth. Brown crabs, green and velvet crabs are widespread in coastal waters of the region, as are whelks and periwinkles.

A1a.4.3 Features of Regional Sea 2

A1a.4.3.1 Fish community

The southern North Sea is a dynamic ecosystem characterised by a sandy, flat, shallow seabed and considerable tidal mixing. Species diversity within the fish community is greater in the southern North Sea than in the central or northern North Sea (Callaway *et al.* 2002) and within the southern North Sea, fish diversity is greatest in the west (Rogers *et al.* 1998). Callaway *et al.* (2002) found that the southern North Sea is characterised by a high abundance of small demersal species (in 2014, fish in the region >40cm made up 6% of total weight (Defra 2015)), typically found closely associated with the seabed, including solenette (*Buglossidium luteum*), dab and common dragonet. Of species more loosely associated with the seabed, three distinct assemblages were identified in the region. The two most extensive of these could be characterised by whiting, grey gurnard, horse mackerel and dab. The third assemblage, located in the far south of the region, was characterised by high numbers of horse mackerel and mackerel. Reiss *et al.* (2010) identified whiting, dab, plaice, grey gurnard, and lesser weever (*Echiichthys vipera*) as characteristic demersal species in the southern North Sea.

Meanwhile, Corten & van de Kamp (1996) identified twelve, "southern," species within the North Sea either as those with a greater abundance in the southern North Sea during summer than during winter, or as those with a distribution restricted to the southern North Sea. These species were: poor cod, bib, red mullet (*Mullus surmuletus*), sardine (*Sardina pilchardus*), lesser weever, anchovy (*Engraulis encrasicolus*), tub gurnard (*Chelidonichthys lucerna*), John Dory (*Zeus faber*), bass, black sea bream (*Spondyliosoma cantharus*), horse mackerel and mackerel. Other common species in the southern North Sea include pogge or hooknose (*Agonus cataphractus*), flounder (*Platichthys flesus*) and sand gobies (*Pomatoschistus minutus*) (Cefas 2007).

A1a.4.3.2 Pelagic species

There are two main herring populations of importance in the southern North Sea: Dogger Bank, or Banks, herring, which spawns from August to September or October; and Southern Bight or Downs herring which spawns from November to January in the Southern Bight of the North Sea and the Eastern English Channel (Coull *et al.* 1998, Ellis *et al.* 2012), after which pelagic larvae will drift towards important nursery grounds such as the Humber Estuary, Thames Estuary and the Wash. There is also a small spring-spawning stock of herring that spawns within the Thames Estuary (Ellis *et al.* 2012). North Sea mackerel overwinter in deep water to the east and north of Shetland, before migrating south to spawn between May and August (Coull *et al.* 1998, Ellis *et al.* 2012). Catch rates of mackerel in the southern North Sea are much greater in summer and autumn than in winter and spring (Ellis & Heessen 2015a). Spawning may take place in waters as far south as the Dogger Bank and juvenile fish remain in nursery areas in the shallow waters of the Southern Bight (Coull *et al.* 1998), although Ellis & Heessen (2015a) report catch rates of small (<22cm) mackerel are much lower in the southern North Sea than larger mackerel, suggesting most juveniles move away from the area.

Sprat are most abundant in the shallow waters of the southern North Sea. Spawning takes place along the east coast of England from May to August with a peak during May and June (Coull *et al.* 1998). Nursery grounds are found around the Southern Bight and Dogger Bank and sprat mature to spawn for the first time at the age of two years. Other clupeids found in the southern North Sea include anchovies (spawn from April to August) and sardines (spawn from June to August). Horse mackerel around the UK are split into two stocks; a western stock and a North Sea stock. The North Sea stock spends most of the year in the central North Sea, Skagerrak and Kattegat, but migrates to the southern North Sea in the summer to spawn (Ellis 2015a). After spawning in the Southern Bight, horse mackerel will generally disperse to the north-east, although later in the year, they will tend to migrate west to over-winter in the warmer waters of the Channel and Celtic Sea (Ellis 2015a).

A1a.4.3.3 Demersal species

Small gadoid species, including poor cod and bib, are typical of the southern North Sea community. In general, poor cod is found in coastal waters at depths of between 25-300m, where they feed on a range of small crustaceans and fish. The species spawns in winter at depths of between 50-100m. Bib tends to congregate in large schools around reefs and wrecks. They spawn in shallow waters, between March and April.

The Southern Bight is a major spawning area for whiting. Much of the southern North Sea acts as a nursery ground for <1 year old whiting while in the pelagic phase, particularly around the mouth of the Thames and on the Dogger Bank (Coull *et al.* 1998). Cod are more abundant in the northern North Sea, but the southern North Sea remains an important area for spawning, with the main spawning season extending from January to April (Coull *et al.* 1998). The south-east North Sea acts as an important nursery ground for 1 and 2 year old cod. Righton *et al.* (2007) showed that there is a significant level of migration of cod from the southern North Sea northwards in spring and summer, although no migration was apparent between the southern North Sea and the English Channel. They also noticed behavioural differences (the use of tidal stream transport in migrations by southern North Sea cod was not commonly observed in English Channel cod) between cod stocks in the region, suggesting different selection pressures may exist in the two areas.

Flatfish of particular importance in the region include solenette and dab, plaice, sole and lemon sole. Plaice is found in greatest abundance in the southern North Sea. Plaice spawn throughout the shallower parts of the southern North Sea, including the Dogger Bank and the Southern Bight, with spawning taking place between December and March (Goldsmith *et al.* 2015). Sandy, shallow bays on the coasts of England and continental Europe act as important nursery grounds for plaice, with juveniles moving further offshore as they mature. While large (>15cm) plaice are widespread and abundant over the southern North Sea, smaller, juvenile plaice are largely restricted to the south and east of the Dogger Bank, with the French and Dutch coasts having the greatest densities (Goldsmith *et al.* 2015).

The sole is close to the northern limits of its distribution in the southern North Sea and is confined to areas where temperatures do not fall below 5°C for prolonged periods (Horwood 1993). Consequently, during cold winters, dense aggregations of sole are known to accumulate in deeper, warmer waters, and will congregate in seabed pits and holes such as Silver Pit, where they become an easy target for fishermen (Rijnsdorp *et al.* 2015). Sole spawn in shallow, inshore areas and sandbanks between March and May. Major spawning grounds include the Thames Estuary and the Norfolk Banks (Coull *et al.* 1998, Ellis *et al.* 2012). Larvae are pelagic for approximately one month, after which they metamorphose into the demersal phase. As a result, local abundances of <1 year old sole are likely to reflect the spawning success of local spawning aggregations (van Beek *et al.* 1989). Nursery grounds are situated in coastal waters shallower than 20m (Rijnsdorp *et al.* 2015).

A1a.4.3.4 Elasmobranchs

The most abundant sharks found in the southern North Sea are the lesser and greater spotted dogfish and tope (a summer visitor). The outer Thames Estuary and the Wash are important areas for a number of ray species, including thornback rays, adults of which migrate into the Thames Estuary to breed in summer (Walker *et al.* 1997). Sightings of other species, such as the common skate, basking shark and porbeagle are rare in the southern North Sea (Rogers & Stocks 2001).

A1a.4.3.5 Diadromous species

Estimates of silver eel biomass for relevant management units (Humber, Anglia and Thames) indicate that eel stocks appear relatively low, with 2016 estimated silver eel biomass currently escaping to sea to spawn representing 3 (Humber), 6 (Thames) and 20% (Anglia) of baseline (1983-1986) estimates. Significant reductions in stock status have been recorded in the Humber and Thames EMUs since 2015, dropping from 31% and 20%, respectively. In part, these reductions were due to large (*ca*. two thirds) decreases in observed yellow eel densities and hence in silver eel equivalent biomass estimates (ICES 2019a). There are small commercial fisheries, primarily for yellow eel in each of the EMUs. The sea lamprey and river lamprey are rare in the region, although they once comprised an important fishery in the rivers of south-east England. The allis and twait shad are present in the Thames Estuary and catches at sea are most commonly reported along the eastern English coast (Dickey-Collas *et al.* 2015). The Atlantic salmon and sea trout are most abundant around the northern and western coasts of the UK but are also present in the southern North Sea. Large numbers of sea trout are found off the north coast of Norfolk, feeding on sprat and sandeels, prior to returning to their home rivers in north-east England (Aprahamian & Robson 1998).

A1a.4.3.6 Shellfish

The main site for *Nephrops* is present to the north and west of the shallow Dogger Bank, while pink and brown shrimp are abundant in the Wash and the Thames and Humber Estuaries. The east coast of England is a site of particularly intense spawning by brown crab (Rogers & Stocks 2001) but they are found throughout the region. Large populations of cockles are found in the Wash and the Thames Estuary. Mussels are abundant in the Wash, as are wild and cultivated oysters along the Essex and Kent coast (Rogers & Stocks 2001). Whelks and periwinkles are widespread in the region. Razor clams, including the introduced species *Ensis directus* as well as native species, are abundant in the Wash and locally elsewhere.

A1a.4.4 Features of Regional Sea 3

A1a.4.4.1 Fish community

The English Channel acts as a biogeographical boundary between the western waters and the North Sea for many species but is also an important migration route for others (Defra 2005). The region supports a similar fish community to the southern North Sea and many species, such as plaice, migrate between the regions (Arnold & Metcalfe 1996). While much of the region is shallow with fine sediment on the seabed, some central areas such as the Dover Straits are deeper with coarser sediment and significant tidal streams (Kaiser *et al.* 1999). These habitats support a high diversity of invertebrates which in turn support small gadoids such as bib and poor cod, along with demersal species such as thickback sole (*Microchirus variegatus*) and red gurnard (Defra 2005). Vaz *et al.* (2007) found the region to be strongly spatially structured. The lower temperatures and salinities in coastal areas favour bentho-demersal species (which particularly dominate when the autumn is cool and wet), while further offshore, or in warmer winters, pelagic species (horse mackerel) and demersal species (red mullet) tend to dominate the assemblage.

The seahorses *H. hippocampus* and *H. guttulatus* are most abundant in the English Channel (Defra 2005). Both species are on the IUCN red list (classified as data deficient).

A1a.4.4.2 Pelagic species

Mackerel is a seasonal visitor to the region, as the western spawning stock migrates eastward through the English Channel into nursery and feeding grounds in the southern and central North Sea over the summer months (Ellis & Heessen 2015a). The Channel represents the southern limit of the herring population and they are most abundant in the eastern Channel and along the French coast (Dickey-Collas *et al.* 2015), where they occupy summer and spring feeding grounds, although there is no major nursery or spawning ground in the region. Horse mackerel are abundant further offshore. Sprat are common in winter particularly in Lyme Bay and between Portland Bill and the Isle of Wight (Pawson & Robson 1998).

A1a.4.4.3 Demersal species

Of the gadoids, whiting and cod are common, with important spawning regions off east Sussex. Haddock and saithe are not common in the region, while other gadoids such as ling and pollack can be found around reefs and rocky outcrops (Pawson & Robson 1998).

Plaice and dab are the most abundant flatfish in the region, with important winter spawning taking place in the centre of the Channel (Goldsmith *et al.* 2015). Some of the North Sea population spawns in the English Channel (Houghton & Harding 1976). Dab spawn between January and June and they, along with sole, migrate to coastal nursery waters before moving into deeper waters as they grow. Lemon sole, flounder, turbot (*Psetta maxima*) and brill (*Scophthalmus rhombus*) are also found in the English Channel. Flounder nursery sites may be found in riverine and estuarine areas. Solenette, common dragonet and lesser weever fish are also abundant in the region (Kaiser *et al.* 1999).

In UK waters, black sea-bream are mainly found in the Channel, where they overwinter in the offshore western Channel before moving eastwards in spring to spawn and spend summer at coastal feeding grounds (Heessen 2015b). Striped red mullet are also most abundant in the Channel, where they spawn in summer, and along the European coastline (Heessen 2015c). Bass are most commonly reported along the Channel and the southern North Sea. Juvenile fish congregate in inshore waters but disperse into a range of inshore and offshore habitats as they mature (Jennings & Ellis 2015).

Seahorses are found along the seagrasses of the southern English coast often in sheltered areas such as Poole Harbour or the Solent. Studland Bay is an important site for the two species typically found in UK waters with the long-snouted seahorse *H. guttulatus* a protected feature of the Studland Bay MCZ designated in 2019. The population at Studland Bay is subject of a long-running tagging and monitoring project run by the Seahorse Trust, as part of the British Seahorse Survey. This work has confirmed that seahorse populations along the south coast are resident, rather than migrating visitors from across the Channel (The Seahorse Trust 2012).

A1a.4.4.4 Elasmobranchs

The thornback ray, starry smooth-hound (*Mustelus asterias*) (Farrell *et al.* 2015) and lesser and greater spotted dogfish are present in the eastern English Channel. The distinctive undulate ray is abundant along the southern coast and around the Isle of Wight (Ellis *et al.* 2015). The basking shark is not common in this region, although is occasionally sighted in waters around the Isle of Wight (Swaby & Potts 1998) or the Hurd Deep, near the Channel Islands (Solandt & Chassin 2014).

A1a.4.4.5 Diadromous species

There are no major salmon rivers in the region, although the Rivers Ouse and Rother are important for sea trout. Estimates of silver eel biomass for the south east management unit indicate that eel stocks appeared to be in relatively good condition in 2016, achieving the 40% escapement target (from the Eels Regulations (England and Wales) 2009) compared to baseline (1983-1986) estimates (ICES 2019a). Sea lampreys are not abundant in the region (Swaby & Potts 1998).

A1a.4.4.6 Shellfish

Substantial scallop grounds are found along the coast of this region (Mason 1983). Cockles, mussels, periwinkles and whelks are all present at shorelines. Crabs and lobsters are abundant on rocky ground in the region, with brown crabs typically found further offshore than lobsters. The Solent supports a healthy population of native oysters (*Ostrea edulis*).

A1a.4.5 Features of Regional Seas 4 & 5

A1a.4.5.1 Fish community

The Western Approaches may be split into three main regions: the western English Channel, the Celtic Sea and the Bristol Channel. The fish communities of these regions are influenced by the Atlantic Ocean and warm water pelagic species are occasionally reported in the area (Stebbing *et al.* 2002).

The western English Channel is deeper than the eastern Channel, with a steep shelving seabed, leading to the open sea. Consequently, the fish community is significantly different from that found further east. Monkfish and cuckoo rays, which are virtually absent from the eastern Channel, are relatively abundant in the western Channel (Ellis & Velasco 2015, Ellis *et al.* 2015). The high number of wrecks and reefs in the region provide habitats for pollack and conger eels (*Conger conger*). In the Celtic Sea, offshore species become increasingly abundant with depth, and species such as hake (*Merluccius merluccius*), megrim (*Lepidorhombus whiffiagonis*), long rough dab, blue whiting and boarfish (*Capros aper*) are common (Warnes & Jones 1995). The Bristol Channel contains a number of important spawning and nursery grounds, such as Carmarthen Bay where a number of juvenile rays and flatfish mature (Ellis *et al.* 2012). Large numbers of the smalleyed ray are present in the Bristol Channel (Ellis *et al.* 2015).

A1a.4.5.2 Pelagic species

Mackerel is abundant at the shelf edge. Over winter they migrate into coastal waters off Cornwall, with the area acting as an important feeding ground (Ellis & Heessen 2015a). Herring are locally abundant, particularly in the Bristol Channel (Dickey-Collas *et al.* 2015) with a limited amount of spring spawning taking place to the south of Cornwall and Pembrokeshire (Coull *et al.* 1998). The western English Channel is notable for the populations of sardine and horse mackerel, which are abundant in the region. Horse mackerel is very abundant throughout the year in the waters along the southern coast of Cornwall, spawning along the western shelf edge (Ellis 2015a), while sardines spawn to the south of the Scilly Isles and Land's End in spring and early summer (Pawson 1995). Summer spawning sprat migrate inshore over the winter months. Argentines are also present in the region, particularly in the Bristol Channel (Heessen 2015a). Atlantic bluefin tuna appear to have returned to the English Channel, seasonally between August and December, after a period of prolonged absence (Horton *et al*. 2021).

The enormous and peculiar ocean sunfish (*Mola mola*) is often observed basking at the surface off the coasts of Cornwall and Pembrokeshire, where they feed on jellyfish, fish larvae and other plankton.

A1a.4.5.3 Demersal species

Cod are numerous in the region, thought to move inshore over winter after spending summer feeding around deep water reefs and wrecks (Pawson 1995). Aggregations of spawning cod form in spring off Trevose Head and to the south of Cornwall. Whiting are also abundant in inshore areas and spawn in similar locations to cod, while pollack and saithe are locally abundant, particularly around reefs and rocky outcrops. Haddock are relatively rare in the region, although more common in the northern part of the Celtic Sea, while hake may be found in the deeper waters of the region. The area around the Cornish peninsula acts as an important nursery ground for ling (Pawson 1995, Ellis *et al.* 2012). Poor cod and bib are also present.

Plaice and dab are the most commercially important flatfish in the region, although sole and lemon sole are also common. All these species spawn in the area, although the spawning periods are staggered throughout the year, perhaps avoiding competition (plaice from December to March, sole from March to May, lemon sole from April to September). These flatfish tend to move into deeper waters as they mature, with relatively little movement along the coast taking place. Sole is most abundant in the Bristol Channel and tends to be confined to areas with high sea bottom temperatures (Rijnsdorp *et al.* 2015).

Bass are abundant in inshore areas from spring as they migrate from warmer waters offshore. Bass spawn in the region from March to May and estuaries in the region, such as the Severn, act as important nurseries for juveniles. It is thought that the strongest recruitment takes place when the sea temperature is warmest at this time of year (Pawson *et al.* 2007). Sandeels are present throughout the region, and other species commonly found include sea bream, John Dory, red mullet, gurnards, conger eel and various wrasse. Rocklings, boarfish, greater pipefish (*Syngnathus acus*), pogge, butterfish (*Pholis gunnellus*), blennies and dragonets have been recorded in trawl surveys in this region.

A1a.4.5.4 Elasmobranchs

A number of ray species are present in the region, including the thornback ray and the cuckoo ray as well as the smalleyed ray and spotted ray (which are both locally abundant in the Bristol Channel) (Ellis *et al.* 2015). The thornback ray spawns in shallow bays around the region. Spurdogs, starry smooth-hounds and lesser and greater spotted dogfish may also be found. High catches of juvenile porbeagles in the Bristol Channel suggest this may be a nursery for the sharks (Bendall *et al.* 2013). Oceanic sharks such as blue sharks (*Prionace glauca*), thresher shark (*Alopias vulpinus*) and mako (*Isurus oxyrinchus*) sharks make occasional, seasonal visits to the region. The Cornish coast is an area where basking sharks are particularly common, with numerous sightings reported annually in the summer months (Solandt & Chassin 2014).

A1a.4.5.5 Diadromous species

Salmon and sea trout are present in many rivers in the region, particularly along the south coast of Wales and are regularly caught in trawls in the Bristol Channel (Heessen & Daan 2015). The Bristol Channel is a particularly important region for shads and lampreys. The Rivers Severn, Usk, Wye and Tywi are the last four rivers in the UK known to contain spawning populations of twaite shad, and the allis shad is regularly recorded in the Severn Estuary, with the Tamar Estuary home to one of only two known UK spawning populations (DECC 2010, Maitland & Hatton-Ellis 2003). Estimates of silver eel biomass for relevant management units (south west and Severn) indicate that eel stocks appear relatively low, with estimated silver eel biomass escaping to sea to spawn in 2016 representing just 0.6% (south west) and 9% (Severn) of baseline (1977-1990 for south west and 1983 for Severn) estimates. Glass eel fisheries are prosecuted by hand-held dipnets, in rivers and estuaries draining into the Bristol Channel, in particular from the Rivers Severn and Wye (Severn) and Parrett (South west). There are also small yellow and silver eel fisheries in the south west (ICES 2019a).

A1a.4.5.6 Shellfish

Offshore *Nephrops* grounds exist in the Celtic Sea, to the south of Ireland. Scallops (and to a lesser extent, queen scallops) are abundant on sandy sediments along the coasts of Dorset, Devon and Cornwall and also south Wales (Mason 1983). Brown crabs, green crabs, velvet crabs and lobsters are all abundant in the region, while the spider crab, a species with a south-westerly distribution in UK waters (Clark 1986), is particularly abundant in the region. The Severn Estuary, and particularly the Burry Inlet and Carmarthen Bay, provide important grounds for cockles, whelks and razor clams. Crawfish are more abundant off the extreme south-west of England and Wales than many other parts of the UK.

A1a.4.6 Features of Regional Sea 6

A1a.4.6.1 Fish community

Beam trawl surveys of the fish community of the Irish Sea identified three distinct categories of demersal fish (Defra 2005). Sandy, inshore areas are dominated by flatfish species, including plaice, solenette, sole and dab and other bentho-demersal fish such as the tub gurnard, lesser weever fish, dragonets and gobies. The offshore assemblage is characterised by species such as thickback sole, lemon sole and red gurnard as well as by elasmobranchs such as the greater spotted dogfish and the cuckoo and spotted rays (*Raja montagui*). The third grouping is found over muddy sediments found to the west of the Isle of Man and is characterised by the presence of witch and long rough dab. Otter trawl surveys reveal a distinction between western and eastern inshore fish assemblages in the region, with haddock, Norway pout and various clupeid species all more abundant in the west.

A1a.4.6.2 Pelagic species

Mackerel is present in the region, but there is little spawning or nursery activity in the region with the greatest abundances following the edges of the continental slope along the west coast of Ireland (Ellis *et al.* 2012). Herring is the most important pelagic stock in the Irish Sea, with particularly large abundance around the Isle of Man and Pembrokeshire. Spawning grounds are present to the east and to the north of the Isle of Man (late summer/autumn spawning) and off the Pembrokeshire coast near Milford Haven (spring spawning), with juvenile fish entering nursery grounds along the English and Irish coasts (Coull *et al.* 1998, Ellis *et al.* 2012). The Clyde Estuary also supports a spring spawning population. Sprat are widely distributed throughout the region, spawning over a wide area between May and August (Dickey-Collas *et al.* 2015).

A1a.4.6.3 Demersal species

Cod are widely distributed throughout the region in the summer, particularly in the deep water off the coast of Cumbria. Spawning grounds are situated in this area and to the west of the Isle of Man, with an important nursery ground located between the Isle of Man and the coast of Ireland. Whiting is abundant and widely distributed, particularly around coastal areas, while haddock, ling, pollack and saithe are found around wrecks and rocky reefs. Haddock are found in greatest numbers in the deeper waters to the west of the region. Important spawning grounds for whiting exist off the west of England and in Cardigan Bay, between February and June (Parker-Humphreys 2004, Ellis *et al*, 2012).

Important flatfish in the Irish Sea include plaice, sole and dab, which are found over sandy areas of the seabed. Spawning areas for these species exist in coastal areas in the east of the region, such as within Cardigan Bay. Lemon sole can be found in deeper offshore areas. Bass and grey mullet are seasonally abundant inshore, with abundance decreasing further north. Sandeels are widely distributed throughout the region and juvenile and some adult monkfish may also be found in coastal waters.

Other demersal species common in the Irish Sea include the poor cod, abundant in the deeper central waters, dragonets and lesser weevers which are particularly abundant in the shallow waters of Liverpool Bay, as well as coastal species such as grey and red gurnards, the thickback sole and the solenette (Parker-Humphreys 2004).

A1a.4.6.4 Elasmobranchs

There are a number of sharks and rays present in the region. Lesser and greater spotted dogfish, tope, cuckoo rays, thornback rays and spotted rays are all present, particularly around the north Wales coast and in deeper offshore regions. Anglesey and the Lleyn peninsula is an area of particular abundance for the greater spotted dogfish, with large numbers of egg cases washed up on local beaches (Defra 2005, Ellis 2015c). Cardigan Bay is a probable nursery site for thornback rays (Ellis *et al.* 2015). The basking shark is often observed in the region, particularly to the south and west of the Isle of Man (Dolton *et al.* 2020), but also off the Pembrokeshire coastline. Satellite tracking reveals the Irish Sea to be an important migration route for basking sharks between the west of Scotland, the Isle of Man and south-west England (Witt *et al.* 2016), with Dolton *et al.* (2020) also identifying inter-annual site fidelity to the Irish Sea and the Isle of Man, specifically.

A1a.4.6.5 Diadromous species

Sea trout is abundant in Welsh and other rivers, while sea lamprey, allis and twaite shads and smelt (*Osmerus eperlanus*) have all been recorded in the Dee estuary. The Solway Firth contains one of only two known spawning populations of allis shad in the UK (DECC 2010). Atlantic salmon is also present in various parts of the region (Potts & Swaby 1995). Four principal salmon rivers drain into Liverpool Bay (Clwyd, Conwy, Dee and Ribble), while the Mersey also supports a small population of salmon (Dong Energy 2013). Estimates of silver eel biomass for relevant management units (Wales, Dee, north west and Solway-Tweed) indicate that eel stocks appear relatively low, with estimated silver eel biomass escaping to sea to spawn in 2016 representing between 2 (north west) to 7% (Wales) of baseline (1977-1990, 1984 for Dee) estimates. There are small glass, yellow and silver eel fisheries in the management units (ICES 2019a).

A1a.4.6.6 Shellfish

Nephrops is found in the soft sediments to the east and west of the Isle of Man as well as in the Firth of Clyde. The Irish Sea is an important region for scallops and queen scallops, with large grounds in Cardigan Bay, around the Isle of Man, the Solway Firth, Morecambe Bay and around islands in the Firth of Clyde. Cockles and oysters are also abundant throughout the region, particularly in the Solway Firth. Lobsters and brown crabs are abundant, particularly on the rocky shores of north Wales and the Lleyn Peninsula, while spider crabs are also present in the region (Clarke 1986). Whelks are also abundant in places, including around the Isle of Man and off the north Wales coast.

A1a.4.7 Features of Regional Sea 7

A1a.4.7.1 Fish community

The Minch and the firths along the west coast provide important sheltered, inshore nursery grounds for many species, with maerl beds an important habitat for large numbers of juvenile gadoids (Bailey *et al.* 2011). The fish assemblage in this region is comprised mainly of the gadoids haddock, hake and whiting and Norway pout as well as small pelagic species such as sprat (Gordon 1981). There is a high diversity of small bentho-demersal species including flatfish, gobies and blennies in the shallow, warm waters and sheltered sea lochs (Potts & Swaby 1997).

A1a.4.7.2 Pelagic species

A small number of mackerel migrate into the Minch after spawning in the autumn, although a change in the normal migration route in the 1980s has led to the western stock increasingly moving into the northern North Sea and the Norwegian Sea instead (Ellis & Heessen 2015a).

Spent herring migrate into the Minch in winter following spawning. A number of spawning cohorts exist to the west of Scotland, with spawning taking place to the south-east of the Outer Hebrides, to the west of the Hebrides and to the north of Skye from August to September and again in the latter two sites in March and April. Larvae from the west coast spawning populations may be carried into the North Sea, mixing the stocks (Dickey-Collas *et al.* 2015). Sprat is very common in winter in the Minch. Sprat spawn over the summer and juveniles use the sea lochs and firths of the coastline as nursery areas (De Silva 1973).

A1a.4.7.3 Demersal species

Cod spawn to the north of the region in the early months of the year with peak activity in February. Whiting and Norway pout also spawn in the region. The Minch is an important nursery ground for juvenile gadoids, including cod, whiting, saithe, haddock and Norway pout. Haddock are widespread in the area throughout the year.

Plaice, lemon sole and sandeels use the region as spawning and nursery grounds and are present throughout the year. Other demersal species abundant in the region include bib, cuckoo wrasse (*Labrus mixtus*), common dragonet, butterfish, bullrout, pogge, topknot (*Zeugopterus punctatus*) and red and grey gurnards. A number of gobies and blennies, at the northern edges of their distributions, inhabit the lochs of the region, including the tompot blenny (*Parablennius gattorugine*), black goby (*Gobius niger*) and butterfly blenny (*Blennius ocellaris*) which are more typically found in waters to the south-west of the UK (Ellis & Rogers 2015, Ellis 2015d). The leopard spotted goby (*Thorogobius ephippiatus*) and Fries' goby (*Leseurigobius friesii*), reportedly rare in most UK waters, are frequently recorded in the sheltered sea lochs of the region. The former is a shy species that is rarely caught by remote methods, and is almost certainly not as rare as once thought. It is regularly observed by divers by its preferred habitat of small crevices or fissures (MacDougall 2002).

A1a.4.7.4 Elasmobranchs

The lesser spotted dogfish (but rarely the greater spotted dogfish), spurdog, common skate, cuckoo ray, nursehound (*Scyliorhinus stellaris*) and thornback ray have all been recorded in the Minch. The coastal waters of the west of Scotland are notable for the high abundance of basking sharks, particularly in the summer (Robson 1997). The areas around Hyskier, Coll and Tyree were identified as, "hotspots," by Witt *et al.* (2012), with satellite tracking revealing that individual sharks stayed close to the islands over the summers of 2012, 2013 and 2014 (Witt *et al.* 2016, Doherty *et al.* 2017a, see also Rudd *et al*. 2021). The Sea of the Hebrides has been identified as a possible MPA with basking sharks, one of the protected features. Based on a collation of existing data sources, key areas within the site in which basking sharks are expected to occur and where they are considered to be more vulnerable to vessel collisions and disturbance have been identified. Two options have been drafted for consideration as basking shark awareness zones to inform discussions on site advice and management, one incorporating a larger area (3,290km^2 compared to 1,300km^2), but both incorporating waters around Coll and Tiree (Witt *et al.* 2019).

A1a.4.7.5 Diadromous species

Sea trout and salmon are abundant in the rivers and lochs of this region. Important lochs for these species include Loch Ewe, Loch Morar, Loch Shiel and Loch Lochy. As indicated for Regional Sea 1, Scottish eel stocks appear to be in relatively good condition. The twaite shad and allis shad have also been recorded in the region (Robson 1997).

A1a.4.7.6 Shellfish

The waters of the Minch provide important habitats for *Nephrops*. The seabed in the region is soft and muddy and the species can be found in greatest abundance from the west of Skye to the Stanton Bank, between Islay and Jura and along the Kintyre Peninsula (Chapman 2006). *Nephrops* may also be found in the sea lochs around the coast of the mainland. Two species of shrimp are abundant in the region, *P. montagui* and the similar *Dichelopandalus bonnieri* (which typically has a more western distribution (Lee & Ramster 1981)). Scallops and queen scallops are abundant in sandy areas around the islands. Lobsters are present in greatest numbers around rocky areas of the coasts of the Hebridean Islands, while brown crabs are common throughout the region (Chapman 2006). Cockles are present, although individual cockle beds in the region are not large (Chapman 2006). Razor clams, whelks, periwinkles and velvet crabs are also abundant in the region and crawfish are present.

A1a.4.8 Features of Regional Sea 8

A1a.4.8.1 Fish community

The Scottish continental shelf is an ecosystem characterised by oceanic inflows from the Atlantic Ocean, such as the warm continental shelf current. The water is generally deeper than areas closer to the coast and the shelf edge is located at a depth of 300-450m. To the west of the Hebrides and around the north coast of Scotland, haddock, whiting, Norway pout, poor cod and grey gurnards dominate the assemblage. In deeper water along the shelf edge silvery pout, bluemouth (*Helicolenus dactylopterus*) and the hollowsnout rattail (*Caelorinchus caelorhincus*) are key members of the community (Pinnegar *et al.* 2010).

A1a.4.8.2 Pelagic species

Large numbers of mackerel move northwards along the continental shelf edge towards the northern North Sea in spring, having overwintered to the south-west of the UK. Consequently, this region is an area of mixing between the western and North Sea mackerel stocks with mackerel originating from both regions (Ellis & Heessen 2015a). Limited spawning takes place around Shetland and Orkney during the summer feeding migration, but the majority of the stock goes past the islands to feed in the deep waters at the shelf edge to the north-west of Shetland (Gordon 2006). However, during the return trip in autumn, most of the stock passes around Shetland. The western mackerel stock spawns from March to July in waters to the west of the Hebrides (Coull *et al.* 1998). Herring is locally abundant in the region, particularly when feeding in summer and autumn, and also around Orkney and to the south-west of Shetland during the late summer spawning period (Gordon 2006). To the west of the Hebrides, spawning takes place from March to April and again in late summer (Coull *et al.* 1998). Sprat is abundant with spawning occurring around the west and north coasts of the mainland. In some years, sprat is present around the coast of Shetland during migration, but their presence is irregular and unpredictable (Lee & Ramster 1981). Blue whiting is very abundant in deep waters to the north of Orkney in February, and spawning takes place between February and April along the continental slope to the west of Scotland at depths of 300-600m (Gordon 2006). After spawning, fish disperse to the North and Norwegian Seas to feed (Gordon 2006). Juvenile blue whiting remain on the nursery grounds for 2-4 years before returning to spawn (Gordon 2006). Argentines are abundant along the edge of the coastal shelf (Heessen 2015a).

A1a.4.8.3 Demersal species

Cod, haddock and whiting are all abundant in the region, with cod widely distributed off Orkney in the summer and whiting abundant in inshore waters. Spawning areas for these species exist to the west and north of the Hebrides and in the case of whiting, to the west of Shetland. Ling, pollack and saithe are also present, with saithe particularly abundant around Shetland.

Norway pout is abundant in offshore regions and spawns around the shelf from January to April and further offshore a few months later (Defra 2005).

Plaice, dab and long rough dab are abundant in areas of sandy seabed, while megrim and witch are more abundant in the deeper waters of this region than elsewhere. Megrim is particularly abundant to the north-west of Orkney. The main area for witch in the North Sea is to the east of Orkney. Halibut (*Hippoglossus hippoglossus*), which are rare elsewhere, are frequently found off the coast of Shetland. Flounders spawn offshore in late winter. Monkfish and gurnards are also abundant in the area, with juvenile monkfish and non-spawning adults found in inshore regions of Orkney and Shetland. Sandeels are common in sandy areas across the region. A number of cold water species such as Vahl's eelpout (*Lycodes vahlii*), Esmark's eelpout (*Lycodes esmarkii*) and the wolf-fish (*Anarhichas lupus*) are present in the northern parts of the region (Pinnegar *et al.* 2010).

A1a.4.8.4 Elasmobranchs

The spurdog, lesser spotted dogfish, thornback ray and cuckoo ray are all abundant in the region. Common skate are locally abundant within certain sea lochs (Pinnegar *et al.* 2010). Porbeagle sharks are found along the edge of the continental shelf (Bendall *et al.* 2013), and genetic studies suggest they migrate south in the winter. They have been recorded, on occasion, as far out to sea as the oceanic ridge (Pade *et al.* 2009), and have been reported to gather south of Sumburgh Head in Shetland to give birth (Swaby & Potts 1997). The basking shark is frequently observed throughout this region, particularly west of the Hebrides (e.g. Doherty *et al.* 2017b) and to the west of Shetland (Hayes *et al.* 2018). The common skate, listed as, "critically endangered," on the IUCN Red List, is relatively abundant in northern parts of the Scottish continental shelf, particularly around Shetland. In 2015, a rarely encountered false catshark (*Pseudotriakis microdon*) (colloquially, the sofa shark) was found off the Hebrides during a demersal survey, a reminder that open ocean and deep-sea fish may occasionally venture into waters near the coast.

A1a.4.8.5 Diadromous species

There are few rivers in the region to support populations of salmon. Lochs such as the Loch of Spiggie in Shetland, contain sea trout, while eels can be found in the small rivers of Orkney and the Hebrides.

A1a.4.8.6 Shellfish

The most important shellfish species on the Scottish continental shelf and slope is *Nephrops*, which is found on suitable sediments across the region down to depths of 600m (Chapman 2006). The shrimps *P. montagui* and *D. bonnieri* are also abundant. Lobsters and brown and velvet crabs are present in coastal regions, including the east of the Hebrides, the north of Scotland, Orkney and Shetland. Cockles, mussels and whelks are abundant around the coasts of Orkney and Shetland (Chapman 2006).

A1a.4.9 Features of Regional Seas 9, 10 & 11

A1a.4.9.1 Fish community

These Regional Seas may largely be characterised as offshore, deep water regions and consequently the fish assemblages found here are quite different from those of other regions. Many of the key pelagic and demersal species from Regional Sea 8 are still found in these regions, but there are fewer small, coastal species and a community of deep water species. This section will therefore concentrate on the deep water communities. The regions within this area can broadly be characterised as: Faroe-Shetland Channel (Regional Sea 9); Rockall

Trough; and Rockall Bank and Plateau (Regional Sea 10). Regional Sea 11 comprises the Atlantic north-west approaches, where the water depth exceeds 1,000m. Deep-water fish tend to be slow-growing and long-lived. They often have a high age of maturation and the sparsity of life in the deep sea requires adult fish to aggregate at certain sites, usually seamounts, to spawn.

The Faroe-Shetland Channel is separated from the deep shelf edge waters to the west of Scotland by the Wyville Thomson Ridge, which rises to a depth of approximately 500m. This separation means that the fish communities on either side of it are quite distinct, particularly below 500m (Gordon 2001). At this depth, the water of the Faroe-Shetland Channel is cold and comprised mainly of Norwegian water, while to the west, water is of warmer Atlantic origin. The continental slope margin of the Faroe-Shetland Channel may be divided into three zones: an upper slope, the transition zone and the deep Norwegian Sea zone (Bullough *et al.* 1998).

A1a.4.9.2 Pelagic species

Blue whiting and mackerel may pass through the Faroe-Shetland Channel when migrating south to reach spawning grounds (Pinnegar *et al.* 2010). Herring are unlikely to be found in these deep seas, which are out of reach of their spawning grounds. They are also notably absent from the Rockall Bank (Dickey-Collas *et al.* 2015). Argentines, in contrast, aggregate at the Rockall Bank (Heessen 2015a).

Little is known about mesopelagic species. Some of these species can be very abundant and it is thought that the dominant fish species to the west of the UK are the light-emitting lantern-fish (*Notoscopelus kroyeri*) and the pearlside (*Maurolicus muelleri*) (Pinnegar *et al.* 2010, Kloppmann & Ellis 2015). The snipe-eel (*Nemichthys scolopaceus*) and the dragonfish (*Melanostomias bathyphilus*) are sometimes reported in mid-water surveys, while large ocean wanderers such as the dealfish (*Trachipterus arcticus*) and the oarfish (*Regalecus glesne*), the longest bony fish in the world, are occasionally washed up on UK coasts (Pinnegar *et al.* 2010).

A1a.4.9.3 Demersal species

Within the Faroe-Shetland Channel, the upper slope zone lies approximately between 200-500m depth and is characterised by Atlantic water with temperatures similar to those of the west coast. The dominant species found in this region are rabbitfish (*Chimaera monstrosa*), Norway redfish (*Sebastes viviparus*), bluemouth and blue whiting (Gordon & Swan 1997, cited by Gordon 2006). A similar community can be found at similar depths in Regional Seas 10 and 11, although redfish (*Sebastes* spp.) are less abundant to the west of the Hebrides (Gordon 2003).

The transition zone was identified by Bullough *et al.* (1998) and defined as the area of the slope where the bottom temperature changes rapidly with depth at the transition between the warm Atlantic water and the cold Norwegian Sea water. The main species identified by Bullough *et al.* (1998) were the Greenland halibut (*Reinhardtius hippoglossoides*) and roughhead grenadier (*Macrourus berglax*) (which are associated with cold water overflows (Gordon 2003)) along with blue ling (*Molva dypterygia*), tusk (*Brosme brosme*), two species of redfish (*S. marinus* and *S. mentella*) and the Arctic skate (*Amblyraja hyperborea*). This assemblage is quite diverse and similar to that of the Norwegian continental shelf margin. A number of these species, such as the Greenland halibut and the roughhead grenadier, are rare to the west of the Wyville Thomson Ridge (Gordon 2003). Analysis of the results of MAFF (Ministry of Agriculture, Fisheries and Food) surveys carried out in the mid 1970s (Gordon and Swan 1997, cited by Gordon 2006) suggests that the transition zone in the Faroe-Shetland Channel occurs approximately between 625-785m depth.

The deep Norwegian Sea Water lies below the transition zone and is an area of low biomass and diversity. In surveys carried out by the Scottish Association for Marine Science (SAMS) in 1996 at depths of between 1,060m and 1,520m, a number of species of eelpout were identified as well as the Greenland halibut and Arctic skate.

Over 120 demersal fish species have been identified on the continental slopes to the west of Scotland below 400m depth (Gordon *et al.* 1994). There is no evidence of zonation in the fish assemblage in deep waters to the west of Scotland, such as is seen in the Faroe-Shetland Channel. The slope is characterised by a gradual decrease in temperature with depth and as each species occupies its own, highly variable, depth range, there is also a gradual change in the fish fauna with depth (Gordon 2003). Four distinct communities of demersal fish were identified by visual and trawl surveys of the Rosemary Bank (Eerkes-Medrano *et al.* 2020). On the summit (330-700m depth), the most common species were rabbitfish, greater argentine (*Argentinus silus*), Atlantic codling (*Lepidion eques*) and beaked redfish (*Sebastes mentella*). Mid-slope (700-1,100m) catches were dominated by Baird's smoothead (*Alepocepahlus bairdi*), black scabbard (*Aphanopus carbo*), roundnose grenadier (*Coryphaenoides rupestris*), blue ling and mora (*Mora moro*). Much fewer trawls were made on the deep slope (1,100-1,500m), but catches were dominated by Baird's smoothead, roundnose grenadier and orange roughy (*Hoplostethus atlanticus*). Spear-snout grenadiers (*Caelorhinchus labiatus* and *Trachyrhincus murrayi*) were also common. Catches were low in the deep moat (1,900-2,150m) and dominated by Gunther's grenadier (*Coryphaenoides guentheri*), the Mediteranean grenadier (*Coryphaenoides mediterraneus*) and Agassiz's smoothhead (*Alepocephalus agassizi*). Two species of chimaerids were also recorded (*Hydrolagus affinis* and *H. pallidus*) (Eerkes-Medrano *et al.* 2020).

Within the Rockall Trough, the dominant species at 250m depth are silvery pout, bluemouth and blue whiting, while in deeper waters a variety of morid cod (*Lepidion guentheri*), grenadiers, arrowtooth (or cut-throat) eels and deep water sharks dominate (Gordon & Bergstad 1992).

The Rockall Bank maintains a demersal fish community not dissimilar from that of the continental shelf, with the assemblage dominated by blue whiting, poor cod, Norway redfish, haddock and grey gurnard (Pinnegar *et al.* 2010). Other large gadoids on the Rockall Bank include cod, saithe, whiting and ling (Hislop *et al.* 2015). Flatfish include megrim (Velasco *et al.* 2015), witch, long-rough dab and lemon sole (Goldsmith *et al.* 2015). Monkfish (Ellis & Velasco 2015) and snake pipefish (Daan 2015b) are also common at the Rockall Bank.

A1a.4.9.4 Elasmobranchs

The Arctic skate is a key feature of the assemblage in the Faroe-Shetland Channel. There is a greater abundance of elasmobranchs to the west of Scotland than in the Faroe Shetland Channel with deepwater sharks such as the leafscale gulper shark (*Centrophorus squamosus*) and the blackmouth dogfish (*Galeus melastomus*) present (Gordon *et al* 1994). The velvet belly (*Etmopterus spinax*), a lantern shark that uses light producing cells in its stomach as camouflage against the ocean surface, is sometimes caught in demersal hauls in the deep waters of the Rockall Plateau (Ellis & Heessen 2015b). On the Rockall Bank, thornback rays, common skate and the black-mouth dogfish are present (Ellis *et al.* 2015, Ellis 2015c). The mid-Atlantic skate (*Rajella kukujevi*) and the little gulper shark (*Centrophorus uyato*) have been caught on longlines in the Rockall Trough in recent years (Pinnegar *et al.* 2010). On the Rosemary Bank, common elasmobranch species on the mid-slope (700-1,100m) included the bird-beak dogfish (*Deania calcea*), the long-nose velvet dogfish (*Centroscymnus crepidater*) and the leafscale gulper shark (*Centrophorus squamosus*). Down slope (1,100-1,500m), black dogfish (*Centroscyllium fabricii*), pale ghost catshark (*Apristurus aphyodes*) and the greater lantern shark (*Etmopterus princeps*) were found, with smalleye catshark (*Apristurus microps*) and the large deepwater skates *Bathyraja richardsoni* and *Amblyraja jenseni* found in the deep moat around the seamount (1,900-2,150m) (Eerkes-Medrano *et al.* 2020).

A1a.4.9.5 Diadromous species

The area is distant from the coast and so diadromous species will only occur on migration and are unlikely to be encountered.

A1a.4.9.6 Shellfish

Although most of the species considered in this baseline tend to have a largely coastal, shallow water distribution, the Rockall Bank supports a range of crustacean and mollusc species and *Nephrops* may be found. The deep-sea red crab (*Chaecon affinis*) which inhabits seamounts thoughout the east Atlantic is present in greatest numbers at depths between 600-900m and is targeted in fisheries in the region.

A1a.4.10 Evolution of the baseline

Recent research has suggested that there have been substantial changes in the fish communities in the north-east Atlantic over several decades. These communities consist of species that have complex interactions with one another and the natural environment. Fish species will undergo natural variation in population size, largely as a result of year to year variation in recruitment success. These population trends will be influenced by human exploitation and broad-scale climatic and hydrological variations.

A1a.4.10.1 Climate

Climate change may influence fish distribution and abundance through affecting growth rates, recruitment rates, behaviour, survival and responses to changes at other trophic levels, although exact responses are very difficult to predict. This could have a major effect on the community structure of the region.

An analysis of 50 species around the UK demonstrated that 70% changed distribution and abundance in response to warming between 1980 and 2008, with three-quarters of these species increasing in abundance (Simpson *et al.* 2011). Alheit & Hagen (1997) analysed data on herring and sardine landings at ports around the English Channel and southern North Sea dating back to the 10th Century. They found that large landings of herring were correlated with cold winter weather, while warm winters lead to large catches of sardine. Perry *et al.* (2005) showed marked changes in the distributions of North Sea fish over the past 25 years with the distributions of two-thirds of species having shifted in mean latitude. They found a northwards shift in the southern or northern population boundaries of a number of species had occurred. The northern boundary of bib, a southern North Sea species, was shown to have moved northwards by 342km between 1978 and 2001. Based on the projected SST increases of Hulme *et al.* (2002), Perry *et al.* (2005) predicted that the bib population may extend over the entire North Sea by 2080, while blue whiting may have retracted from the region by 2050. Drinkwater (2005) predicts that cod stocks in the Celtic and Irish Seas will have disappeared by 2100 as a result of temperature and hydrodynamic changes. Studies have shown that anchovy, which were absent from the North Sea until the mid 1990s, have extended their distribution as far north as the west coast of Norway (Brander *et al.* 2003, Alheit *et al.* 2012). A similar expansion of the distribution of southern species was reported by Baudron *et al.* (2020) following analysis of 30 years (1985-2015) worth of scientific bottom surveys data covering UK and waters to the south. Their analysis suggested an overall increase in the area occupied by southern species accompanied by a dramatic northward expansion occurring in the northern part of the study area, especially for subtropical species (such as anchovy and sardine). This accords with a global analysis of abundance trends of 304 widely distributed marine species over the last century, across a range of taxonomic groups from phytoplankton to fish and marine mammals (Hastings *et al.* 2020). Abundance increases were found to be most prominent where sampling had taken place at the poleward side of species ranges, with abundance declines most prominent where sampling had taken place at the equatorward side of species ranges.

Habitat requirements are likely to play a significant role in vulnerability to climate change, with species such as plaice and herring likely to be vulnerable at different stages in their life-cycles (nursery grounds and spawning grounds, respectively (Petitgas *et al.* 2013)). Increasing freshwater temperatures over the past four decades have implications for the survival rates of juvenile diadromous fish, although not necessarily negative ones (Simpson *et al.* 2013). Although salmon populations in Scottish rivers have been declining since the 1990s, partly due to poor growth of juveniles at sea, twaite shad (Aprahamian *et al.* 2010) and sea lamprey (Rodríguez-Muñoz *et al.* 2001) demonstrate increased larval survival at warmer temperatures. Shellfish populations are often strongly tied to particular sediment types and so these too will be vulnerable to climate-induced impacts on their preferred habitat. The settlement of many bivalve species (e.g. cockles, mussels) is dependent on a range of environmental factors (Chapman 2004). As a result, significant changes in the environment may cause low stock recruitment and potentially the disappearance of a species from a ground. Changing environmental conditions may also affect the distributions of migratory crustaceans, such as lobsters and crabs.

Hedger *et al.* (2004) found that North Sea aggregations were present in deeper water in the 1990s than the 1980s, while a study of distribution data from 1980-2004 conducted by Dulvy *et al.* (2008) found that the North Sea demersal fish assemblage had deepened by 3.6m per decade over this time. However, modelling carried out by Rutterford *et al.* (2015) suggests that demersal fish are constrained by the availability of habitat at a suitable depth. Consequently, the capacity of fish to adapt to increasing water temperature by relocating to deeper water may have already been exhausted and little or no further movement to deeper water is possible. Unable to move into deeper, cooler water, fish will be exposed to higher temperatures, with potential physiological and ecological consequences. Evidence of the physiological stresses experienced by cod has been demonstrated by studies of the otoliths (ear bones), which reveal slower growth rates during warmer years (Pilling *et al.* 2007, Millner *et al.* 2011). Sandeels are also unlikely to be able to migrate easily into deeper waters, as they are reliant on a coarse, sandy seabed habitat (Holland *et al.* 2005). Declining recruitment in sandeel populations around northern UK waters is inversely correlated with increasing temperature (Heath *et al.* 2012). Species such as sandeel, a key link between trophic levels in the food web, that are unable to adapt to changing temperatures as a result of specific habitat requirements are likely to be most vulnerable to the effects of climate change. Recent declines in some sandeel sub-populations largely appear related to climate (Wright *et al.* 2020), especially in the north-west North Sea, where much of the area is closed to fishing (Régnier *et al.* 2017, Lindegren *et al.* 2018).

Species richness in the North Sea has increased, with 8 times more species increasing their distributions than have decreased their distributions (Hiddink & ter Hofstede 2008 (see also Simpson *et al.* 2011)). Species richness shows a positive correlation to average bottom temperature (Henderson 2007), and it is predicted that a 2ºC rise in sea bottom temperature would result in an increase in species richness in the Bristol Channel of 10% (Henderson 2007, Henderson & Bird 2010). The increase in species richness, along with an increase in small, southerly species is possibly influenced by the release of predation pressure from large, exploited commercial fish, acting in combination with the changing climate (Hiddink & ter Hofstede 2008). Changes in species composition may mean a change in the community structure. Twelve fish species which were classified as typical southern North Sea species by Corten & van de Kamp (1996) were observed by Beare *et al.* (2004) to have increased in abundance dramatically in the northern North Sea since the mid 1990s. Vaz *et al.* (2007) detected an increase in species diversity in the English Channel community between 1997 and 2002, and sightings of a number of warm water fish such as blue-fin tuna (*Thunnus thynnus*) (e.g. Horton *et al.* 2021), grey triggerfish (*Balistes capriscus*) and large pelagic sharks have increased (Stebbing *et al.* 2002). The distribution range of the short-snouted seahorse seems to be moving northwards from the English Channel and is increasingly recorded in the southern North Sea (Pinnegar *et al.* 2008).

The Celtic and Irish Seas, have seen increases in the distribution and abundance of warm water species such as the John Dory, and species richness increased between 1999 and 2008. In contrast, waters off the west of Scotland saw a reduced number of species over this period (ter Hofstede *et al.* 2010). There is, however, significant spatial variation in these general trends; increases in richness can be observed at smaller spatial scales within the region, for example off the north coast of Ireland (Heath & Speirs 2012). Analysis of trawl survey results from 1986-2008 reveal the Rockall Bank to have been colonised by whiting and the oceanic, southern species Ray's sea bream (*Brama brama*) in recent years (Neat & Campbell 2011). Groundfish assemblages to the west of Scotland were found to show no systematic change in species richness through time (1985-2013), but rather steady change in species composition, leading to an increase in spatial homogenisation; with the species identity of colder northern localities increasingly resembling that of warmer southern localities. This biotic homogenisation mirrored the spatial pattern of unevenly rising ocean temperatures over the same time period suggesting that climate change may be responsible for the spatial homogenisation (Magurran *et al.* 2015). The west coast assemblage also appears to have shown a greater degree of change with respect to the proportion of dominance and the identity of the most dominant species than assemblages on the east coast of Scotland over a similar time period (Moyes & Magurran 2019). On the east coast, which exhibits less temporal variation in identity of the most dominant species, the Norway pout was the overall dominant for around two thirds of the time series with the exception of the initial decade where haddock featured more prominently. In contrast, on the west coast the identities changed from herring in the first decade, to Norway pout in the second and finally mackerel in the third. The authors postulate that these differences may be linked to the different patterns of change in sea surface temperatures between the areas but recognise that temporal variation in sea surface temperatures is unlikely to be the only driver influencing the trends since fishing pressure also leads to marked changes in the structure of marine assemblages (Jackson *et al.* 2001).

Dippner (1997) found a high correlation between SST and variability in the recruitment of cod, whiting and mackerel in the North Sea. A reduction in the survival of cod larvae (and consequently, recruitment) in the North Sea since the mid 1980s has been linked to a change in the copepod community and in particular to the decline of *C. finmarchicus*, an important prey item for larval cod (Beaugrand *et al.* 2003). Similarly, shifts in the *Calanus* species composition linked to climate (see Section A1a.1) has led to a mismatch in timing of the occurrence of the early larval stages of sandeel and food availability, a factor behind recent recruitment failure (van Deurs *et al.* 2009). The large-scale distribution of basking sharks in recent years has been positively correlated with sea temperature, a pattern that may be linked to the distribution of the warm water copepod *C. helgolandicus*, the abundance of which is indicative of shark distribution over small spatial scales (Cotton *et al.* 2005).

A changing climate may affect migration routes of some species. There has been a northerly shift in the mackerel spawning grounds and a change in the timing of adult migration into these grounds with the result that fewer mackerel now pass through the Minch during their migration (Walsh *et al.* 1995). However, recent studies that have also considered depth and geographical attachment suggest that climate is just one of several contributory factors (Hughes *et al.* 2014; Bruge *et al.* 2016, Wright *et al.* 2020). For example, Brunel *et al.* (2018) suggested that the mackerel expansion may also have been related to density-dependence as mackerel used areas of lesser habitat suitability in years when the stock size was large (particularly in 1992 and 2010), although there was no consistent density effect (Wright *et al.* 2020). Flounder has been observed to undertake spawning migrations up to two months earlier in cooler conditions (Sims *et al.* 2004), while the navigation of salmon back to home rivers may be severely affected as it relies on a range of environmental cues, potentially affecting recruitment success (Pinnegar *et al.* 2008). The timing of spawning may also be affected, with Greve *et al.* (2001) noting the earlier appearance of fish larvae in the southern North Sea in recent years. Kjesbu *et al.* (2010) report that temperature increases may act to bring forward the onset of spawning in bass. In addition, female bass have been found not to reach maturity unless they remain in water above 10ºC during maturation (Pawson *et al.* 2000), which may, in part, explain the increased abundance in sea bass in the southern North Sea and Channel although over-fishing and a few cooler winters (in 2009/10 and 2010/11) seem to have halted the expansion of this species (ICES 2018a, Wright *et al.* 2020). Fincham *et al.* (2013) report that four out of seven stocks of sole showed significant long-term trends towards earlier spawning (at a rate of 1.5 weeks per decade), with winter SST significantly affecting the date of peak spawning. In addition, any climate change effects on larval dispersion are currently a major unknown factor (Petitgas *et al.* 2013). Lacroix *et al.* (2018) simulated the possible consequence of a future 2°C warming on spawning, predicting that future warming would lead to earlier spawning and, together with projected wind change, a much greater dispersal distance (+70%) and pelagic larval duration (+22%). Consequently, larval recruitment to nursery grounds was predicted to be affected but with a likely positive impact on recruitment (Lacroix *et al.* 2018, Wright *et al.* 2020). As described in Section A1a.5.2.1, Fässler *et al.* (2011) have demonstrated how the timing of spawning in herring may influence larval dispersal and development.

Lenoir *et al.* (2011) attempted a forecast of the distributions of eight fish species in the north-east Atlantic, using ecological niche modelling with explanatory variables including SST, salinity and bathymetry under various greenhouse gas emission scenarios. The forecast concluded that by 2090 horse mackerel and anchovy would show increased occurrence in northern UK waters, while pollack, sole, haddock and saithe would show a decrease in southern UK waters; turbot and sprat would show no significant change. However, climate change effects on marine fish populations are difficult to predict and the evidence is not easy to interpret. As an example, from 2003, the snake pipefish, previously rare in the region, showed a sudden and dramatic increase in northern European waters, particularly to the west of Scotland and the northern North Sea (Harris *et al.* 2007) and could be found as far north as Svarlbard (Fleischer *et al.* 2007). This sudden expansion had significant impacts on seabird populations as chicks, used to a diet of sandeels, struggled to eat the bony, awkward prey item (Harris *et al.* 2007). Numbers peaked in 2007 and this was considered by many to be indicative of a major marine ecosystem shift in response to climate change. Since 2007, however, catch rates of snake pipefish have dwindled back to their pre-2003 average, with the sudden outburst remaining unexplained (Heath *et al.* 2012, Daan 2015b). A similar situation arose when large catches of bluemouth, generally a rare species in the North Sea were reported near Shetland in 1991, spreading over the entire North Sea within a few years (Heessen & Blasdale 2015). By 1997, however the species had almost completely disappeared again. It is thought that the fish all belonged to a single cohort, perhaps swept into the North Sea by an abnormally large inflow of Atlantic water that year (Mamie *et al.* 2007). These examples serve as a reminder that the factors governing fish distribution and abundance are complicated and interdependent.

There has been a marked increase in research using both empirical (statistical) and mechanistic models to examine the impacts of climate change on marine fish (Wright *et al.* 2020). Predictions from any one approach are subject to uncertainty, including the many detailed aspects of species' ecological and physiological constraints that are still largely unknown (Rijnsdorp *et al.* 2009). However, confidence in projections of changes in fish distribution and productivity can be increased by using an ensemble of these models, that yield more-robust conclusions overall (Wright *et al.* 2020). For example, Fernandes *et al.* (2020) used a dynamic bioclimate envelope model forced by physical–biogeochemical output from eight ocean models to simulate changes in fish abundance and distribution around the UK at scales down to a spatial resolution of 0.5°. When comparing these simulations with annual fish survey data, they found the largest differences at the 0.5° scale, concluding that whilst model results could be used to guide fisheries management at larger spatial scales, more caution was needed at smaller scales.

A1a.4.10.2 Overfishing

Many fish are subject to considerable fishing pressure, which will act to reduce biomass of commercially valuable species and, potentially, non-target species. Fishing may affect the abundance, diversity, size, composition and life-history of fish communities, through the pressure exerted and the selective removal of larger, mature individuals from populations. The impacts of long-term exploitation of a fish stock are typically a decrease in body size, age of maturation and productivity.

Data indicate that the biomass of fish from high trophic levels declined by two thirds in the North Atlantic in the second half of the 20th Century (Christensen *et al.* 2003). Thurstan *et al.* (2010) showed that over 118 years from 1889-2007, the landings per unit of fishing power in the bottom trawl sector fell by 94%, a demonstration of the scale of the decline in demersal fish stocks since the advent of industrial fishing. Anderson *et al.* (2008) and Perry *et al.* (2010) argue that the de-stabilisation of fish stocks caused by heavy fishing leads to increased fluctuations in abundance and therefore increased vulnerability to natural events. This was also illustrated by Lindegren *et al.* (2010) who demonstrated the increased resilience to environmental change of the Atlantic cod in the Sound, the narrow strait separating the North and Baltic Seas, where a trawling ban has been in place since 1932, compared to the neighbouring waters.

Consequently, fishing pressure is likely to enhance the impacts of climate change. Off the south-west of Britain, the pattern generally observed is for warm-water species to have increased in abundance in recent decades. However, Genner *et al.* (2004, 2010) showed that warm-water species of commercial importance, such as skates, rays and brill have declined over the same period. The conclusion drawn from this was that species under fishing pressure may be unable to respond to the more favourable environmental conditions. Modelling carried out by Beggs *et al.* (2013) suggests that cod is more sensitive to climate variability during periods of low spawning stock biomass.

Bailey *et al.* (2009) showed that fish abundance recorded from depths of 800-2,500m in the Porcupine Seabight and Abyssal Plain (south-west of Ireland), has fallen significantly since 1977, possibly as a result of impacts on the species in shallower waters resulting in declines in the deeper parts of the range. These depths are considerably deeper than the maximum depth of commercial fishing (approximately 1,600m), indicating that the effects of fishing extend into deep, un-fished waters, where there is little or no routine monitoring or management. The tendency of deep-sea fish to form spawning aggregations makes them an easy target for trawlers, while their slow growth rates and long life expectancies make them highly vulnerable to over-fishing.

The latest updated assessment towards achieving good environmental status as part of the UK Marine Strategy (Defra 2019) reported that in 2018 demersal fish communities were recovering from over-exploitation in the past, but GES had not yet been achieved in either the Greater North Sea or the Celtic Seas, nor would be achieved for all fish communities by 2020. A partial assessment of pelagic shelf fish did not provide a clear result. Since 2012, the UK has worked to develop new OSPAR-wide indicators for fish communities covering population abundance of sensitive fish species, size structure in fish communities and the mean maximum length of large fish, with Defra (2019) indicating that recovery in the population abundance of sensitive fish species will be used to assess status for the period 2018-2024. With respect to this indicator, fish species with life history traits such as large ultimate body size, slow growth rate, large length and late-age-at-maturity, are particularly sensitive to additional sources of mortality, for example fishing mortality. Populations of such species are known to have declined markedly in abundance through the 20th century, a period of marked expansion in fishing activity. The 2018 assessment of this indicator found that population recovery among a significant number of sensitive fish species was evident in the Celtic Seas, but not in the North Sea. However in both regions, recent trends in the number of sensitive species increasing in abundance suggest an improving situation and further decline in the population abundance of sensitive fish species has been halted[12] (see also OSPAR Intermediate Assessment[13]).

Most (29 of 46) of the North Sea stocks that are assessed by ICES are exploited at rates at or below F_{MSY} (fishing mortality with a given fishing pattern and current environmental conditions that gives the long-term maximum sustainable yield, ICES 2018b). Mean fishing mortality for crustacean, demersal, and benthic fish stock groups have declined since the late 1990s and mean spawning-stock biomass (SSB) for all groups of stocks is above MSY $B_{trigger}$ (if falls below this level of spawning–stock biomass fluctuation when fished at F_{MSY}, triggers a cautious response to reduce fishing mortality to allow a stock to rebuild to levels capable of producing MSY, ICES 2018b). Note that though the mean fishing mortality and biomass ratios are in a desirable condition, this does not infer that all stocks are in that condition. Several North Sea stocks have current fishing mortality rates above F_{MSY} (e.g. cod, whiting, haddock, mackerel, and blue whiting) (ICES 2020b).

The relationship of biomass status or the fishing mortality to reference points is not known for more than 44% of the 103 stocks that are assessed in the Celtic Seas ecoregion. Though only 30% of the stocks are fished below F_{MSY}, these stocks account for nearly 11% of the total landings. There has been a trend of declining fishing mortality since the mid-1990s for the benthic and demersal stocks with known status and the trend for stock size in these stocks has been increasing over the same period. The average F/F_{MSY} ratio for pelagic assessed stocks has been above one in recent years (indicate unsustainable fishing levels) and the average stock size indicator is declining in recent years but remains above MSY $B_{trigger}$ (ICES 2019c).

A1a.4.11 Environmental issues

A1a.4.11.1 Trophic interactions

Fish and shellfish are important components of marine ecosystems, operating at a number of trophic levels. They utilise a variety of feeding strategies, including filter feeding for plankton and detritus suspended in the water column, scavenging for detritus on the seabed, and both pelagic and demersal predation of plankton, small fish, cephalopods, crustaceans and other benthic organisms. Pelagic fish such as mackerel and herring primarily feed on planktonic

[12] https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/fish/abundance/
[13] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/fish-and-food-webs/recovery-sensitive-fish/

crustaceans, other zooplankton and small fish. Demersal fish such as gadoids and flatfish often consume a wide range of benthic invertebrates including crustaceans, polychaetes, molluscs and echinoderms, along with cephalopods and fish. Sandeels main prey is calanoid copepods, but other planktonic prey including fish larvae are also taken; larger individuals may also take benthic prey such as polychaetes. Most benthic crustaceans are scavengers to some extent, feeding on detritus, although many species are also active predators of a variety of benthic organisms. Many molluscs such as scallops, cockles and mussels are filter feeders of material suspended in the water column.

Fish and shellfish play a pivotal role in the transfer of energy from some of the lowest to the highest trophic levels within the ecosystem, and also through the recycling of nutrients from higher levels through the consumption of detritus. Consequently, their populations will be determined by both top-down factors, such as predation, and bottom-up factors, such as ocean climate and plankton abundance. Fish and shellfish are important prey items for top marine predators including elasmobranchs, seabirds, cetaceans and humans, and small planktivorous species such as sandeels and herring act as important links between zooplankton and top predators (Frederiksen *et al.* 2006). The influence that fish abundance can have on predators is best illustrated by sandeels, which have declined in abundance dramatically in recent years, with sandeel landings in the North Sea decreasing by over 50% since 2003 (Frederiksen *et al.* 2006, Lindegren *et al.* 2018). This decline has coincided with a series of breeding failures amongst sandeel-dependent seabirds such as puffins (*Fratercula arctica*) and kittiwakes (*Rissa tridactyla*) (Carroll *et al.* 2017a). Sandeel recruitment and their interactions with higher predators are complex and poorly understood. Further information on the ecological importance of fish and shellfish species to seabirds and marine mammals is provided in Appendices A1a6 and A1a7 respectively.

A1a.4.11.2 Habitat impacts

Many fish and shellfish species are dependent on specific habitats either throughout, or at particular stages of their lives. Herring spawn on coarse sand or gravel, while sandeels live on sandbanks and *Nephrops* require muddy sediments in which they can build burrows. Seahorses and many other cryptic species find refuge in seagrass beds of the south coast, while maerl beds provide sheltered nursery grounds for juvenile gadoids off the west of Scotland. Diadromous fish are dependent on passage through shallow coastal waters, into and up rivers to spawn (or in the opposite direction for eels). Habitat damage through contact with anchors, fishing gear and offshore or nearshore construction can all impact on fish communities.

Stelzenmüller *et al.* (2010) present maps of the sensitivity of 11 fish and shellfish species to aggregate extraction around the southern and western coasts of England and Wales. The maps indicate that the highest sensitivity is typically in coastal regions where spawning and nursery areas are found. The most sensitive species to extraction were scallop, lobster and queen scallop with whiting and plaice the least sensitive. It is estimated that it would take between 2-3 years after a cessation of aggregate extraction for signs of community recovery to show in sandy gravel habitats with moderate wave exposure and tidal currents (Defra 2010).

A1a.4.11.3 Contamination

A significant source of contamination is that of riverine discharge, which may result in toxic algal blooms which can result in fish and shellfish kills and shellfishery closures. Hormonal disruption of flounder through oestrogenic contamination has been observed around UK estuaries (Allen *et al.* 1999). Hormonal disruption through contamination also occurs in gastropod and bivalve shellfish. Female whelks and dog whelks (*Nucella lapillus*) exposed to tributyltin (TBT), an antifoulant used on the hulls of boats until 1987, have been reported to develop male sex organs (Polockzanska & Ansell 1999). This condition, called imposex, can have significant impacts on the reproductive success of a population. Since the ban on the use of TBT, monitoring of dog whelks at sites around Scotland have shown the incidence and severity of cases of imposex to be much reduced (Scottish Government website[14]).

The effects of contamination from oil on demersal fish have been assessed in a number of species both in the field and in the laboratory. A number of indicators of hydrocarbon contamination, such as the activity of certain enzymes in the liver, may be used to investigate this. Within two weeks of the *Sea Empress* spill off the coast of Pembrokeshire, Kirby *et al.* (1999) collected dab and plaice samples from near to the site. They found elevated hepatic enzyme activity, providing evidence of significant levels of hydrocarbon contamination. Aas & Klungsøyr (1998) concluded that cod and haddock were not significantly affected by locally elevated poly-aromatic hydrocarbon (PAH) concentrations surrounding platforms in Norwegian waters. Recent surveys of contaminant concentrations in fish and shellfish from fishing grounds in the Celtic Seas and the Greater North Sea to inform the updated assessment of good environmental status (Defra 2019), confirmed the results from the UK Marine Strategy Initial Assessment in 2012, showing that there had been a high level of compliance with the standards set in European food legislation, and that the UK target had been achieved[15].

As part of the Deepwater Horizon oil spill final damage assessment, the Trustees combined empirical data from numerous field studies and laboratory studies with different modelling analyses, to estimate the scale of impact with respect to fish resources (Section 4, Deepwater Horizon Natural Resource Damage Assessment Trustees 2016). They estimated that exposure to oil in the surface slick and subsurface mixed zone resulted in the death of between 2 and 5 trillion fish larvae, with exposure to oil in the rising cone of oil and in the deep water plume, resulting in the death of between 86 million and 26 billion fish larvae. The Trustees determined that additional injuries occurred, including adverse effects to fish physiology (e.g. impaired reproduction and reduced growth) and adverse effects to reef fish communities (e.g. reductions in abundance and changes in community composition), but these were not quantified. Pasparakis *et al.* (2019) provides a recent review of the physiological impacts of the oil spill on fish.

Micro-plastics in the marine environment may result from the break-down of plastic waste over time, or from specifically manufactured micro-beads or fibres typically found in products such as toothpaste or exfoliants. Analyses of micro-plastics recorded from Continuous Plankton Recorder (CPR) samples indicate that the quantity is increasing over time in the north-east Atlantic (Ostle *et al.* 2019), with greatest concentrations found at the coasts (Edwards *et al.* 2014). It has been demonstrated that micro-plastics may be ingested by zooplankton and will be passed to higher trophic levels by predation on affected zooplankton. Desforges *et al.* (2015) estimated that adult salmon in the north-east Pacific could be ingesting up to 90 particles each day.

There have a been a number of recent evidence reviews at both UK (Defra 2020) and European (SAPEA 2019, Group of Chief Scientific Advisors 2019) level to inform policy on plastic pollution. Defra (2020) indicates that in UK waters, microplastics have been identified in 2.9% of fish larvae and 37% of adult fish sampled from the western English Channel (Steer *et al.* 2017, Lusher *et al.* 2013), 11% of mesopelagic fish sampled from the north east Atlantic (Lusher 2015), and 71-90% of European flounder and 20-83% of European smelt sampled

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[14] http://www.gov.scot/Publications/2011/03/16182005/33
[15] https://moat.cefas.co.uk/pressures-from-human-activities/contaminants-in-seafood/contaminant-concentrations-in-seafood/

from the River Thames (McGoran *et al.* 2017). Steer *et al.* (2017) noted that with distance from the coast, larval fish density increased significantly ($P<0.05$), while waterborne microplastic concentrations ($P<0.01$) and incidence of ingestion decreased. Defra (2020) concludes that while there is evidence for critical life processes that are affected by ingestion of plastic, in a range of marine species, including metabolism, growth, reproduction and behaviour, and mortality; information on the risk to marine populations is missing. Further work is required to determine the bioavailability and effects of fragments and fibres; the relative sensitives of different species and life-stages; better understand the mechanisms by which microplastics cause toxicity, and explore the risk nanoplastics pose to marine life (Defra 2020).

A1a.4.11.4 Noise disturbance

Fish exhibit large variation in their ability to emit and detect sound, dependent on diversity in anatomical features, hearing physiology and behaviour. For example, drumming noises produced by the swimbladder have been found to have an important role in mating of cod, haddock and probably other gadoids (Rowe & Hutchings 2004). Staaterman *et al.* (2014) made the first acoustic recordings of sounds produced by fish larvae (those of the grey snapper (*Lutjanus griseus*)), while the larvae of some coral reef fish and shellfish have been shown to navigate to suitable settling locations on the reef using sound signals (Stanley *et al.* 2012). This suggests that even at this young, under-developed stage, fish are sensitive to acoustic signals in the marine environment. A study conducted by Buscaino *et al.* (2010) exposed European sea bass and gilthead sea bream (*Sparus aurata*) to acoustic stimuli of a frequency typical of vessel traffic, with the noise resulting in increased motility and intense muscle activity in both species.

The primary mechanism through which they hear sounds is the direct detection of particle motion within the inner ear. Among species, there is much variability in the structure of the inner ear anatomy, along with the structure of gas-filled chambers and their distance and connectivity to the inner ear, resulting in a wide range of hearing capabilities. The number of species for which accurate data are available is still small and measuring the hearing abilities for a wider range of species has been recommended as high research priority (Hawkins *et al.* 2015). In particular, field measurements of particle motion are very limited and require greater consideration in order to improve understanding of the effects of sound on fish and other aquatic life (Nedelec *et al.* 2016; Popper & Hawkins 2018).

There have been numerous reviews of the effects of anthropogenic sound on fish; for example: Popper *et al.* (2014), Hawkins *et al.* (2015), Carroll *et al.* (2017b) and, most recently, Slabbekoorn *et al.* (2019). Slabbekoorn *et al.* (2019) note that there are few good case-studies in the peer-reviewed literature that report on the impact of a seismic survey on the behavioural response of free-ranging fish or the direct impact on local fisheries. Existing studies do not yield completely coherent results but suggest that fish could stop foraging and move down in the water column. The paucity of such studies relates in no small part to the complexity of observing free-ranging fish in open water (e.g. Bruce *et al.* 2018).

Studies of caged fish in outside conditions have provided information on physical damage and behavioural responses, although the latter may be affected by the enclosure, prior capture or habituation (e.g. for animals sourced from aquaculture). Evidence suggest that exposure to seismic survey noise or pile driving does not lead to immediate mortality but may lead to hearing damage at high levels, and can induce temporary behavioural changes. These studies generally suffer from a lack of adequate controls and replication, and insufficient data are currently available for dose-response curves. While studies of captive fish in tanks provide a more controlled experimental environment and greater replication, there are numerous limitations in terms of their value in terms of understanding effects of realistic exposures in free-ranging animals (Carroll *et al.* 2017b, Slabbekoorn *et al.* 2019).

A1a.4.11.5 Electromagnetic Field disturbance

Many fish species are able to detect electric and magnetic fields (EMF) and it is a matter of concern that anthropogenic sources of EMF, in particular subsea cables, might be detected by and negatively influence sensitive species. Elasmobranchs possess an electrosensory system called the Ampullae of Lorenzini, an array of receptors that allow them to detect the weak electric fields produced by prey items. Consequently, they are most frequently linked with potential EMF effects.

The primary consideration for EMFs emitted by subsea cables is the magnetic field. In general, the limited field surveys of buried subsea AC and DC cables indicate that they produce fairly weak magnetic fields (<100 μT), which drop to background levels within the immediate environment (<5-10m) of the cable. Current flow through the cable, depth of burial and the configuration of conductors are the key factors determining the intensity of the magnetic field. Research has shown exposure to magnetic fields induces effects and responses of individual species at behavioural, physiological, developmental and genetic levels but in general laboratory exposures do not reflect the intensity of magnetic fields likely in the field.

Available data assessing elasmobranch responses to subsea cable EMFs is limited. The first and only documented example of a marine fish responding to an emission from a subsea cable comes from evidence of shark bites on optical telecommunication cables (Marra 1989). Gill *et al.* (2009) demonstrate that the behaviour of a number of species of elasmobranchs are affected by EMFs from undersea cables. The authors indicated that the effect was only likely to be observed within a very small distance around the cable and it was unclear whether the effect was positive, negative or neutral. More recently, Hutchison *et al.* (2018, 2020) reported on an *in-situ* enclosure experiment with acoustically-tagged little skate *(Leucoraja erinacea*), an electro-sensitive elasmobranch and the commercially-important Amercian lobster *(Homarus americanus)*, thought to potentially have magneto-sensory abilities. Skates were found to travel further at overall slower speeds, with increased large turns while being closer to the seabed, indicative of increased exploratory and/or area restricted foraging behaviour when exposed to EMF. The lobsters exhibited a more subtle behavioural response to EMF in that they were found more frequently in the central space of the treatment enclosure, were closer to the seabed and used more large turns, most likely foraging or in search of burrows (Hutchison *et al.* 2020). For both species the EMF associated with the cable did not constitute a barrier to movements across the cable (Hutchison *et al.* 2018).

Some teleost fish have been demonstrated to be EMF sensitive. Relevant species in UK waters include plaice and the diadromous species European eel, Atlantic salmon, sea trout and river and sea lamprey (Gill & Bartlett 2010). Migratory eels and salmonids are able to use the earth's magnetic field for orientation during migrations (Durif *et al.* 2013) and magnetic field detection has been demonstrated in a range of fish species, notably by Formicki *et al.* (2004), who found a number of species to be more attracted to fyke nets on which a magnet was mounted than to nets with no magnet. A biotelemetry tracking study of Chinook salmon *(Oncorhynchus tshawytscha)* smolts indicated that the proportion that successfully migrated through the San Fransisco Bay before and after installation of subsea cable were not significantly different, and cable activity was not associated with the probability of successfully exiting the system, or crossing the cable location. Fish migration paths moved closer to the cable at some locations, but farther away at others, which was attributed to other higher-intensity magnetic field sources, such as metal bridges (Wyman *et al.* 2018). While there is a range of evidence to support the EMF detection abilities of these fish, and little doubt that highly mobile, migratory species will encounter anthropogenic EMF sources, evidence is limited as to whether such EMFs are likely to provoke a behavioural response (Öhman *et al.* 2007, Gill & Bartlett 2010).

A1a.4.11.6 Conservation frameworks

In addition to fisheries management measures, a number of conservation frameworks apply to fish species within UK waters (see Table A1a.5.2). The *Wildlife and Countryside Act 1981 (as amended)* applies to territorial waters and lists (Schedule 5) several species of marine and estuarine fish which receive protection under the Act. The Act makes it an offence (subject to exceptions) to kill, injure, or otherwise disturb any wild animal listed on the schedule and prohibits interference with places used for shelter or protection by these species. The Act does not apply in Northern Ireland, where the equivalent is the Wildlife (Northern Ireland) Order 1985 (although no marine fish are covered by this Act). European Protected Species (Annex IV species) receive protection via the various UK Habitats Regulations. The 2007 amendments to these Regulations resulted in consequential amendments to the Wildlife and Countryside Act with respect to whole or partial removal from Schedule of the Act 5 of European Protected Species to ensure consistency of regulation. There are six diadromous species that require the designation of SACs (Special Area of Conservation) in UK waters under Annex II of the EC Habitats Directive, although the salmon is only protected in freshwater habitats. Other diadromous species are protected under Annex IV or V, which offer protection against deliberate disturbance, capture or killing.

As well as this, a number of species have been listed under Annex V of the OSPAR list of threatened and/or declining species and habitats and by CITES (Convention on International Trade in Endangered Species), an international agreement between governments to regulate international trade in wild animals and plants. A number of species are also listed on the IUCN (International Union for the Conservation of Nature) Red List of Threatened Species. A number of fish species are also the subject of UK Biodiversity Action Plans (BAPs), as priority species. In addition to, individual lists exist for Scottish, Welsh and Northern Irish species and there is some variation between these lists.

A European Council Regulation (EC No 1100/2007) establishing measures for the recovery of European eel stocks entered into force in September 2007. The regulation requires the development of Eel Management Plans (there are 15 such Management Plans in the UK) which include measures to allow the escapement to sea of at least 40% of the silver eel biomass. Under the regulation, from 2013 EU countries with a glass eel fishery will be required to reserve 60% of the eel catches with a body length less than 12 cm for restocking European eel river basins. European eel was included in CITES Appendix II in 2007 and in 2008 was listed as “Critically Endangered” on the IUCN Red List.

Table A1a.5.2: Marine fish afforded protection under national legislation and international conventions

Species	Wildlife and Countryside Act[1]	EC Habitats Directive	OSPAR	CITES	IUCN	Priority Species[2]
Pelagic fish						
Mackerel (*Scomber scombrus*)					Least concern	England, Scotland

Species	Wildlife and Countryside Act[1]	EC Habitats Directive	OSPAR	CITES	IUCN	Priority Species[2]
						(PMF), Wales, NI
Herring (*Clupea harengus*)					Least concern	England, Wales, Scotland (PMF), NI
Horse mackerel (*Trachurus trachurus*)					Vulnerable	England, Scotland (PMF), Wales, NI
Blue whiting (*Micromesistius poutassou*)						England, Scotland (PMF)
Northern bluefin tuna (*Thunnus thynnus*)			Y		Near threatened	England
Demersal species						
Atlantic cod (*Gadus morhua*)			Y		Vulnerable	England, Wales, Scotland (PMF), NI
Whiting (*Merlangius merlangus*)					Least concern	England, Wales, Scotland (PMF), NI
Saithe (*Pollachius virens*)						Scotland (PMF)
Hake (*Merluccius merluccius*)						England, Wales, Scotland, NI
Ling (*Molva molva*)						England, Wales, Scotland (PMF), NI
Blue ling (*Molva dypterygia*)						England, Scotland (PMF)
Tusk (*Brosme brosme*)						Scotland
Norway pout (*Trisopterus esmarkii*)					Least concern	Scotland (PMF)
Monkfish (*Lophius piscatorius*)					Least concern	England, Scotland

Species	Wildlife and Countryside Act[1]	EC Habitats Directive	OSPAR	CITES	IUCN	Priority Species[2]
						(PMF), Wales, NI
Black scabbardfish (*Aphanopus carbo*)						England, Scotland (PMF)
Roundnose grenadier (*Coryphaenoides rupestris*)					Critically endangered	England, Scotland (PMF)
Norway redfish (*Sebastes viviparus*)						Scotland
Plaice (*Pleuronectes platessa*)					Least concern	England, Wales + Scotland, NI
Sole (*Solea solea*)					Data deficient	England, Wales, NI
Deepwater sole (*Bathysolea profundicola*)					Least concern	Scotland
Atlantic halibut (*Hippoglossus hippoglossus*)					Endangered	England, Scotland (PMF)
Greenland halibut (*Reinhardtius hippoglossoides*)						England, Scotland (PMF)
Giant goby (*Gobius cobitis*)	Schedule 5					
Couch's goby (*Gobius couchii*)	Schedule 5				Least concern	
Sandeel (*Ammodytes marinus*)						England, Wales, Scotland (PMF)
Sandeel (*Ammodytes tobianus*)					Data deficient	Scotland (PMF)
Short snouted seahorse (*Hippocampus hippocampus*)	Schedule 5 (England only)		Y	Appendix II	Data deficient	England
Long snouted seahorse	Schedule 5 (England only)		Y	Appendix II	Data deficient	England, Wales

Species	Wildlife and Countryside Act[1]	EC Habitats Directive	OSPAR	CITES	IUCN	Priority Species[2]
(*Hippocampus guttulatus*)						
Orange roughy (*Hoplostethus atlanticus*)			Y			England, Scotland (PMF)
Elasmobranch species						
Basking shark (*Cetorhinus maximus*)	Schedule 5		Y	Appendix II	Endangered	England, Wales, Scotland (PMF), NI
Tope (*Galeorhinus galeus*)					Critically endangered	England, Wales, NI
Spurdog (*Squalus acanthias*)			Y		Vulnerable	England, Scotland (PMF), Wales, NI
Porbeagle (*Lamna nasus*)			Y	Appendix II	Vulnerable	England, Scotland (PMF), Wales, NI
Blue shark (*Prionace glauca*)					Near threatened	England, Wales
Shortfin mako (*Isurus oxyrinchus*)					Data deficient	England
Angel shark (*Squatina squatina*)	Schedule 5 (England only – not between 6-12nm of coast)		Y		Critically endangered	Wales, NI
Gulper shark (*Centrophorus granulosus*)			Y			England
Leafscale gulper shark (*Centrophorus squamosus*)			Y		Endangered	England, Scotland (PMF)
Portuguese dogfish (*Centroscymnus coelolepis*)			Y		Near threatened	England, Scotland (PMF)
Kitefin shark (*Dalatias licha*)					Endangered	England
Common skate (*Dipturus batis*)			Y		Critically endangered	England, Wales,

Species	Wildlife and Countryside Act[1]	EC Habitats Directive	OSPAR	CITES	IUCN	Priority Species[2]
						Scotland (PMF), NI
Spotted ray (*Raja montagui*)			Y		Least concern	
Sandy ray (*Leucoraja circularis*)					Endangered	Scotland (PMF)
Undulate ray (*Raja undulata*)					Endangered	England, Wales, NI
White skate (*Rostroraja alba*)			Y		Endangered	England, Wales
Thornback ray (*Raja clavata*)			Y		Least concern	Wales, Scotland
Diadromous species						
European sturgeon (*Acipenser sturio*)	Schedule 5 (not Scotland)	Annex II & IV	Y	Appendix I	Critically endangered	England, Wales, Scotland
Allis shad (*Alosa alosa*)	Schedule 5	Annex II & V	Y		Least concern	England, Wales, Scotland, NI
Twaite shad (*Alosa fallax*)	Schedule 5	Annex II & V			Least concern	England, Wales, Scotland, NI
River lamprey (*Lampetra fluviatilis*)		Annex II & V			Least concern	England, Wales, Scotland (PMF), NI
Sea lamprey (*Petromyzon marinus*)		Annex II	Y		Least concern	England, Wales, Scotland (PMF)
Smelt (*Osmerus eperlanus*)					Least concern	England, Wales, Scotland (PMF), NI
Whitefish (*Coregonus lavaretus*)	Schedule 5	Annex V	Y		Vulnerable	England, Wales, Scotland
European eel (*Anguilla anguilla*)			Y	Appendix II	Critically endangered	England, Wales, Scotland (PMF), NI
Atlantic salmon (*Salmo salar*)		Annex II (freshwater only)	Y		Vulnerable	England, Wales,

Species	Wildlife and Countryside Act[1]	EC Habitats Directive	OSPAR	CITES	IUCN	Priority Species[2]
						Scotland (PMF), NI
Sea trout (*Salmo trutta*)					Least concern	England, Scotland (PMF), Wales, NI
Commercial Shellfish species						
Crawfish (*Palinurus elephas*)					Vulnerable	England, Scotland (PMF), Wales, NI
Native oyster (*Ostrea edulis*)			Y			England, Wales, Scotland (PMF), NI
Horse mussel (*Modiolus modiolus*)						NI

Note: [1]Does not apply to Northern Ireland and may vary between England, Wales and Scotland. [2]Priority species include those listed under Section 41 (England) and Section 42 (Wales) of the Natural Environment and Rural Communities (NERC) Act 2006, Section 2(4) of the Nature Conservation (Scotland) Act 2004, Section 3(1) of the Wildlife and Natural Environment Act (Northern Ireland) 2011 and Schedule 5 of the Wildlife (Northern Ireland) Order 1985, also includes species on Scotland's list of Priority Marine Features (PMF). Sources: Information sourced July 2020.

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